1

General survey

1.1 Definitions

There are two definitions of a 'coated fabric' in the Textile Institute's publication, *Textile Terms and Definitions*.[1] The first one is, 'A material composed of two or more layers, at least one of which is a textile fabric and at least one of which is a substantially continuous polymeric layer. The layers are bonded closely together by means of an added adhesive or by the adhesive properties of one or more of the component layers'. The second definition is, 'A textile fabric on which there has been formed *in situ,* on one or both surfaces, a layer or layers of adherent coating material'. For the purposes of this book, this second definition will be regarded as that definition which most closely describes *coated fabrics*; the operative words are, 'formed *in situ*'. The first quoted definition could also be applied to a *laminated* fabric.

Textile Terms and Definitions defines a 'laminated fabric' (or a 'combined fabric') as, 'a material composed of two or more layers, at least one of which is a textile fabric, bonded closely together by means of an added adhesive, or by the adhesive properties of one or more of the component layers'. For the purposes of this book, a 'laminated fabric', also sometimes called a 'bonded fabric', is considered to be different from a coated fabric, in that the layers are already pre-prepared and the second material can be a film, another fabric, or some other material. However, these definitions are of academic interest and there is little benefit in taking a rigid view.

1.2 Historical background

How long ago the coating and laminating of fabrics began, depends upon on what is regarded as being a coated or laminated fabric; some writers see the fabric wrapping the Egyptian mummies as a coated material. For as long as people have been wearing clothes made from fabric, they must have sought ways of making the material less permeable to wind and water, for increased comfort, increased weather protection and, indeed, for survival. Natural oils, such as linseed oil and tar, were applied to the fabric, dried in the sun and then more oil applied in a repeat process. After this had been done several times, water-repellent fabric was obtained, which would afford better protection against the elements. In fact, an ‘oil cloth’ industry developed in England and Germany during the 1700s, applying a variety of oils to cotton and even to silk, for the manufacture of garments, sails, tents and other coverings.[2]

It is virtually impossible to ascertain when rubber was actually discovered, but it was already being used by the Latin-American Indians as a proofing material for fabric when the Spanish arrived in the mid-1500s. The *New Shell Book of Firsts* attributes the first ‘raincoat’ to Francois Fresnau, Chief Engineer at Cayenne, French Guyana, who, in 1747, proofed an old overcoat by smearing latex over it. However, many writers regard Charles Macintosh as the founder of the modern coating and lamination industry, but the success of his invention has depended on important contributions from others. He is recorded as having produced a waterproof material by sticking two pieces of cloth together with rubber dissolved in naphtha. Another version is that he produced a film of rubber and sewed it on to fabric with a needle and thread. Producing commercial garments from this rather cumbersome material was difficult until James Syme, a medical student at Edinburgh University, managed to dissolve rubber in a solvent derived from coal tar. Evaporating the solvent away left behind a deposition or film of rubber. Macintosh obtained the patent rights to this process in 1823 and began to produce the waterproof material which has made his name a household word all over the world.[3–5] One of his first customers used the new coated fabric material to equip Sir John Franklin’s expedition to the Arctic in 1824.[3]

Macintosh’s material was used by travellers riding on the top of stagecoaches, but when the railways arrived and higher standards of comfort and quality were demanded, wearers began to complain about the ungainly appearance of the garments and the offensive smell. In addition, the rubber tended to soften, become sticky and melt in hot weather. These disadvantages were overcome with advances in technology, and especially by the discovery of vulcanisation by Thomas Hancock in 1843. Vulcanisation, which is a crosslinking process, overcame raw rubber’s main defect of becoming physically weak with rising temperature. Charles Goodyear in the USA is also credited with discovering vulcanisation quite independently from Hancock in 1841. Hancock, who manufactured rubber goods in Manchester, became an associate of Macintosh in 1830 and together they produced inflatables, including air beds and pillows and pontoons for floating bridges, in addition to garments. It is interesting to note that Hancock patented the use of inflatable bags to raise sunken ships.[5]

Later, in the mid-nineteenth century, nitro-cellulose was discovered and developed as a fabric coating material for cotton. The material became known as 'gun cotton' (Schoenbein), 'pyroxylin' and 'collodion', and was used in many applications, including car upholstery. During the First World War, the British Government invited the Dreyfus Brothers of Switzerland to build a factory at Spondon, Derby to produce cellulose acetate (referred to as 'dope') to be used for coating fabric for aircraft wings. This factory later produced acetate yarns and became British Celanese – later acquired by Courtaulds – and is now the headquarters of Acordis. In the first half of the twentieth century, several other new polymers and synthetic rubbers were invented and, after some development, came to be used as fabric coatings. The most important ones were polyvinyl chloride (PVC), polychloroprene (the best known being Neoprene made by Du Pont), acrylates and polyurethane. These polymers, plus several other specialist materials, are still used in the modern industry, but much research and development has been carried out to improve properties and, more recently, to produce more environmentally friendly materials and methods. This process continues and has assumed greater importance in recent years.

The earliest adhesives used by people were natural materials such as beeswax, tars, gums, derivatives from animal and fish bones, egg white and rice products. Bitumen was used in the construction of the Tower of Babel. Sealing wax was probably the first commonly used 'hot melt' adhesive. The modern lamination industry has at least part of its origins in the garment industry. Cellulose acetate was the first manufactured plastic to be used to bond collars for shirts in the 1930s, but the process used solvents to soften the cellulose acetate and, although millions of shirt collars were produced every year, it was a 'wet' and therefore not a convenient process. Research work was carried out to discover better methods. In 1948 Harold Rose began to experiment with polyvinyl acetate plasticised with dibutyl phthalate; he developed a continuous process for producing a material which could be used in a 'dry' lamination process for garments. No solvents were involved, and the new interlining could be heat activated using a Hoffman press. He was awarded a bulk order for the material and immediately set up a company called Staflex in 1951.[6] Other materials, including hot melt powders, were later developed, and the turnover of Staflex reached £5 million by 1965 and £30 million by 1975. It is interesting to note that, in the early days, polyethylene was used in collars, but it was discontinued because of discomfort in wear caused by lack of air permeability. Hot melt adhesives are now the focus of much attention because they are solventless and also do not require large amounts of energy to dry off water.

1.3 Fabric coating

The basic method of producing a coated fabric is the direct spreading of a polymer, in the form of a thick liquid or paste, using a sharpened length of metal called a doctor blade or knife. The doctor blade is set up over a fabric, which is held flat by the application of tension – both lengthways and, ideally with the use as stenter pins, widthways – in a coating machine. The thickened polymer fluid is placed in front of the doctor blade and is spread over the surface of the fabric by the forward movement of the fabric into a heated oven. The thickened liquid can be either water based or solvent based, and evaporation of the water or solvent leaves behind a polymer deposit on the fabric. In the case of PVC, the thickened liquid is neither water- nor solvent-based, but consists of a mixture of PVC powder, liquid plastisols and other chemicals. The thickened liquid is referred to as the compound or resin, and is a mixture of the polymer and certain other ingredients to produce specialist properties or to assist the spreading process. This process, described in detail in Chapter 3, allows coated fabric to be produced on a much larger scale than could be achieved by hand. It was first used for coating rubber, and is still sometimes referred to as 'the rubber spreading' machine even though it is now used for other polymers. Hancock's original machine probably did not have stenter pins and, in fact, some older machines do not have them, relying entirely on lengthways tension. Compounding or mixing of resin is an important process, both in the actual formulation of the recipe and also in the actual physical mixing, see Chapter 2. In the quest for more comfortable, softer, more aesthetically pleasing products, transfer coating and more technically sophisticated methods, such as rotary screen techniques, have been developed. These methods are discussed in Chapter 3.

Coated fabrics are engineered composite materials, produced by a combination of a textile fabric and a polymer coating applied to the fabric surface. The polymer coating confers new properties on the fabric, such as impermeabilty to dust particles, liquids and gases, and it can also improve existing physical properties, such as fabric abrasion. The fabric component generally determines the tear and tensile strength, elongation and dimensional stability, while the polymer mainly controls the chemical properties, abrasion resistance and resistance to penetration by liquids and gases. Many properties, however, are determined by a combination of both these components, and both base-fabric and polymer must be carefully selected by a thorough consideration of the properties required in the finished article.

The most familiar coated fabric is probably the waterproof jacket worn for protection from the rain. Protective clothing for the police, firemen, postmen and the services also made from coated fabric. Examples of domestic articles made from coated fabrics include shower curtains, mattress tickings, flame retardant (FR) upholstery, wipe-clean table cloths and curtain linings. Aesthetic effects and easy clean features can also be achieved by fabric and polymer combinations, and man-made leathers used for seat covers and apparel are essentially coated fabrics. Coated fabrics in the industrial area include materials for tarpaulins, life jackets, life rafts, aircraft safety chutes, hovercraft skirts, protective coverings, awnings, aircraft fuel tanks and flexible containers. Seat upholstery for automobiles, coaches and trains is likely to be coated to improve abrasion resistance, improve FR properties and reduce dust particle penetration. The product enjoying the largest growth at the time of writing is the airbag, which is coated mainly in order to control porosity, although coating also reduces edge fraying and makes panel cutting and certain other processes easier to carry out.

1.4 Fabric finishing

A process related to fabric coating is 'fabric finishing', where a chemical or a polymer covers only the yarns making up the fabric without closing the gaps in between. In fabric coating, the small gaps in between the individual yarns are covered to varying degrees. In the case of a waterproof coating, the gaps are fully 'bridged' by the coating, the polymer forming a continuous layer on the fabric surface. In other coated fabrics, the gaps may not be fully covered, and these fabrics will be porous to varying degrees. Fabric finishes are usually applied by a 'dip and squeeze' process known as padding or impregnation, which is widely used in textile factories. The need for distinction between 'coating' and 'finishing' is again largely academic – the two merge in certain instances, because repeated impregnation with some polymers can produce a continuous coating on a fabric.

Most apparel fabrics or household textiles have a fabric finish of some description on them, e.g. an easy care finish on cotton, a mothproof finish on wool, a water-repellent finish, or a soft finish to improve the handle or soft touch of the fabric. The technology of fabric finishing covers a very large area with many dozens of different chemicals, and the term also embraces mechanical finishing processes such as embossing. This area is outside the scope of the present book, but certain chemical fabric finishes can also be applied by a coating process involving foamed compounds and a description of this process is included in Chapter 3. The foam processing method of fabric 'finishing' can provide benefits both in terms of properties obtained and also in environmental factors.

1.5 Fabric lamination

Polymer materials, which may not be easily formulated into a resin or a paste for coating, can be combined with a fabric by first preparing a film of the polymer, and then laminating it to the fabric in a separate process. There are various techniques and several different types of adhesive and machinery used in the lamination process. Producing an adhesive bond, which will ensure no delamination or failure in use, requires lamination skills and knowledge of which adhesive to use. It is generally relatively simple to produce a strong enough bond, the challenge is to preserve the original properties of the fabric and to produce a flexible laminate with the required appearance, handle and durability.

Adhesives are available as water-based or solvent-based fluids or as a 'hot melt' material, i.e. a material which is either a solid or a jelly and which melts on the application of heat. Hot melt adhesives are produced in the form of films, webs (rather like a net curtain), granules, powders or as jellies. They can be of several different chemical types, such as polyolefin, polyurethane, polyester, polyamide, or alloys, or blends of different polymers or copolymers. Of course different machinery is required to apply the different forms of adhesive and this must be done under controlled production conditions to produce an acceptable bond without stiffening the fabric or any other undesirable effects.

Which lamination process and which machinery to use are also determined by the physical properties of the fabric being processed and by the performance requirements, such as bond strength and durability of the laminate being produced. The fabric may be a flat woven, which is dimensionally stable and which can be tensioned to produce a flat uniform surface for the lamination process to take place without any difficulty, or it may be a stretchy knit material or a fabric with a pile or raised surface, which is easily distorted or crushed. Machines and methods of lamination are available to process each of these fabrics without altering the physical properties or appearance. The machinery selected should also produce the required performance specifications at a commercial production rate and cost.

As has been mentioned, lamination techniques have been used in the garment industry for collars, waistbands and hems, generally replacing or supplementing sewing. The lamination process shortened production times, reduced costs and allowed more consistent quality. Lamination techniques are also used to replace sewing in other areas, such as the automotive and even sail making industries. Laminated fabrics are used in waterproof and breathable protective clothing, car seat upholstery, footwear, and in numerous other applications. According to the Textile Institute's definition, car headliners, parcel trays and door casings are also laminated fabrics – they are certainly covered by a laminated fabric. As will be seen, environmental considerations also play a significant part in process selection, and they are likely to become more important in the future. Chapter 3 will explain and discuss the main methods.

1.6 Composite materials

Composites are textiles and plastics in a macroscopic combination – alloys are combinations on the microscopic scale. In general, the chemical properties are determined by the plastic component and the physical properties by the fibre. An example is the glass fibre/plastic group of composites; the glass fibre has very high tensile strength, but is very brittle because it is extremely sensitive to cracks and surface defects. If the surface is protected by plastic in a composite, the formation of cracks is prevented and the composite has very high strength. Composites are produced using some of the techniques used in manufacturing coated and laminated fabrics, e.g. surface coating, impregnation and lamination. Coated and laminated fabrics are composite materials, but the term ‘composite’ has come to be recognised as an engineering material produced from combination of plastics with both fibres and fabrics, frequently used in structural, specialist and high technology applications. The science of composites depends significantly on mechanical engineering, in addition to plastics and textile technology, and is outside the scope of this book.

1.7 The commercial scope of coated and laminated textiles

Fabric coating and lamination are technical processes and the products are, therefore, technical products which form an important sector of the textile industry. Much depends on definitions and how products are categorised, and it is difficult to find figures which specifically apply to coated and laminated fabrics. A recent analysis by David Rigby Associates (DRA) estimates that technical textiles constitute over 40% of the textile industry in the developed countries of the world; and it is particularly important because in these developed countries it is the major sector for growth.[7–9] This figure is expected to grow to 50% within the next few years. However, even in developing counties such as China, where technical textiles represented only about 12% of the industry when the report was published (April 1997), substantial growth, to reach 20% by the year 2000, was forecast. Significant rates of growth are expected in the developing world in general, including Eastern Europe and South East Asia. In 1997, the total global textile fibre consumption was estimated to be approximately 53 million tonnes, of which technical textiles were believed to constitute over 10 million tonnes, i.e. 19% worth at least $54 billion (US dollars) – even before coating and conversion which adds further value. These figures, however, apply to the four product areas of yarns and fibres, fabrics, nonwovens and composites. Coated and laminated fabrics are grouped in the fabrics product area, although some nonwovens are coated and laminated.

Many nonwovens incorporate a polymer binder of some description, which is similar to the materials used for textile coatings. Both nonwovens and composites are growing substantially faster than actual fabrics (see Tables 1.1 and 1.2).

The Techtextil Symposium (for Technical Textiles), held annually at the Messe, Frankfurt, divides the technical textile area into 12 application areas – agricultural, building and construction, clothing (interlinings, sewing threads, waddings and fibre fillings), geotextiles, household textiles,

Table 1.1 World consumption of technical textiles and nonwovens by region ('000 tonnes)

	1985	1995	2005 (forecast)	% compound average growth 1989–95	% compound average growth 1995–2005
West Europe	1674	2367	3111	3.5	2.8
East Europe	407	296	418	–3.1	6.6
North America	2240	3057	3886	3.2	2.4
South America	181	280	428	4.4	4.3
Asia	1262	2696	4510	7.9	5.3
Australasia	83	120	179	3.7	4.1
Rest of world	214	505	1011	8.9	7.2
All world	**6062**	**9321**	**13688**	**4.4**	**3.9**

Source: David Rigby Associates World Technical Textiles Consumption Model and reproduced with kind permission.

Table 1.2 World consumption of technical textiles by product type, 2000–2005

	2000 10^3 tonnes	2005 10^3 tonnes	Growth (% pa)	2000 $ million	2005 $ million	Growth (% pa)
Fabrics	3760	4100	1.7	26710	29870	2.2
Nonwovens	3300	4300	5.4	14640	19250	5.6
Composites	1970	2580	5.5	6960	9160	5.6
Other textiles*	2290	2710	3.4	11950	14060	3.3
All textile products	**11320**	**13690**	**3.9**	**60260**	**72340**	**3.7**

* Includes ropes, twines, thread, fibrefill, etc.
Source: David Rigby Associates/Techtextil and reproduced with kind permission.

industrial textiles, medical uses, transportation textiles, environmental protection, packaging, protective clothing (both industrial and leisure), and sports applications (not clothing). Coated and laminated fabrics appear in most, if not all, of these areas, especially transportation, industrial, clothing, and medical uses. Significant growth is expected in all 12 application areas, especially in the geotextile, environment and protective clothing categories. Transportation textiles, which includes uses in automobiles, other road vehicles, aircraft, marine and rail, is the largest single area in technical textiles. This is shown in Table 1.3, prepared from DRA's World Technical Consumption Model.[7,8]

Information is also available on the volumes and various types of the European protective clothing market with six areas classified.[9] Clothing for purely personal use, e.g. for sports activities, is not included. The largest areas are for dust and particle barrier protection and for gas and chemical protection. Over half of the total volume (1996 figures) of 206 million m^2 is nonwoven fabrics (124 million m^2), the remainder being woven or knitted. A proportion of non-disposable garments is likely to be produced from coated or laminated fabric. With future restrictions on landfill, there may well be a decrease in the amount of nonwoven disposable garments and an increase in washable coated protective garments. Some industrial protective garments are heavy, bulky, movement restricting and uncomfortable, but with development and use of new fibres and materials, there is opportunity for improvement. Leisurewear protective clothing is significantly lighter and more comfortable today compared to, say, the mid-1980s.

A Japanese report (October 1999) put the world clothing market volume at $1062 billion with an annual increase of 2.5% each year until 2010. It stated that sportswear represented 6% of the total in 1996, but predicted this to be 13% in 2010.[10] The report commented that technical clothing for active sports has entered the 'casual' field, that technical fabrics are on the increase, regardless of the age of the purchaser, and that top brands are preferred to cheaper ones.

The production of fabric for protective clothing is expected to increase in developing countries, as industrial workers demand a level of protection and comfort comparable to that available to their fellow workers in the USA and Western Europe. In developed countries, government legislation on health and safety and the threat of employer legal liability for workers' safety has already produced an increase in personal protective equipment (PPE). Protective clothing, whether for the sportsman, the military or the industrial worker, represents a large area in technical textiles. These classifications merge and overlap, and it is difficult to find figures which apply to the individual areas. *Datamonitor* puts the 1999 market value for the UK sports clothing market at £2675 million or $4314 million. Waterproof coats

Table 1.3 World consumption of technical textiles by application, 2000–2005

	2000 10^3 tonnes	2005 10^3 tonnes	Growth (% pa)	2000 $ million	2005 $ million	Growth (% pa)
Transport (auto, train, sea, aero)	2220	2480	2.2	13080	14370	1.9
Industrial products and components	1880	2340	4.5	9290	11560	4.5
Medical and hygiene textiles	1380	1650	3.6	7820	9530	4.0
Home textiles, domestic equipment	1800	2260	4.7	7780	9680	4.5
Clothing components (thread, interlinings)	730	820	2.3	6800	7640	2.4
Agriculture, horticulture and fishing	900	1020	2.5	4260	4940	3.0
Construction – building and roofing	1030	1270	4.3	3390	4320	5.0
Packaging and containment	530	660	4.5	2320	2920	4.7
Sport and leisure (excluding apparel)	310	390	4.7	2030	2510	4.3
Geotextiles, civil engineering	400	570	7.3	1860	2660	7.4
Protective and safety clothing and textiles	160	220	6.6	1640	2230	6.3
Total above	**11340**	**13680**	**3.9**	**60270**	**72360**	**3.7**
Ecological protection textiles*	230	310	6.2	1270	1610	4.9

* Already counted in several categories above.
Source: David Rigby Associates/Techtextil and reproduced with kind permission.

and jackets are estimated at 9.5% of this total, i.e. £254 million or $409.8 million.[11] Waterproof protective clothing has undergone a revolution between 1940 and 1980, in the quest for more thermal comfort, and comfort in general, combined with light weight, fabric softness and high performance in protection from the elements. This process continues with developments in breathability, warmth without bulk, phase change material, and better performance at lower cost. This search for more comfort with high performance has spread to footwear, socks, and even gloves. The process was probably initiated with the introduction of Gore-Tex by W L Gore and Associates in the mid-1970s. Since then the sports world has seen the introduction of a large number of laminated waterproof breathable fabrics and waterproof and breathable coatings.

The European Personal Protective Equipment Directive 89/686/EEC ensures that industrial protective clothing not only provides effective protection against the hazard, but is also well designed and comfortable to wear. Similar regulations are already in place in other developed areas of the world and are likely to be introduced in developing countries, which will present opportunities for future market growth. Even in developed countries, there is still the need for improved performance and more satisfactory test methods as living standards continue to increase. In recent years, additional requirements due to ecological considerations pose more challenges and offer opportunities for research and development.

The biggest single item in the transportation area is the automobile, with about 48 million units made each year. The volume of cars made in the developed countries is now steady, and there is production overcapacity. However, there is still opportunity for substantial growth in the developing world, especially in Eastern Europe and South America over the next five years and in South East Asia over the next ten, see Tables 1.4 to 1.6. Each car contains about 7 m^2 of car seat fabric laminated to polyurethane foam, and most also contain at least one airbag, which is more often than not made from a coated fabric. Airbags have seen quite spectacular growth in recent years – the fastest growth item in the entire textiles industry – but, although the growth is thought to be past its peak, steady growth is still expected for the next few years. However, much research is being applied to reduce injuries in traffic accidents, and the introduction of new or improved products could prolong this growth for longer than many analysts would predict. Acordis Industrial Fabrics estimate that the 1999 figure of 18000 tonnes of yarn (equivalent to 75 million m^2 of fabric) for airbags in Europe will increase to 25000 tonnes (115 million m^2) by 2004. Worldwide, the 1999 figure of 50000 tonnes (200 million m^2) is expected to reach 80000 tonnes (300 million m^2) by 2004.[12]

With the ending and phasing out of import quotas and China's entry to the World Trade Organisation, investment in technical textiles is likely

Table 1.4 World personal vehicle sales ('000 units)

	2000	2001	2002	2003	2004	2005	2006	2011	2016
North America*	18 652	17 545	17 300	17 511	17 712	17 910	17 865	18 898	19 861
% change	*4.1*	***–5.9***	***–1.4***	***1.2***	***1.1***	***1.1***	***–0.3***	***5.8***	***5.1***
Argentina/ Brazil	1 385	1 535	1 681	1 864	2 034	2 181	2 303	2 708	3 253
% change	*9.1*	***10.8***	***9.5***	***10.9***	***9.1***	***7.2***	***5.6***	***17.6***	***20.1***
Western Europe	14 941	14 649	14 806	15 143	15 587	15 844	15 997	17 373	18 027
% change	*–1.6*	***–2.0***	***1.1***	***2.3***	***2.9***	***1.6***	***1.0***	***8.6***	***3.8***
Eastern Europe	2 469	2 173	2 446	2 738	3 048	3 302	3 572	4 354	4 938
% change	*–0.2*	***–12.0***	***12.5***	***12.0***	***11.3***	***8.4***	***8.2***	***21.9***	***13.4***
Japan	4 260	4 336	4 426	4 523	4 609	4 680	5 026	5 432	5 556
% change	*2.5*	***1.8***	***2.1***	***2.2***	***1.9***	***1.5***	***7.4***	***8.1***	***2.3***
Asia/Pacific	3 160	3 173	3 379	3 573	3 784	4 025	4 281	6 114	8 135
% change	*10.8*	***0.4***	***6.5***	***5.8***	***5.9***	***6.4***	***6.4***	***42.8***	***33.1***
Other†	4 354	4 529	4 698	4 872	5 038	5 197	5 278	6 232	6 913
% change	*4.6*	***4.0***	***3.7***	***3.7***	***3.4***	***3.2***	***1.5***	***18.1***	***10.9***
World	**49 221**	**47 940**	**48 735**	**50 225**	**51 813**	**53 140**	**54 323**	**61 110**	**66 682**
% change	*2.5*	***–2.6***	***1.7***	***3.1***	***3.2***	***2.6***	***2.2***	***12.5***	***9.1***

* North America includes USA, Canada and Mexico and the figures refer to cars and light trucks that are used as personal transport vehicles.

† The total for sales in 'Other' also includes a statistical balancing item to compensate for inconsistencies and inadequacies in national data and to equate sales to world production.

N.B. For countries in each heading, please see foot of Table 1.6.

Source: National Sources, JD Power-LMC. Reproduced with kind permission of JD Power-LMC.

to become more essential for the survival of the textile industry in many of the developed nations of the world. Some forecasters predict 75% or more of fibre consumption in the more advanced economies will eventually be in technical applications. These products are less price sensitive in the market place than regular apparel and household goods, and also command better profit margins. It should be noted, however, that, although China is the largest exporter of textiles, it is also, since 1997, the world's third largest importer.[13] There is scope for the export of high tech products to China, both for industrial purposes and also for high quality consumer products for the rapidly growing number of Chinese with large disposable incomes.

Table 1.5 World light commercial vehicle* sales ('000 units)

	2000	2001	2002	2003	2004	2005	2006	2011	2016
North America	1113	1065	1084	1103	1141	1158	1377	1578	1543
% change	*–0.2*	*–4.3*	***1.8***	***1.8***	***3.4***	***1.5***	***19.0***	***14.6***	***–2.2***
Argentina/ Brazil	286	330	395	459	500	537	569	653	779
% change	*8.1*	*15.5*	***19.6***	***16.2***	***9.1***	***7.4***	***5.9***	***14.7***	***19.4***
Western Europe	1785	1682	1587	1602	1674	1739	1778	1765	1859
% change	*5.5*	*–5.8*	***–5.7***	***1.0***	***4.5***	***3.8***	***2.3***	***–0.8***	***5.4***
Eastern Europe	416	344	418	502	594	678	722	880	1031
% change	*17.1*	*–17.3*	***21.5***	***20.1***	***18.3***	***14.0***	***6.5***	***22.0***	***17.2***
Japan	1617	1642	1687	1735	1810	1841	1882	2222	2295
% change	*–0.4*	*1.5*	***2.7***	***2.9***	***4.3***	***1.7***	***2.2***	***18.1***	***3.3***
Asia/Pacific	2169	2207	2279	2381	2494	2661	2856	3648	4282
% change	*23.2*	*1.7*	***3.3***	***4.5***	***4.8***	***6.7***	***7.3***	***27.7***	***17.4***
Other	432	456	482	499	514	525	541	575	650
% change	*4.2*	*5.7*	***5.6***	***3.5***	***3.0***	***2.2***	***2.9***	***6.4***	***13.0***
World	**7818**	**7727**	**7931**	**8281**	**8728**	**9139**	**9726**	**11321**	**12439**
% change	***8.2***	***–1.2***	*2.6*	*4.4*	*5.4*	*4.7*	*6.4*	*16.4*	*9.9*

* Light commercial vehicles are those of less than 6 tonnes gross vehicle weight (GVW).

N.B. For countries in each heading, please see foot of Table 1.6.

Source: National Sources, JD Power-LMC. Reproduced with kind permission of JD Power-LMC.

Demand for coated fabric in the USA is expected to reach 635 million square yards (531 million m^2) by the year 2000 – an annual increase of 3.9% from the 525 million square yards (439 million m^2) in 1998 (see Table 1.7). The Freedonia Group have categorised the US market into eight product areas.[14] The growth areas are believed to be in transportation, both automobile and non-automobile applications, and in specialist niche protective clothing for the increased safety of industrial workers, for example from pesticides and biological agents. Growth is likely for apparel to protect sensitive microelectronics against contamination from the human body; anti-static and lint-free properties are also essential in this application. Specialist sports and leisure industry goods, and apparatus for improving the environment, such as better and more economical filters for gases and

Table 1.6 World heavy commercial vehicle* sales ('000 units)

	2000	2001	2002	2003	2004	2005	2206	2011	2016
North America	532	448	481	547	580	597	605	639	714
% change	***–9.6***	***–15.8***	***7.4***	***13.8***	***6.1***	***2.8***	***1.4***	***5.6***	***11.7***
Argentina/ Brazil	92	93	91	90	99	107	116	139	169
% change	***22.9***	***0.7***	***–2.3***	***–0.9***	***10.1***	***8.6***	***7.8***	***20.1***	***21.6***
Western Europe	377	336	317	328	351	371	387	465	518
% change	***5.3***	***–11.0***	***–5.4***	***3.2***	***7.1***	***5.8***	***4.4***	***20.0***	***11.4***
Eastern Europe	179	178	216	247	271	280	289	325	385
% change	***18.9***	***–0.9***	***21.5***	***14.6***	***9.6***	***3.5***	***3.3***	***12.3***	***18.5***
Japan	81	77	80	98	134	147	153	152	170
% change	***–2.2***	***–5.7***	***4.7***	***22.3***	***36.3***	***9.9***	***3.8***	***–0.2***	***11.5***
Asia/Pacific	674	717	804	898	971	1081	1163	1201	1376
% change	***6.2***	***6.4***	***12.0***	***11.7***	***8.2***	***11.2***	***7.6***	***3.3***	***14.6***
Other	42	45	49	52	55	57	61	80	106
% change	***7.6***	***6.1***	***8.2***	***6.7***	***6.6***	***2.0***	***8.2***	***30.3***	***33.1***
World	**1979**	**1893**	**2037**	**2260**	**2462**	**2640**	**2774**	**3001**	**3438**
% change	***2.5***	***–4.3***	***7.6***	***10.9***	***8.9***	***7.2***	***5.1***	***8.2***	***14.6***

Source: National Sources, JD Power-LMC. Reproduced with kind permission of JD Power-LMC.
* Heavy commercial vehicles include trucks of more than 6 tonnes GVW, and (except in USA/Canada) coaches.
Countries in each grouping are as follows:
North America – USA, Canada, Mexico
Western Europe – Germany, Italy, France, UK, Spain, Portugal, Ireland, Netherlands, Denmark, Bel/Lux, Greece, Sweden, Norway, Finland, Austria, Switzerland
Eastern Europe – Bulgaria, Croatia, Czech Republic, Hungary, Poland, Romania, Russia, Slovakia, Slovenia, Turkey, Ukraine
Asia/Pacific – Korea, China, India, Malaysia, Indonesia, Taiwan, Thailand, Philippines
Other – Australia, Colombia, Venezuela, South Africa plus others

liquids, also present opportunities. The current trend for real leather is expected to moderate and the durability of coated fabrics could be an advantage, especially in contract furniture markets. Another growth area with potential for technical products is the aviation and aerospace industries; air travel is set to grow at about 15% for the foreseeable future, with

Table 1.7 Coated fabric demand in USA (millions of square yards)

	1989	1998	2003	% annual growth (1989/98)	% annual growth (1998–2003)
Coated fabric demand	355	525	635	4.4	3.9
Item					
Motor vehicles	79	137	182	6.3	5.8
Furniture	74	101	115	3.5	2.6
Industrial	46	53	61	16	2.9
Protective clothing	28	47	56	5.9	3.6
Wall coverings	37	45	47	2.2	0.9
Book coverings	27	32	34	1.9	1.2
Non-automotive transportation equipment	12	25	36	8.5	7.6
Awnings, tents, others	52	85	104	5.6	4.1

Source: Freedonia Group Inc. (Cleveland OH) and reproduced with kind permission.

competition between airlines intensifying. Populations in the developed world have higher disposable incomes and more leisure time and will take part more in active sports, such as sailing, windsurfing and ballooning – all of which are likely to require coated fabrics.

The fear of occupational exposure to bloodborne pathogens, such as the human immunodeficiency virus and hepatitis B, led to a growth in use by the medical profession of barrier materials for clothing. These range from micoporous PTFE (polytetrafluoroethylene) film based products to laminated nonwovens. Expensive goods have to be washable and able to withstand sterilisation treatments. Disposable garments, however, incur environmental concerns, such as landfill or incineration. A significant growth in the market for incontinence garments is also expected as the aged populations of the world increase. The US retail and institutional market is expected to reach \$2.1 billion in 2005, whilst the worldwide figure is expected to be \$5.8 billion.[15] At present the bulk of this market is in disposable items but, in a similar way to medical products, the environmental factors may well produce a need for products which are more durable and washable.

1.8 The technical scope of coated and laminated textiles

The textile coating industry is heavily dependent on the polymer and speciality chemicals industries for polymers, additives, process aids, and many other chemicals necessary to produce the specified customer properties at the quality standard and durability demanded. The manufacturing procedures used in textile coating and lamination are related to similar processes in the film and paper industries; both films and papers are coated with polymers and laminated to other materials, and in fact the dividing line between paper and some nonwoven fabrics is quite diffuse. The nonwovens fabric industry is possibly the biggest single user of many polymer resins as binders. Textile coating uses some polymers used in the paint industry, such as acrylics and polyurethanes, and in fact some analysts now refer to the paint industry as the coating industry. An analogy has been made to painting; the best results are obtained in textile coating by the application of a few thin layers, rather than one thick layer – just like painting.

Coating machines of more complexity than those used in textiles are used in film processing, and the volumes and processing speeds are far higher. Paper is also coated and laminated and, again, the volumes and speeds of processing are higher than those used in textiles. However, films and paper are in general more dimensionally stable than textiles, but there are other problems which arise when producing at such high speeds. There are probably lessons to be learnt and synergies to be gained by comparisons with these related industries.

Other industries related to fabric coating are rubber, where coated fabric has its origins (many rubber materials are still used as textile fabric coatings), and the highly technical and growing area of fabric/polymer composites. The present book, however, will deal only with the more 'traditional' textile aspects, and will only mentions these other industries briefly. Fabric coating is also related to fabric printing; indeed, by some definition a print is a coating of ink, held on by binders, some of which are polymers used in coating, and the printing ink contains thickeners similar to those used in fabric coating. An 'all over' print is indistinguishable from a very lightweight coating, and the rotary screen printing machine is a convenient way of applying such coatings.

Fabric coating and lamination draws on several disciplines, including textile technology, chemistry and polymer chemistry and engineering skills. Textile technology is required for design, construction and preparation of the base fabric, which determines tear and tensile strength and coating suitability. The fabric must also be prepared by the appropriate finishing processes, to ensure satisfactory polymer adhesion and to provide a soft, flexible handle and drape. Polymer chemistry is required to decide polymer type, e.g. PVC, polyurethane, acrylic, and also the knowledge and skills necessary to mix coating recipes. Coating compounds incorporate chemical additives to produce specific properties, for example FR chemicals, plastisols, processing aids, etc. Chemical engineering and mechanical engineering knowledge is required to design coating machine ovens with the correct drying rate and fume and solvent (or water) extraction, and to produce goods with the specified technical properties at commercial production rates. Material handling, especially of coated (and laminated fabrics), is sometimes neglected but is an extremely important factor. It is frequently critical in determining profitability, because soiled, damaged, and creased fabrics are responsible for much downgrading.

There is now more instrumentation, as the 'human element' is reduced and more automatic and also more reliable controls are built into processing machinery. Information technology and computers are playing an important part in work scheduling, and are optimising use of machine time and resources by better communications, stock control and more efficient purchasing. These trends are likely to increase with even further advances in information technology and more use of computers generally.

People-management skills are needed to train and motivate both operatives and staff, to cultivate team spirit and to maintain a culture of continuous improvement. These are necessary for innovation and to produce quality products with minimum second quality material – preferably with 'zero' defects to ensure commercial success. The commercial bulk production of goods is as challenging as the original development in the laboratory – perhaps more so, because the operatives are generally less qualified than laboratory staff. The work can be somewhat repetitive, but requires conscientious attention to detail at all times, especially when producing at speed, because many metres of fabric may be processed incorrectly before a fault is noticed. Regular machine maintenance and meticulous cleaning are also essential requirements.

Environmental considerations are becoming increasingly important, and governments and local authorities strive to improve air quality by the reduction of volatile organic compounds (VOCs) and other process emissions. Good air quality is not only important for health and safety reasons, but also in the prevention of global warming and climate change. There are now restrictions on effluent and on the use of certain potentially harmful chemicals used in compounds for textile coating. Reduction in the quantity of waste going to landfill and the encouragement of recycling are also having their effect on the coating and lamination sector of the textile industry. The recyclability of coated fabrics is under review and could well become a significant factor in choice of materials. It would seem that many coated fabrics, comprising two or more polymers joined together, will be difficult to recycle. With this problem in mind, research work is being carried

Table 1.8 Properties that can be obtained by fabric resin coating or by film lamination

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General fabric properties
Improved dimensional stability
Less stretch distortion
Less pattern distortion
Increased tear strength (use of silicone resins)
Reduced tear strength (if desirable)
Anti-fray/reduced unravelling of edges
Stiffening (when desirablez
Improved handling (in processing)
Easier and more accurate panel cutting/sewing
Increased friction, more grip (if required)
Increased slide (less friction if required)
Improved crease resistance
Improved abrasion/pilling/snagging
Reduced tendency to curl
Reduced porosity/permeability to gases/liquids
Full impermeability to gases/liquids
Improved/easier cleanability
Soil resistance
Water/liquid repellence
Wipe clean properties
Thermoformability
Heat sealability
Weldability
Thermal insulation
Acoustic insulation
Increased bulk
Increased thickness
Improved printability
Improved embossability (patterns/grained effect)
Artificial leather/suede

Appearance/aesthetics
Gloss/matt appearance
Smooth continuous surface
Opacity
Full black-out
Coloration (by pigments in coating/film)
Enhanced printability
High visibility, 'dayglow'
Reflective surfaces
Metallic effects
Pearlescent effects
Iridescent effects
Glitter effects
Fluorescent
Photoluminescence (glows in dark)
Hologram effects
'Chameleon' effects (colour change with heat)

Barrier properties to produce
Shower resistance
Waterproofness/water resistance
Chemical resistance
Dustproofness
Windproof
Barrier to gases/liquids
Protection against liquids, chemicals, microbes
Functional processing aid to assist manufacturing processes, e.g. vacuum moulding techniques, '*in situ*' moulding techniques
Filtration
Thermo-shielding
Light shielding
EMI/RFI* shielding

Using coating or film as a matrix/container for functional material
Pigments (various types – see appearance/aesthetics)
Reflective/fluorescent/photoluminescence material

Table 1.8 (*Continued*)

Using coating or film as a matrix/container for functional material cont.

Metal dust/flake (e.g. nickel, iron for magnetic strips)
Conductive material
Phase change material
Antistatic material
Humectants (moisture retention materials)
Antimicrobial chemicals
Fragrances/perfumes
Deodorising chemicals
† Microcapsules (containing different substances)
FR chemicals (high loadings possible)
Activated carbon (for absorption)
Oil absorbing
UV/IR absorbing chemicals
Radiation absorbing material
Hollow glass/other material microspheres (for weight saving or thermal insulation)
Blowing agents for soft touch–pore structure
Adhesives (may be microencapsulated)
Fillers for bulk, weight, economy
Heat/light/UV stabilisers
Specialist fillers/chemicals

'High tech' fillers

Micro-instruments
Sensors
Probes
Heating elements
Thermoshape memory polymers
Nanocomposites

Summary: Coatings or film lamination can be used as:

a) coverings or as a barrier for protection, separation or containment
b) for appearance modification for decorative or functional purposes
c) improving dimensional stability, controlling stretch, preventing edges from fraying or curling
d) for control of porosity, e.g. for filtration
e) as a matrix for holding some functional material, chemical, pigment or other agent
f) as a processing aid, for example in '*in situ*' moulding, vacuum technique or thermomoulding
g) combining the specialist properties of polymers with the flexibility, strength, drapeability and covering power of a fabric.

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* EMI/RFI = electromagnetic/radio frequency interference

† Micro-encapsulation can be used as a means of improving the durability of chemical finishes or for gradual release of chemicals, e.g fragrances, perfumes, anti-microbial chemicals. Finishes micro-encapsulated and applied to garments may be resistant to many machine washes. 'Post it' note paper is produced from micro-encapsulated, pressure sensitive adhesive. Phase change materials, when micro-encapsulated, confer 'cool when hot' and 'warm when cold' properties to garments.

Table 1.9 Novel properties and exploratory development chart

Material	General property
Fibre or Fabric	Tear and tensile strength Stretch and recovery Covering power Filtering ability Speciality types available: high tenacity FR (moderate to very high) anti-static 'anti-cut' energy absorbing anti-microbial aramids/UHM* polyethylene, high strength to weight ratio and other exceptional properties. Easy handling and storage (rolls) Easy fabrication
Polymer/resin/ compound	Covering power from 100% downwards Chemical resistance Thermoformability Enhanced printability, receptive to artwork Some have weldability See Table 1.8 and 2.1
Filler	Coloration opportunities: pigments pearlescent metallic FR chemicals Encapsulated material UV and other radiation absorbing Heat stabilisers Many other properties possible, virtually all textile chemicals may be used as filler or additive, see Table 1.8
Film	100% covering with smooth surface Barrier properties Printability/receptive to artwork Some have weldability Allows film technology to be combined with fabric technology and fabric properties Speciality films available: Tedlar – PTFE – wide temperature resistance Kapton – polyimide – wide temperature resistance PVDC (exceptional impermeability) Decorative films – e.g. Mearl (Mearl Corporation) Reflective surface (heat, light, other radiation)
Foam	Soft touch Improved aesthetics (deep sew lines, e.g. car seat covers) Thermal insulation Sound insulation

Table 1.9 (*Continued*)

Material	General property
	Bulkiness (enhanced safety) Impact absorbing Controllable filtering ability
Non-woven/ compound fabric (e.g. tufted fabric, wadding)	Soft touch Thermal insulation/sound insulation Controllable filtering ability Bulkiness (enhanced safety) Impact absorbing Non-woven fabric can be a speciality fibre or an inexpensive base material, i.e. allow a cost saving

* UHM = ultra high modulus

out in Germany to develop water dilutable polyester polymers as coating material for polyester fabric, the reasoning being that a coated fabric composed of the same or a similar polymer will be easier to recycle.

In addition to modifying base-fabric properties, the polymer coating can be used as a matrix or 'container' for speciality chemicals or pigments. For example, high visibility or 'day glow' articles can be produced by mixing the appropriate treatments into a polymer coating and applying it to a fabric. This route is generally more versatile than dyeing the fabric with high visibility dyes – a higher concentration of pigment or dye can be loaded into the coating than can be dyed on to the fabric. Speciality chemicals, such as anti-microbial or anti-static agents, applied as finishes to the fabric, may be easily removed by washing, wiping or abrasion. However, if these chemicals are mixed into the polymer coating, they will be more difficult to remove. Other speciality chemicals which can produce novel effects include photoluminescent chemicals, which emit light in the dark, dyes which change colour with temperature, UV light absorbing agents (against skin cancer), 'phase change material' (which provides heating when cold, cooling when hot), anti-odour agents, chemicals, perfumes and fragrances, and FR chemicals. Micro-encapsulation in millions of tiny capsules, each about 3–5 micrometres in diameter, can prolong the durability, and hence effectiveness of many of the chemicals mentioned. Encapsulation protects the chemical or substance from evaporation, washing off or other means of removal, and releases the substance gradually as a number of the capsules are ruptured. A summary of physical and chemical material properties which may be obtained by the process of coating and lamination of textiles appears in Tables 1.8 and 1.9.

Coating and lamination are versatile techniques and offer the means to innovate and develop new products. However, the coating and lamination technologist must keep up to date with developments and requirements and seek continuous improvements in each of the 12 technical areas (as categorised by Techtextil) in order to identify opportunities immediately they arise. He or she should be well informed about the latest fibres and polymers which, when combined together, could offer unique, novel properties to provide for a particular need, solve a particular problem or offer the opportunity to develop a new product.

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2

Materials and their properties

2.1 Introduction

A coated fabric combines the benefits of the base fabric with those of the polymer with which it is coated. The resulting coated fabric will have many properties which cannot be offered by either component individually, and careful consideration is necessary to select both base fabric and coating polymer. The base fabric provides the mechanical strength of the composite material and supports the layer of coating applied to it. 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, and so second quality fabrics may be sent for coating. In fact, the defect is frequently made more prominent and the cost of rejected coated fabric, with the added value of coating, will be significantly higher than that of the base fabric alone.

2.2 Fabrics

Polyester and nylon are the main fibres used, because of their strength and general resistance to moisture, oils, micro-organisms and many common chemicals. Generally, polyester is more resistant to light and ultraviolet (UV) degradation than nylon while nylon is more resistant to hydrolysis. Polyester, however, has grown at the expense of nylon because of its better dimensional stability and shrink resistance, lower extensibility and generally lower cost. High tenacity nylon and polyester yarns are used in many coated articles for extra strength, and aramid fibres are used where more specialist properties, such as high strength to weight ratio and resistance to high temperatures, are required. Acrylic fibres are used for some applications where very high UV resistance is necessary, such as for awnings, car roofs and hoods for convertibles. Cotton was the first fabric used in textile coating and it is still used in large quantities. In applications where strength is required, however, it has been replaced by nylon and polyester which have considerably higher strength to weight ratios. Cotton is also vulnerable to wet rotting and microbial attack, but it has certain advantages over synthetic fibres, such as better polymer adhesion. The rougher surface of the cotton and the short fibre length provide more opportunity for mechanical anchoring of the polymer. The smoother, continuous filament synthetic fibres frequently require more specialist means of promoting fibre–polymer adhesion, especially with PVC plastisols and rubber coatings. However, cotton or fabrics produced from spun yarns cannot in general be direct coated to produce lightweight, coated fabrics, especially waterproof materials, because the fibre ends may cause pin holing, or be 'scraped or teased up' causing a raspy surface, usually with poor abrasion and waterproof performance. This, of course, does not apply when the coating thickness is sufficient to cover any fibre ends completely. Fabrics incorporating some continuous filament textured yarns, such as false twist textured, can, in some cases, be direct coated and the yarn texture can improve the coating adhesion by mechanical means.

There are speciality variants of nylon and polyester, such as high tenacity (HT) and low shrinkage (LS), which are used in coating applications, such as tarpaulins and conveyer belts. Glass woven fabrics are use as bases for PTFE coatings for industrial uses, such as calender belts and building structures. These applications make specific use of the glass properties of very high strength with very low elongation and excellent flammability resistance. Glass fibres cannot be used in applications that involve significant flexing, because of their poor flex resistance.

2.2.1 Fabric construction

Only a relatively very small number of fabric constructions are employed for polymer coating, i.e. plain woven, twill and basket constructions. Excessively loose constructions could distort dimensionally, especially on the bias, whilst excessively open structures would lead to resin penetration. If the fabric construction is too open, the coating resin may not be able to 'bridge' the gaps between the yarns to form a continuous layer necessary for performance such as waterproofness. To combine lightness of weight with high tear strength, rip-stop constructions are sometimes used, i.e. a stronger yarn is included in the fabric every 5 mm or so. Woven fabric constructions, especially plain weaves, are generally rigid with little stretch, and any required stretch has to be introduced via the yarns. Yarn mobility in the fabric construction, as well as inherent yarn tensile strength, determines fabric tear strength. If the yarns can move and bunch together, higher tear strength will result compared to a situation where they are broken individually. It can be appreciated that coating penetration between individual threads will tend to reduce tear strength. A modified Oxford weave which enhanced tear strength and allowed direct coating was patented in the 1960s. This was later developed into the Poly-R^R weave which has double the tear strength of a standard weave.[1] Knitted fabrics are used when significant elongation is required but, as will be seen, knitted fabrics cannot generally be direct coated because of their stretchiness and open construction. Fabrics woven from continuous filament yarns are generally relatively stiff compared with fabrics woven from spun yarns, and especially knitted fabrics. When direct coated these woven fabrics become stiffer, and they can be very stiff if excessive resin penetration occurs. The softest handle can be obtained with the minimum of penetration, but this could result in poor resin adhesion. A balance, therefore, has to be reached between coated fabric handle and resin adhesion. As has been stated, fabrics woven from spun yarns – which usually have better drape and softer handles compared to continuous filament woven fabrics – generally cannot be direct coated but, as will be seen later in Chapter 3, they can be coated with crushed foam or transfer coated. Woven fabrics produced from continuous filament textured yarns, or from a blend of yarns, have properties somewhere in between, and may be direct coated in certain circumstances.

Knitted fabrics, which cannot generally be direct coated and which invariably have softer handles with better drape than woven fabrics, are usually transfer coated, see Chapter 3. Coated fabrics with excellent drape and soft handles are made possible by this process. The knitted base fabrics are sometimes slightly raised or napped to improve coating adhesion and to maximise the softness and flexibility of the coated fabric. A notable difference between direct coating and transfer coating is that in direct coating, the resin is on the back of the fabric and is on the inside of the garment. On the other hand, with transfer coated fabrics, the polymer forms the face of the material and is on the outside of the completed garment.

Nonwovens are an industry in their own right and resins, referred to as binders, are extensively used in their manufacture. Nonwovens, with some exceptions, generally have limited tear strength, poor handle and drape and are not used for apparel, apart from disposable protective clothing. Many cannot generally be direct coated because of their rough surface, and because they are not strong enough to be tensioned on a coating machine. Needlepunched nonwoven fabrics, however, are used as floor coverings; they are coated with both water-based resins and hot melt coatings to improve surface abrasion and to confer mouldability properties, see Section 3.3.13.

The main fibre properties which influence choice as a coating substrate are summarised in Tables 2.1 and 2.2. There are also papers published on fabric substrates for coating.[1–8]

Table 2.1 Properties of fibres commonly used in coating and laminating

Fibre	Density (g/cc)	Melting point (°C)	Tenacity (g/den)	Stiffness (flexural rigidity) (g/den)	Limiting oxygen index (% oxygen)	Abrasion resistance	Resistance to sunlight and UV
Acrylic	1.12–1.19	150d	2.0–5.0HT	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	4.3–8.8HT	17–48	20	Very good	Poor – good if stabilised
Nylon 66	1.14	260	4.3–8.8HT	5.0–57	20	Very good	Poor – good if stabilised
Polyester	1.40	260	4.2–7.5HT	10–30	21	Very good	Good – excellent if stabilised
Cotton	1.51	150d	3.2	60–70	18	Moderate	Moderate
Wool	1.15–1.30	132d	1.0–1.7	4.5	25	Moderate	Moderate
Polypropylene	0.9	165	4.0–8.5HT	20–30	18	Good	Poor – good if stabilised
UHM polyethylene	0.97	144	30	1400–2000	19	Good	Good
Aramid	1.38–1.45	427–482d	5.3–22	500–1000	29–33	Moderate	Moderate
Carbon	1.79–1.86	3500d	9.8–19.1+	350–1500	64+	Brittle	Excellent
Glass	2.5–2.7	700	6.3–11.7	310–380	not burn	Brittle	Excellent

Notes:

1. d = does not melt but starts to decompose.
2. HT = high tenacity.
3. UHM = ultra high modulus.
4. Thermoplastics begin to *soften* at temperatures below their melting point and therefore 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 mechanical pressure as for example in a lamination or moulding process. Surface pile can be crushed or deformed or glazing can occur.

N.B. Data compiled from several different sources and intended only as a guide.

Table 2.2 Fabric substrates for coating

Fabric	Advantages	Disadvantages
Cotton	Excellent coating adhesion No bonding agents required Low thermal shrinkage	Low strength to weight ratio Absorbs moisture Vulnerable to mildew, rotting, insects
Polyester	Strong with HT, low shrinkage and many other variants available Relatively inexpensive Resistant to mildew, rotting and insects High abrasion resistance Blendable with cotton for garments and other end uses Good overall properties/price	Low moisture absorbency (for garment comfort) Limited resilience (not used in carpets)
Nylon	Strong with HT variants available Good elasticity and resilience High abrasion resistance Resistant to mildew, rotting and insects Good thermal absorbency (used in airbags)	UV resistance low unless protected Fabric may sag due to moisture absorption Relatively expensive compared to polyester
Polyethylene, polypropylene	Lightweight Inexpensive Chemically inert Resistant to mildew, rotting and insects	Low melting point – especially polyethylene Adhesion difficult to some substances
Aramid	Very high tensile strength Excellent strength to weight ratio High melting point Good FR properties	Expensive Degraded by sunlight/UV
Glass	Very high temperature resistance High tenacity Excellent FR properties Good dimensional stability Resistant to mildew, rotting and insects Zero moisture absorbance Excellent UV stability	Adhesion difficulties Relatively heavy Brittle, poor flexing properties

N.B. There are now available many variants of these fibres specially developed for specific applications, including low shrinkage (LS), high tenacity (HT), ultra high modulus (UHM), FR resistance, anti-wicking polyester, etc.

2.3 Preparation of fabrics

2.3.1 Scouring

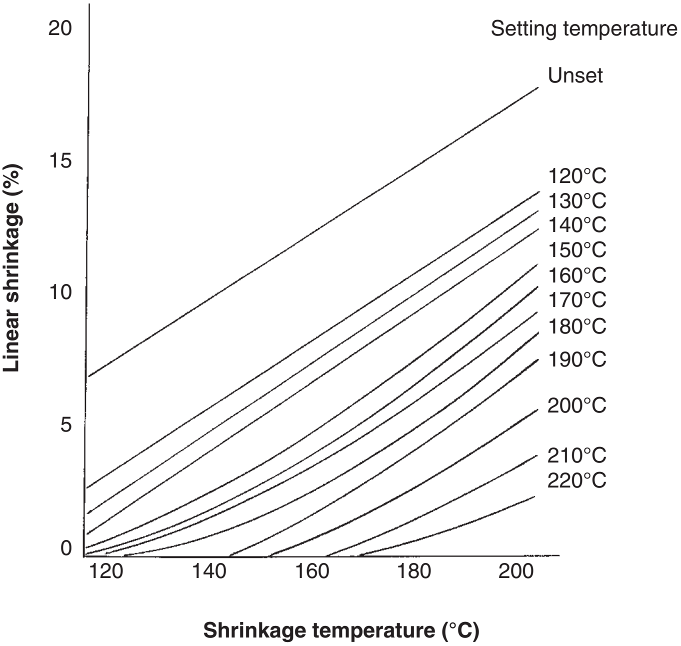
A fundamental requirement for any coated or laminated fabric is that the coating or material joined to the fabric must be strongly combined to that fabric, and at must not separate throughout the lifetime of the product. One of the most frequent reasons for premature breakdown of a coated or laminated article is delamination. For good adhesion, the fabric must normally be clean and free of any soiling. Coating and lamination are essentially joining operations, and all the principles governing satisfactory adhesion apply, see Sections 2.7.1 to 2.7.3. Any dirt or contaminant on the fabric – or on the machinery from which the contaminant can transfer to the fabric – is likely to affect the adhesion of the coating to the material to which it is being joined. Waxes, oils and silicone-based materials, even in small amounts, are especially likely to reduce bond strength. Cotton fabrics should normally be desized and synthetic fibres such as nylon and polyester should be scoured. Sometimes this is not done to save costs, but there is always the risk of poor bonds being formed. However, a continuous scouring range set up in front of a finishing stenter is relatively inexpensive to run, once the initial costs of installation have been met.

Scouring itself can sometimes cause problems – if the fabric is not properly rinsed, the scour chemicals themselves may become contaminants and can reduce adhesion. A typical scouring liquor will contain a chemical such as sodium carbonate to ensure that the pH is alkali, a wetting agent, and detergent to remove lubricants and oils and hold them in suspension to prevent re-deposition back on to the fabric. In regions with hard water, it is sometimes necessary to include a water softener for effective scouring. The textile chemical companies have developed agents which perform many of these functions. If the material does not wet out readily, a wetting agent may be necessary, but this is an extra chemical which needs to be removed so that coating or lamination adhesion is not jeopardised. There are available wetting agents which thermo-degrade on stentering (e.g. Sandozin NRW by Clariant), and are therefore less likely to influence adhesion. Occasionally frothing can occur during scouring, especially at high speeds, and anti-foaming may be used. Excessive amounts of anti-foam agents, and especially silicone based anti-froth agents, should be avoided, because of possible influence on coating adhesion.

Virtually all fabric finishes and residual scour bath chemicals will reduce coating or lamination adhesion from a hypothetical ideal of completely ‘clean’ fabric – difficult to achieve in a commercial process. However, fabric, especially synthetic fabric with absolutely no finish or residual lubricant on it, would be very difficult to process, because of the generation of static electricity. The static electricity would cause fabric to cling to rollers and to the sides of containers, giving rise to creasing, and to static electrical shocks which will be a nuisance and pose a risk to the safety of operatives. Even seam slippage agents, fabric softeners and, in the case of nylon, after-treatments to improve dye fastness (syntans), can reduce adhesion substantially – although some syntans reduce adhesion less than others. Sometimes the loss in bond strength can be tolerated, and sometimes a finish such as a fluorocarbon is actually applied beforehand to help control resin penetration during coating. If finishes are necessary, they should be kept to a minimum concentration and their effect on adhesion should be examined before proceeding to bulk production. It is possible to apply finishes to one side of the fabric by a foam processing or rotary screen technique, which will minimise the risk to adhesion. However, it is still advisable to check beforehand – the finish may be penetrating through the fabric to the other side. When adhesion is especially critical, and for the best possible adhesion, the fabric should be 'pure finished', i.e. no special finish applied.

2.3.2 Heat stabilisation

Fabric coating or lamination generally entails a heating process, and thermoplastic base fabrics should be heat set at a temperature higher than the temperature that will be used in the coating or lamination process. If this is not done, the fabric will shrink – or try to shrink – during production and possibly even when the finished article is being used. The general relationship between heat and shrinkage of polyester yarn is shown in Fig. 2.1. Creases may be caused and, even if the fabric is held to width on pins, it may well shrink a little when released and put on to a roll. Ideally the base fabric for coating should be in a stable and generally relaxed state on the coating machine. Even non-thermoplastic fabrics such as cotton can be mechanically stretched under tension and, when this tension is released, fabric creasing may occur or patterns may be distorted. It should be tensioned sufficiently to present a flat and uniform surface for uniform and even application of the coating resin. Excessive tensions, including those induced by shrinkage, could cause creasing. Other fabric faults, such as creases or slack selvedges, will also give rise to problems in coating or lamination. Fabrics must be presented to the coating or lamination head in a stable relaxed state, so that they are flat and at the correct width. If they have not been finished correctly, e.g. pulled out excessively in width, they may physically shrink ('neck-in') at the point of lamination or coating, thus presenting the operatives with major problems. Fabric must be supplied at the required width and then stentered to the correct width. Excessive pulling out of woven fabric can also cause excessive penetration of resin, stiffening of fabric or reduced tear strength, as well as resulting in an under-



2.1 The effect of setting temperature on the dimensional stability of DuPont polyester fabric. Technical Information from DuPont (UK) Ltd (April 1999). Reproduced with kind permission.

The higher the setting temperature, the more thermal-dimensionally stable the fabric, i.e. no or less shrinkage on the application of heat which usually occurs during a coating or laminating process. However, width loss due to excessive lengthways tension will still occur.

weight and out-of-specification fabric. Priming chemicals (such as RFL – resorcinol formaldehyde latex – see Section 2.6.4) to improve the coating adhesion of PVC and rubber coatings, can be applied by impregnation during the heat setting process. Fabric heat setting should be carried out after scouring, especially when aesthetics are important, because any stains on the fabric can be 'set in' and difficult to remove later. Woven nylon fabric may present problems because, on leaving the stenter, it is likely to be completely dry. The moisture absorbency of nylon is up to 0.4% and, if the material absorbs this moisture during storage on the roll, trellis-like creases may be formed.

2.3.3 Batch preparation

Batches for coating or lamination are normally made up from several pieces sewn together to produce one long continuous length for uninterrupted continuous runs of production. Needless to say, all individual pieces should be of the same width. The joining seams must be carefully sewn and must be strong enough to withstand the longitudinal tensions required for direct coating. Poorly prepared seams can result in creases, streaks in the coating and many metres of unsaleable coated fabric on each side of the seam. An excessively thick seam may burst open if caught under the doctor blade, cause the fabric to rip and could even damage the coating head. Burst seams, ripped fabric or holes in the fabric all necessitate considerable cleaning up, resetting and restarting of the process – all very time consuming and costly in lost production time. In an ideal world, there would be no seams. Fabric batches should be as long and in one continuous length as is practically possible. Even in the modern factory, this is usually what a person can lift manually! Sewing up individual pieces for scouring, heat setting or any other process always presents a risk of creases or potential creases – least handled, is best handled – preferably in one continuous length.

2.4 Materials for coating

2.4.1 Properties of plastic materials

Apart from the natural fibres such as cotton and wool, most other material which may be used in coating and laminating processes, i.e. fabrics, adhesives, films and foams, is likely to be thermoplastic. During the coating or laminating process, both fabric substrate and polymer resin will generally be subjected to a heat treatment, and it is important to know beforehand what is likely to happen. Plastics can be broadly divided into two types; thermoplastics, which soften and eventually melt when heated, and thermoset plastics, which do not soften or melt when heated. All plastics are made from long-chain, linear polymer molecules but, in the case of thermoset plastics, the molecules are crosslinked, which makes the whole structure more rigid and largely prevents them moving when heated. The long-chain molecules in thermoplastics, however, not being crosslinked, are more free to move about when heated above certain temperatures specific to the molecular length and chemical nature of the particular plastic. It is possible – as will be seen – to crosslink plastics and rubbers to various degrees, in order to improve durability and wear properties. Crosslinking also generally makes the material more rigid, less stretchy and harder; and a high degree of crosslinking will usually cause the plastic to become brittle. The person who formulates the resin, the compounder, see Section 2.6.1, can control the degree of crosslinking to produce the coated fabric properties required, by choice of type of crosslinking agent and concentration of the agent in the coating recipe.

Synthetic fibres are made from thermoplastic materials which soften, shrink and melt under the action of heat. As has been seen above, it is necessary to heat stabilise polyester and nylon before coating, to prevent shrinkage during the coating process. Man-made fibres, e.g. cellulosic, are regenerated polymers and are not as heat sensitive as thermoplastic fibres. In some polymer/fibre combinations, such as hoses, belts and car tyres, the dimensional stability at high temperatures of cellulosic fibres, such as viscose, is an advantage. Themoplastic yarn shrinkage under the action of heat is one of the causes of delamination which, in turn, leads to premature breakdown.

Thermoplastic properties of some plastics are useful in that they allow the material to be used as hot melt adhesives and, in certain cases, to be joined by welding techniques. In general terms, for a given chemical type of thermoplastic, the shorter the molecular length, the lower the melting point, and the longer the molecular length, the higher the melting point. Adhesives are generally shorter chain length molecules and melt at relatively low temperatures, for example polyester fibre melts at about 260 °C, but there are polyester-based adhesives which melt as low as 100 °C. The thermoplastic nature influences the ease with which recycling can take place; if thermoplastic, the material can be melted down and reprocessed into the same or another useful article. Thermoset plastics are not as easily recycled, and for this reason thermoplastics may be preferred over thermoset materials – if there is a choice. Thermoset plastics are harder, more rigid and more heat resistant, but the vast majority of plastics are thermoplastic.

The main plastics used for textile coating are polyvinyl acetate, acrylics, PVC, polyurethanes and natural and synthetic rubbers. In addition to the main types, there are variants and copolymers and even terpolymers, i.e. resins made from three starting materials. As will be discussed later, adhesives and hot melt adhesives can be produced from copolymers, giving a wide range of properties. The chemical structures and basic chemistry of these polymers are available in standard chemistry textbooks, but there are available a number of excellent summaries of the chemistries with respect to fabric coating.[9–11] Numerous articles are also available on individual polymer types, their properties and their applications.[12–39] These polymers are generally applied to fabric as solutions or dispersions in water or as solvent in an uncrosslinked state. Crosslinking of the polymer can be effected after deposition on the fabric, which improves the durability of the resultant coating to abrasion and its resistance to solvents and water. However, this crosslinking always causes some stiffening and hardening of the coating. The degree of crosslinking is influenced by the nature of the polymer itself, the type and concentration of crosslinking agents added, the catalyst type and concentration, and by the time and temperature used to effect the crosslinking process. The higher the temperature, the greater the degree of crosslinking – a very rough 'rule of thumb' states that the crosslinking rate doubles for every 10 °C increase in temperature. This may not be strictly true in pure scientific terms, but it does emphasise the importance of temperature control in coating operations involving crosslinking polymers. If not properly crosslinked, coatings can be slightly sticky (tacky) to the touch and have inferior wearing properties. In general the degree of crosslinking, which determines performance, has to be balanced with the aesthetics of handle, drape and softness. The term 'crosslinking' generally has the same meaning as 'curing' which appears to be used more often when surface finishes are applied, and 'vulcanisation' which is used in rubber technology.

It is important to realise that a 'plastic' generally consists of the plastic itself plus several additives. Amongst these are UV radiation and heat stabilisers, antioxidants, fillers to improve the mechanical properties, fillers for economy, FR chemicals, reinforcement fibres (turning the plastic into a 'composite'), pigments and other compounds necessary to confer further special properties or to assist with processing. Sometimes it is necessary to add materials specially to make all the various ingredients compatible with each other. When fibres are added, or when the compound is to be coated on to a fabric, coupling or bonding agents – also called adhesion promoters – may also be required. Plastic compounding or mixing of components is a specialised process and, if not carried out correctly, it can cause production problems and variations in quality. In addition, volatile compounds used in formulations for car interiors can cause 'fogging', see Chapter 5. Furthermore, there are many variants of each chemical type, and the terms 'polyurethane' or 'polyester' in fact refer to families of polymers of related chemical constitution and not just to a single type. During the 1960s and early 1970s there was considerable activity in the development of polyurethanes for both direct and transfer coating, and many research papers were published at that time. Although there have been improvements in properties and developments, especially to make materials and processes more environmentally friendly, most of the general principles of the properties and practical application methods are unchanged and much can be still be learnt from these papers.[25–29]

A summary of polymer resin properties is presented in Table 2.3 (some trade names appear in Table 2.4), but some general comments can be made. Polyurethanes generally have good adhesion to fabric substrates and have good elongation and excellent flexibility, even at very low temperatures. They have excellent surface abrasion properties and, in fact, are used as lacquers for leather. Acrylics are extremely versatile materials with many variants and price ranges. They have good clarity, and good UV resistance. Some low temperature cure acrylic resins are available from certain suppliers, such as Rohm and Haas, which, if suitable for the purpose, will result in energy savings.

Table 2.3 Summary of main polymers used in textile coating

Polymer	Properties/Advantages	Disadvantages	Typical products
PVC Polyvinychloride	Versatile material. Plastisols and water-based available which can be compounded to give wide range of properties Good inherent FR which can be improved Good oil, solvent and abrasion resistance Heat and RF weldable for good watertight seams	Cracks when cold Plasticiser migration Moderate heat and age resistance	Tarpaulins, coverings, large tents and architectural uses Seat upholstery 'Leathercloths' Protective clothing, aprons Leisure products, banners, bunting
PVDC polyvinylidene chloride	Very good FR (blendable with PVC and acrylic latex). Very low gas permeability Heat weldable Clear, high gloss	Hard and brittle	Blends with acrylics to improve FR in coatings, e.g. for roller/louvre blinds (film is used as shrinkwrap) (coating on drinks bottles)
Polyurethane PU	Several grades available in solvent and latex form. Tough, good extensibility, good weathering and abrasion resistance Films available for lamination	Some grades (aliphatic) discolour and have limited hydrolysis resistance FR is only moderate Relatively expensive	Waterproof protective clothing Waterproof/breathable protective clothing Aircraft life jackets Adhesives Used as lacquers for PVC tarpaulins and leather
Acrylic	Large number of variants and co-polymers. Wide range of properties. Blendable with other latices. Good UV resistance and optical clarity, generally inexpensive	FR may be poor unless compounded with FR chemicals	Back coatings for upholstery including auto seats Binders for nonwovens and glass fibres Adhesives Used as lacquers for tarpaulins

Table 2.3 (*Continued*)

Polymer	Properties/Advantages	Disadvantages	Typical products
EVA Ethylene vinyl acetate	Good adhesion to all fibres, good tuft binding properties Flexible at low temperature Good thermoplastic properties and easily thermomouldable Heat sealability Relatively inexpensive	May be some tendency to discolour May be sensitive to water – poor washing resistance	Backings for carpets and upholstery Wallcoverings, exhibition board backing Adhesives
Polyolefins LDPE HDPE Polypropylene	Good resistance to acids, alkalis and chemicals. Easily recycled Lightweight Inexpensive	Low melting point FR limited and limited resistance to ageing	Lightweight coverings, tarpaulins, (alternative to PVC) Sacks FIBCs, bulk bags
Silicone	Odourless, inert, good resistance to many chemicals and micro-organisms. Wide temperature service range from –60 to 200+°C. High tear resistance and puncture resistance of coated fabric Low toxicity, water repellent Available as fluid (no solvent or water to remove) Blendable with acrylics/polyurethanes Coating has some breathability	Attracts oily soiling, seaming is difficult due to release properties Expensive Difficult to print or apply artwork	Airbags Food, medical applications Gaskets, seals Parachutes Oven curtains

PTFE Polytetrafluoroethylene	Excellent resistance to acids, alkalis, chemicals, solvents, oils, oxidation and weathering Non-stick properties Outstanding electrical properties Wide service temperature up to 260 °C	Very expensive	Architectural applications Calender belts Food and medical uses Gaskets, seals
Natural rubber (NR)	Excellent stretch and flexibility, general purpose material, working temperatures to 70 °C, fillers improve mechanical properties Many grades and properties obtainable by compounding and blending	Moderate sunlight and oxidative resistance Moderate solvent and oil resistance Flammable – requires FR agents Unmodified is biodegradable	Carpet backing Tyres Life rafts Conveyer belts Protective clothing Escape chutes
SBR (styrene butadiene rubber)	Generally similar to natural rubber but somewhat better resistance to abrasion, flexing and micro-organisms	Generally similar to natural rubber	Carpet backing As natural rubber
Nitrile rubber (acrylonitrile/ butadiene) NBR	Very good oil resistance which increases with acrylonitrile content. Better resistance to heat and sunlight than natural rubber	Limited FR	Oil resistant clothing Oil seals, especially for hydrocarbons Belts and items handling oily or greasy products
Butyl rubber BR	Very low permeability to gases Better resistance to heat, oxidation and chemicals than natural rubber	Solvent resistance limited FR limited Seaming difficult	Items containing gases, e.g. air cushions, pneumatic springs, bellows Protective clothing – especially for chemicals and acids Lightweight life-jackets Life rafts

Table 2.3 (*Continued*)

Polymer	Properties/Advantages	Disadvantages	Typical products
Polychloroprene rubber (e.g Neoprene-DuPont) CR	Excellent resistance to oils, chemicals and oxidation Working temperature to 120°C Good FR properties Versatile material Generally inexpensive	Coloration difficult – generally only in black	Protective clothing Aircraft carpet backing Aircraft slide/rafts Life rafts Life jackets Hovercraft skirts Flexible gangway bellow (trains) Airsprings Radome covers Airbags V-belts
Chlorosulphonated rubber (e.g Hypalon-DuPont) CSM	Excellent oil, chemical and oxidation resistance. Generally similar to Neoprene, but higher temperature to 135°C (some grades to 170°C). Can be pigmented. More expensive than Neoprene Accepts higher level of filler than Neoprene		Similar to Neoprene. Used where coloration is necessary and higher temperature resistance is required
Fluroelastomer (Viton-DuPont) FKM	Very good heat, weathering, chemical and solvent resistance 'Elastic PTFE'. Service temperature –20 to 200°C	Expensive Poor resistance to ketones	Specialist protective clothing High performance applications, e.g. seals and gaskets

FIBC, flexible intermediate bulk containers; RF, radiofrequency.
N.B. All rubbers have limited resistance to aliphatic and aromatic solvents, except for Neoprene and Chloroprene which have moderate resistance and nitrile which has very good resistance to both types of solvent.
For more specialist details, see References 43–48, especially the works by Pruett (47 and 48).

Table 2.4 Some trade names and suppliers

Polymer, compound or resin	Trade name and supplier
Polyurethane	Witocoflex (Baxenden) Permuthane-solvent based (Stahl) Permutex-water based (Stahl) Dicrylan (Ciba)
Acrylic	Appretan (Clariant) Dicrylan (Ciba) Plextol-water based (Rohm-Huls) Plexisol-solvent based (Rohm-Huls) Acronal (BASF) Primal (Rohm & Haas-Cornelius) Vinacryl (Vinamul)
Vinyl acetate	Appretan (Clariant) Vinamul (Vinamul)
PVC plastisols/dispersions	Acrylon Lutofan (Bayer/Huls) European Vinyl Corporation (EVC)
Speciality halogen-free barrier resin	Epotal (BASF)
PVDC	Solvin (BASF/Solvay)
Silicone	Wacker Dicrylan (Ciba)
SBR	Butofan (butadiene rich) (BASF) Styrofan (styrene rich) (BASF)
Natural/synthetic rubbers	Acrlonitrile (Clariant) Vibatex (Ciba) British Vita BF Goodrich DuPont
Fluorocarbon (for water and stain repellent finishes)	Nuva (Clariant) Teflon (DuPont) Ashahiguard (Ashahi Glass)

Resin compounders: Synthomer, Noveon (formerly Mydrin/BG Goodrich), Industrial Latex, Texas Adhesives, Vitabond (adhesives).
General textile chemicals: Clariant, Ciba, CHT-Tubungen, Dr TH Boehme, Huls.
Specialist FR chemicals: Albright & Wilson, Thor, Schill and Seilacher, Great Lakes.
Crosslinking agents: BIP (Beetle Resins), Clariant (Cassurit), Ciba (Knittex and Lyofix), Bayer (bonding agents for rubbers and polyurethane).
In addition: Clariant manufacture a whole range of water-based resins of different chemical constitution under the trade name Appretan. Ciba have ranges under the trade name Dicrylan.

PVC is an extremely well researched material that can be compounded to produce very many different properties.[22–24] It is the most used material in fabric coating, is economical and has a high degree of inherent FR properties. However, it has come under attack from environmental pressure groups and alternatives are being researched. Polyvinylidene chloride (PVDC) resins have excellent FR properties which can be improved by blending with PVC. In addition, they have good impermeability to gases and, in fact, PVDC lacquers are used on polyester bottles to prevent the loss of carbon dioxide which would cause the drinks inside to go flat. Styrene butadiene rubber (SBR) latex, see below, is used in place of and in combination with some of the above when economy is required.

2.4.2 Natural and synthetic rubbers

Rubbers are polymers and are closely related to plastics. They are used in combination with textiles in many end uses, and indeed the fabric coating industry is in some ways an off-shoot of the rubber industry. There are various types to suit different applications, and they are versatile in that they can be blended together and they will accept additives to provide specific properties. The rubber compounding industry began with the discovery of vulcanisation in 1839, and the modern industry is the cumulative effort of countless rubber technologists working on almost countless applications of rubber since that time. As can be expected, rubber compounding is a very specialised process – there is usually a minimum of about eight or nine different ingredients in each mixture. The largest application by far for rubber is the tyre, which accounts for about 50% of all rubber production in the world. However, there is not enough natural rubber available and so this has to be supplemented with synthetic rubbers, especially SBR. During the Second World War, the supply of Malaysian rubber was cut off during 1942 and alternative materials were developed, such as polyvinyl acetal emulsions. There are a number of specialist rubbers including nitrile rubber, butyl rubber, polychloroprene, the best known of which is Neoprene (DuPont) and chlorosulphonated polyethylene, the best known of which is Hypalon (DuPont). SBR rubber latex is an inexpensive and versatile material and has many applications where economy is important, e.g. carpets. These rubbers are used widely in fabric coating applications, which are described in detail in Chapter 4.

No one single rubber has excellent resistance to all chemicals, solvents and fluids. All common rubbers, apart from Neoprene and nitrile rubber, have generally poor resistance to both aliphatic and aromatic hydrocarbon solvents. Conversely, most common rubbers have good resistance to oxygenated solvents (e.g. ketones), apart from nitrile rubber and Neoprene.

Butyl, nitrile and Neoprene rubbers have the best acid resistance. Butyl rubber has the best resistance to weathering and oxidation and also has very low permeability to gases. Viton (DuPont), referred to as 'elastic PTFE' by some chemists, has excellent resistance to virtually everything apart from oxgenated solvents, such as ketones. A summary of the properties of rubbers used in fabric coating appears in Table 2.3 and further detailed information is readily available in the literature.[30,31,40–48]

2.5 Materials for lamination

2.5.1 Films

Films have the advantage over fabrics of 100% cover at light weights; they are generally completely impermeable to liquids and gases and are also excellent barriers to dust and other particles. Film/fabric laminates are used in sail making, hot air balloons and airships. Films can be used to produce reflective surfaces with efficiencies much higher than can be produced with a fabric. However, they are generally easily torn and easily punctured and damaged by flexing, but some of these physical limitations can be overcome by lamination to a fabric, and the two components combined can offer a wide variety of useful properties. Film production is a large volume industry which uses many different variants of a relatively small number of polymers, produced mainly for packaging. Depending on the method of manufacture and starting material, films can be very inexpensive, such as polyethylene, or extremely expensive, such as Kapton (DuPont).[49] Film coating is widely used to confer heat sealability, low gas permeability, printability and other specialist properties. Photographic films (cellulose triacetate) will have several layers of coating. Pre-treatments, such as corona discharge, and plasma treatments are also used to confer wettability and adhesion and to aid other processes. The film industry in the USA generally measures film thickness in 'mils' which is one thousandth of an inch and equivalent to 25 micrometres.

Clear unsupported PVC film made by calendering is sometimes used in automotive door casing construction. It is laminated to car interior trim fabric, in a separate process, as a barrier against wetness and dampness within the door casing, and the PVC film is also a useful processing aid because of its weldability. Coloured unsupported PVC films (sometimes referred to as 'foils'), and films produced from PVC/ABS (acrylonitrile-butadiene-styrene) mixtures, usually embossed, are used extensively as coverstock in automotive interiors, laminated to polyurethane foam, polypropylene foam or a nonwoven fabric to provide a 'soft touch'. Within the last few years, however, the use of polyolefin films in place of PVC-based films has grown for a number of reasons. Unsupported films are made by a variety of techniques, including casting and extrusion as well as calendering. Calendering is used extensively in the rubber industry, and it is possible for the freshly produced film to be combined with a fabric during the calendering procedure. Other films types available include polyurethane, natural and synthetic rubbers, Neoprene and Hypalon. It is possible to produce polymer mixtures, sometimes referred to as plastic 'alloys', such as PVC/ABS and process them by calendering. Calendering is discussed further in Section 3.11.

Speciality films are widely used in protective clothing as waterproof and breathable barriers against the weather. They are also used in footwear, and medical applications are being explored.[50–55] The market leaders are Gore-Tex which is a PTFE film, Sympatex (Acordis) which is made from polyester, and Porelle (Porvair) which is polyurethane based. There are also several other branded waterproof and breathable films made from polyurethane. These films can be broadly classified into two types: microporous and 'solid' – which is sometimes referred to as 'monolithic'. The microporous varieties, such as Gore-Tex and Porelle, have very small pores in their structure which are too small to allow drops of water through, but large enough to allow water vapour molecules through, thus accounting for their breathability. The 'solid' film variety, such as Sympatex, breathe by a process of water molecules migrating from hydrophilic site to hydrophilic site within the polymer network. There are advantages and disadvantages claimed for each type; surfactants are believed to cause leaks in microporous films but not solid films, water swells solid films but not microporous films. Generally, solid films have better tear strength and are said to be better barriers to odours and to some microbes. Sympatex claim that the pores in microporous films become enlarged when the film is stretched at elbows and knees, thus facilitating water entry, whilst their film can be stretched 300% in any direction and still remain 'solid' and impermeable to liquid water. There are now a large number of films available which are both water resistant and breathable, made by a variety of novel techniques, e.g. making a film containing microscopic solid particles which on stretching produces tiny holes around the particles. Many of these films, however, do not have the physical durability or performance of Gore-Tex or Sympatex. These films are discussed further in Chapters 4 and 5.

Some films are offered for sale dot printed with hot melt adhesive powder. This is a convenient form; the customer can reactivate the adhesive to produce a laminated product with relatively simple apparatus and without powder scattering equipment, as and when required. There are a number of films with a very wide range of working temperatures and specialist properties, such as Kapton, a polyimide film by DuPont which has a service temperature range from –270 to 400 °C. Tedlar, a PTFE material also by DuPont, has a working temperature range –250 to 260 °C. Both films may be the basis of novel product development, perhaps combined with aramid fabrics. Film/fabric laminates are used in sail making, hot air balloons and have recently been introduced in some airbags. In addition to functional specialist uses, there are novel decorative films available, such as those produced from multi-extrusion processes, which give novel coloured patterns produced by interference light effects. These films, available from Mearl Corporation/Cornelius, are used mainly in the packaging industry, but if laminated to black or dark coloured fabric, they can produce interesting coloured effects. Decorative films are also available which produce metallic coloured effects by the etching of submicroscopic lines on the surface of aluminised film using a laser. These films are also used in the packaging industry, but could be laminated to fabric for creative decorative effects on garments or drapes. By a process of co-extrusion, films can be made with two different chemicals on either side and thus offer novel properties. Some adhesive films are produced in this way and allow two very different materials to be joined together. Adhesive films are discussed in Section 2.7.7.

2.5.2 Polyurethane foam

Polyurethane foams are available in various qualities, such as different densities, FR properties, different porosity and other specialist chemical and physical properties. The largest outlet for polyurethane foam is in textile laminates, used for automobile seats covers and for other coverings in the car interior, see Fig. 2.2. The usual form is sheet foam with a thickness of anything between 2 and 10 mm or more, laminated to the face fabric on one side, and a lightweight 'scrim' fabric on the other side. This tri-laminate is used by most car companies in the world, and is in this form to produce a material which is soft to the touch and which never creases or 'bags'. In addition, when the material is sewn, deep attractive sew lines are produced. The scrim fabric, which is usually knitted nylon or polyester, helps control stretchability, improves seam strength and acts as a 'slide aid' during sewing and seat making. If 'slide aid' is the only requirement, a lightweight nonwoven fabric is used. Fabric used for door panels and other areas of the car may also be laminated to polyurethane foam for a soft touch, for comfort and to help reduce vibration and noise. In these cases, the scrim is generally not required.

The polyurethane foam may be either polyester polyurethane or polyether polyurethane. The first mentioned is generally more easily laminated by the flame lamination technique, see Chapter 3, but has limited hydrolysis resistance. In hot, humid areas of the world, polyester polyurethane foam could break down, and in these areas polyether polyurethane foam is more

2.2 Production of sheet polyurethane foam for lamination to automotive seat cover fabric. The photograph shows Caligen Foam's 60 m block slitting facility. Photograph supplied by Caligen Foam Ltd and reproduced with kind permission.

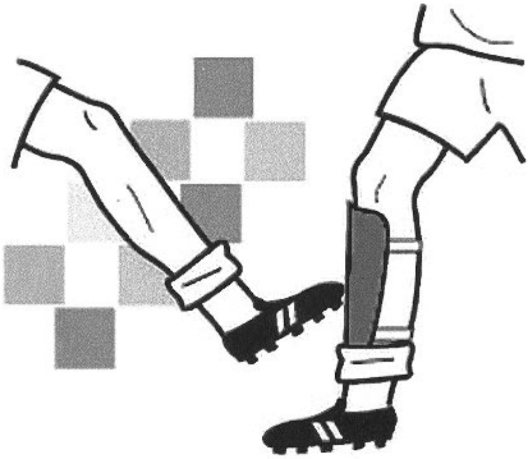
likely to be used. Unmodified polyether polyurethane foam cannot be flame laminated and chemicals are added to the foam to make this possible. The automotive industry is extremely competitive and cost is so important that, at present, flame lamination is the most economical way of producing laminated car seat fabric in volume. Over 48 million cars are made in the world every year and all contain at least 7 m^2 of decorative face fabric laminated to polyurethane foam in the seats. Fabric laminated to polyurethane foam is also in other parts of the car interior, such as door casings, headliners and sunvisors. Because of environmental concerns regarding flame lamination and recyclability, alternatives to polyurethane foam have been researched. These include various types of nonwoven fabrics and 'spacer' knitted fabrics, which have a different 'touch' and poorer resilience at temperature. Automotive seat foam is discussed further in Chapter 4 and recycling aspects in Chapter 6.

Polyurethane foam/textile laminates are also used in the footwear industry and in speciality items such as waistbands, baby diapers and personal hygiene products. In the 1960s and 1970s, polyurethane foam/textile laminates were used extensively in apparel and for curtains and 800 million metres of polyurethane foam/textile laminate were produced in the USA alone during 1970.[56] However, this figure declined to 70 million metres by 1979. The product lost popularity because of a preference for apparel fabric with better flexibility and drapability, and also because of delamination during washing and drycleaning caused by, it is believed, poor quality control and lack of understanding of the factors influencing good adhesion.

2.5.3 Polyolefin foam

Polypropylene and polyethylene foams are available in roll form. Polyolefins have excellent microbial, oil, solvent and chemical resistance and can be fabricated by vacuum forming and moulding techniques to produce smooth, well defined contours in articles such as automotive interior components. These foams produce a soft touch to headliners, dashboards, door casings and sunvisors, and they also contribute to heat, noise and vibration insulation. The soft touch is slightly firmer than polyurethane foam and is considered by some in the automotive interior industry to be more ‘up market’. Polyolefin foams have certain advantages over polyurethane foams, such as no ‘fogging’ in automobiles and better chemical resistance and ageing properties, but adhesive lamination requires some careful consideration owing to the inert nature of polyolefins. Both hot melt adhesive powders and adhesive films are available for bonding. In applications where high service temperature stability is required, reactive crosslinking adhesives are used. Information is available from the manufacturers such as Alveo (parent – Sekisui), and corona discharge is used in many cases to improve adhesion. Flame lamination is possible to certain substrates and textiles, and it is a much cleaner process than flame lamination of polyurethanes. The materials are partly crosslinked, and actual recycling by melting down and reforming is limited to 10–15% by weight inclusion into virgin polymer for injection moulding. Other recycling possibilities include shredding and thermally bonding the foam chips into drainage mats for construction applications, or agglomeration to reduce volume and controlled incineration. Polyolefins have a high calorific value when incinerated and can be used as fuel to incinerate other material, but the fumes may need treating and FR varieties of polyolefin foam may contain FR chemicals such as bromine. Polyolefin foams have good impact resistance and are used as inserts and padding in luggage, helmets, footwear and sports equipment such as shin guards and shoulder pads, see Fig. 2.3.

PVC foams are also produced which are easy to laminate and have the advantage of excellent weldability. Their ‘touch’ is quite similar to polyurethane foam.



2.3 One of the many applications of polyolefin foam, making use of the shock and energy absorbing properties. Polyolefin foam also has thermal insulation properties and a firmer soft touch than polyurethane foam. It is also used in door panels and other parts of the automotive interior. Other applications include padding in body protection clothing, luggage, shoe insoles, and wall and under floor insulation. Diagram supplied by Alveo (Sekisui) and reproduced with kind permission.

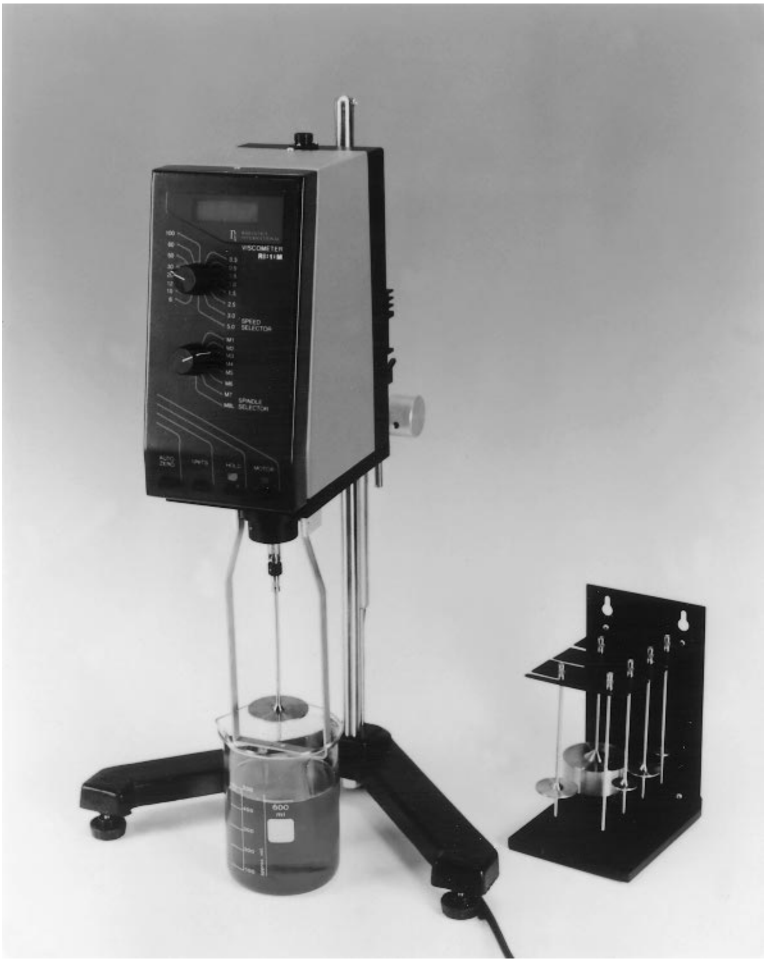
2.6 Compounding of polymers (resins)

2.6.1 General comments

The process of compounding of coating polymer or resin has already been mentioned several times. Note that, within this context, the word 'resin' has become almost interchangeable with coating compound or polymer. Resins are supplied as emulsions or as solutions in water or solvent. The 'solids' content – sometimes referred to as 'dry' weight – is always specified, and from this the resin 'add-on' that needs to be coated on to meet the specified coated weight of the end product can be calculated. Solids contents of water-based products are generally in the region of 40–60%, solvent-based products somewhat lower, 20–50% approximately. In general, a better quality film or coating is produced at lower add-ons and low solids contents, but for economic reasons, the coating operator will try to achieve the highest add-on possible in a single layer, commensurate with achieving satisfactory results and coating film properties. High add-on is helped by a high solids content but, as will be seen, the resin mix must be stable and process well. There is always a limit to the solids content that can be achieved with a particular mix before problems of thickening and instability occur.

The overall task of the compounder is to formulate a mixed compound, which will process without problems and which will produce the coated fabric properties required by the customer – at the correct price. The task of the compounder starts with material selection and formulation of the recipe, and also includes the physical mixing of all the ingredients to produce a uniform mix, which will be stable during storage and also during the coating process. Poorly formulated compounds can develop lumps or go thick, sometimes because of premature crosslinking. In addition, solid may separate out during storage or processing giving rise to streaks and drag lines. An important feature of a compounded resin is that it should have as long a 'pot life' as possible, but there is a limit to this when resins are to be crosslinked using an external crosslinking agent. In these circumstances, the crosslinking agent is added by the user just before use, but even in these cases the pot life should be long enough to ensure trouble free coating. Many resins are self crosslinking, i.e. they crosslink (after the water or solvent has been removed by evaporation) under the application of heat without the need or addition of other chemicals during compounding. Attention must be paid to the resin viscosity, because it must be the optimum thickness for the method of coating being employed, and a viscometer must be used for reproducibility. If a spindle viscometer such as a Brookfield is employed, the same spindle at the same speed should be used to check different batches of the same product (see Fig. 2.4). Use of a different spindle or the same spindle at a different speed is likely to give different results with the same resin. Although the resin should not thicken during storage or in transit to the coating works, this is sometimes unavoidable. However, any thickening should not be significant, and the resin should be easily returned to the original thickness just before use by the addition of small amounts of water or solvent. Some mixes may become thinner on the coating machine (i.e. show thixotropic properties) and, if this cannot be controlled on the coating machine, it may be necessary to reformulate the mix by using a different polymer or by using a lower solids content.

All types of coating resin need mixing and compounding even if it is only mixing in a thickener to prepare a single component resin for coating. PVC



2.4 Spindle viscometer. Measurement and recording of viscosity is a vital part of coating development and quality control to obtain consistent and reproducible first quality products. The spindle and speed used must be noted together with the result. Photograph supplied by SDL International Ltd and reproduced with kind permission.

and especially rubber compounding require much skill and knowledge. Compounding is a specialist operation, the importance of which is frequently underestimated, and many processing faults have their origins in the compounding stage. Unless a competent technician is available to carry out or supervise resin mixing, compounds are generally best bought in ready mixed from a specialist compounder. Even large fabric coating works buy in mixed compounds, especially when pigmented, sometimes as masterbatches which require only dilution. The drawback to buying in ready mixed compounds is that actual precise details of the contents may not be known. In addition, the compounder may buy resins and chemicals from a limited number of suppliers and, indeed, the compounding company may be a subsidiary of a resin manufacturer. In this case, the compounder may have preferences for products which may not be optimum for the particular application, possibly because the profit margin is likely to be less by buying in a competitor's product. The truly independent compounder is able to buy the best products for the job, if necessary from different manufacturers, and use them all in the same recipe. Each coating layer can generally be treated as a separate entity, i.e. the softest resin with the best performance may be used for the base layer and another resin or mixture of resins from an entirely different manufacturer may be optimum for the top or intermediate layer. Having said this, the chemical manufacturers are the source of much useful and essential information, both on chemical properties and also on practical compounding. All are familiar with the major end uses of their products and also the important health and safety aspects. Experimentation in the laboratory followed by thorough testing is of course recommended before any bulk trials.

Every compounding ingredient is likely to have several different manufacturers, but chemical equivalents from different sources may not give identical results in a coating recipe. Apart from the obvious 'solids' content of liquids, there may be purity differences and, in the case of fillers, varying particle size and particle size distribution. The latter factor could give very different results, especially in PVC and rubber compounds. There are numerous auxiliary chemicals and additives, the use of which depends on the properties required, end product and application, but consideration must also be given to safety aspects, such as possible food contact and use by small children. Potentially harmful materials should be avoided and, in the modern environmentally conscious world, disposal at the end of the product's life should also be considered. Compounding of ingredients is likely to require special protective apparatus for safe handling, especially solvents which need precautions against fire risk and good ventilation to minimise breathing them into the body. Powders need care because they may cause skin irritation, dermatitis or some other ailment, especially if handled regularly or breathed in – a face mask may be advisable. The health and safety documents issued by the manufacturer must be read carefully and recommendations noted.

Some indication of the softness can be obtained from the glass transition temperature, T_g, of the resin. A value of say –20 °C is likely to indicate a very soft, stretchy but sticky film which could be useful as a base coat, but not as a top coat, as a value of about 0 °C indicates medium hardness and significantly less tack, whilst a value of about 20 °C or higher is likely to indicate a hard, dry and brittle film. A useful way of examining the physical properties of a resin or resin formulation is to cast a film of the material on to a glass plate or silicone release paper. The casting is dried, crosslinked if necessary and peeled away from the glass or silicone release paper. In this way the tackiness, stretchiness, flexibility and softness of the resin itself can be determined independently of any of the factors associated with coating it on to fabric, such as penetration or the fabric's own individual properties. If an FR coating is being formulated, testing a cast film of the resin formulation on its own could be a way of assessing the effect of the concentration or type of FR chemicals without the interference of all the variables associated with coated fabric, e.g. fabric stiffness, drape, resin penetration, etc. The limiting oxygen index test (LOI) is useful for formulating recipes. However, the actual FR test method specified in the test specification being targeted should be used as early on as possible in the development work. Inclusion of fillers generally reduces film clarity, stretchability and flexibility, and excessive amounts cause the film to crumble.

2.6.2 Compounding of water-based coating polymers

Water-based polymers used for fabric coating include polyvinyl acetates, PVC dispersions, acrylics, polyurethanes, silicones and rubbers. Some trade names of polymers and auxiliary chemicals appear in Table 2.4. The largest outlet for water-based resins is probably in the field of nonwovens as binders. Coating techniques are used extensively in nonwoven technology, but apart from a brief mention these fabrics are outside the scope of this book. In many cases with water-based resins, a single polymer may be used for a particular application or layer of a multi-coat coating, but different grades can frequently be mixed to obtain the required properties. For example, a very soft resin may be mixed with a harder one to soften the harder one or vice versa. Soft resins are invariably sticky (the softest resins are adhesives) and produce a tacky film, while harder resins tend to give films with a 'dry' non-tacky touch. Addition of small amounts of a harder resin to a softer one sometimes reduces the 'tack' of the coating surface.

For direct coating, it is necessary to thicken the polymer to a viscosity appropriate to the fabric construction, resin add-on required, and apparatus to be used, including blade profile. A very broad range of viscosity is used, between say 5000 centipoise and 40 000 centipoise or even higher. It is recommended that the method of viscosity determination, the instrument model and make, e.g. Brookfield, and, for research purposes, the spindle number used and the speed be stated. Some resins are self thickening and require only stirring, but most need the addition of a thickening agent. There are several different chemical types which produce mixes of different consistency, described by terms such as ‘stringy’ and ‘buttery’. Chemical types include aqueous emulsions of acrylic acids, polyacrylate derivatives, vinylpyrrolodone copolymers, urethanes, cellulosics, etc. Addition of small amounts of ammonia is required with some grades of acrylic thickeners. Actual running on a coating head will help decide the best type.

Apart from thickening agents, other additives may be fillers such as chalk or talc for economy, and FR agents if required, see below. Fillers impart opacity, required for curtains, and titanium dioxide may be preferred to cheaper fillers because of its whiteness. Carbon black can be used to produce black-out effects, but other colours are best produced using a pigment of the required colour together with a white base such as titanium dioxide. Fillers also detackify to a certain extent, and matting agents, such as silica powder used especially for top layers in garment coatings, will have some anti-tack properties. There are ranges of different grades of silica or other additives – the chemical manufacturers are able to provide advice on the optimum grade for any particular application. Silicas are quality materials and as such are relatively expensive, while calcium carbonate, clays and talcs are quite inexpensive. Fillers are required to produce bulk, for example in carpets, and can increase toughness and improve abrasion resistance. The densities of some common fillers are (in g/cm^3), clay 2.5 (aluminium silicate), calcium carbonate (talc) 2.8, barium sulphate (barytes) 4.5, carbon black 1.8 and titanium dioxide 3.9 (anatase) and 4.2 (rutile). Barium sulphate is especially useful when mass is important, for example when producing sound insulation effects in automotive carpets. Wetting agents and dispersing agents may also be necessary to form a stable mix, if solids – especially solid pigments – are included in the recipe.

Foamed coatings require foaming agents, with the type depending on the actual foaming operation. For foam finishing (sometimes referred to as ‘froth coatings’), relatively unstable foams are used, i.e. foams which collapse during the drying off stage in the stenter. For crushed foam coatings, the foam must be stable and a secondary foaming agent is sometimes required.

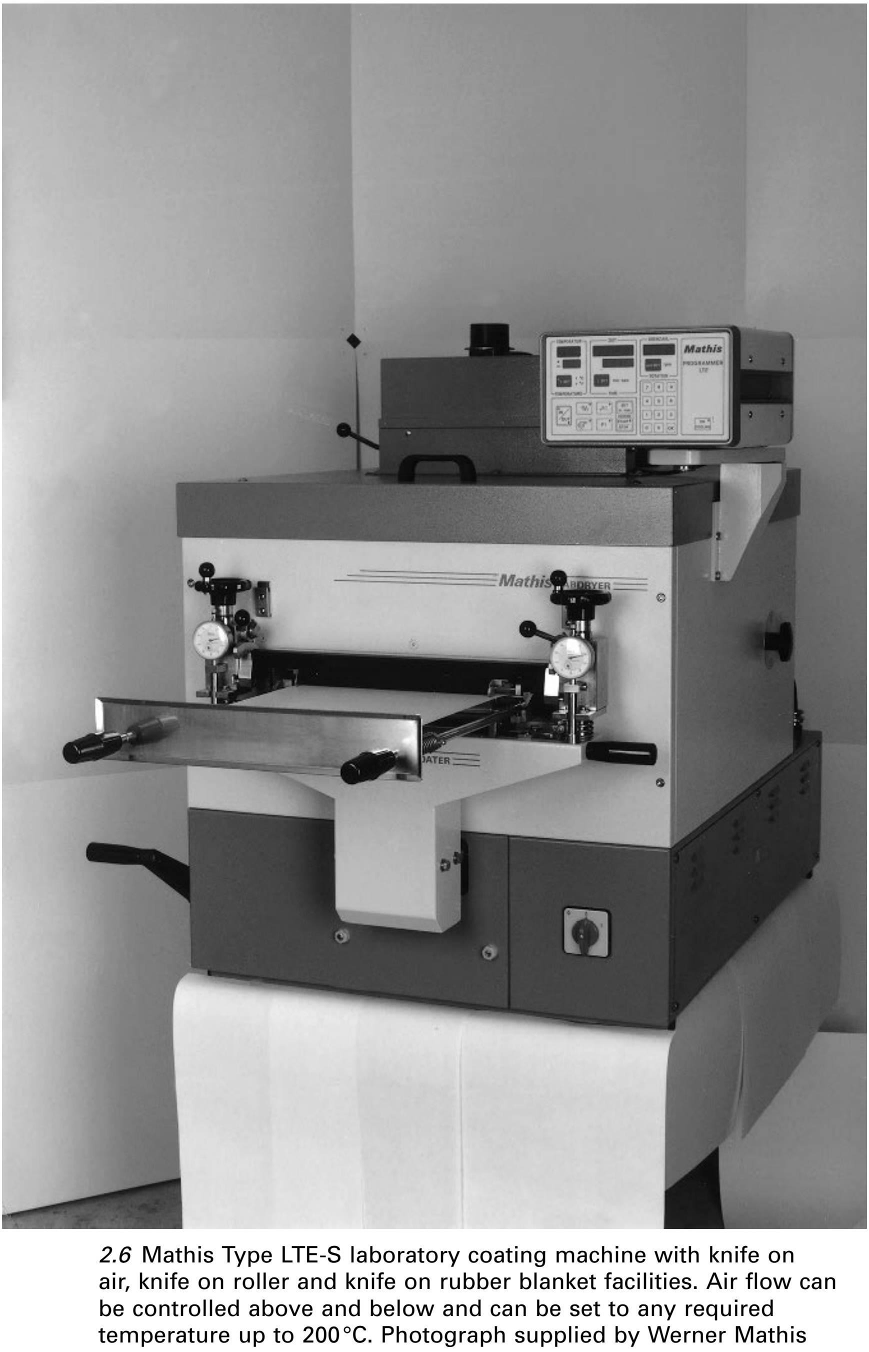
Many resins are produced as self crosslinking and can be applied without additional crosslinking agents or catalysts. Some crosslinking is necessary to produce durability in the end product, such as washability, dry cleanability, abrasion resistance and, in the case of carpets and pile fabrics, pile and fibre retention. For non-crosslinking resins and in situations where additional crosslinking is required, ranges of different external crosslinking agents are available. These differ in their reactivity and the properties they confer. The more reactive ones can be crosslinked at lower temperatures and may allow coating processes to be run at faster production speeds. In general, the more crosslinking the better the durability, but stiffening is an invariable side effect, sometimes with discoloration. Some highly reactive crosslinkling agents always cause stiffening of the coating, which may be tolerated in some applications. There is usually a compromise reached during compounding between performance properties required, handle and other aesthetics, and production rate. Resin selection and crosslinking agent selection play an important part, because they all have individual properties such as handle and drape. There are also various catalysts which may be used and the same general considerations apply, i.e. the more reactive the lower the processing temperature which can be used for crosslinking. Catalysts for water-based compounds include citric acid, ammonium chloride and oxalic acid (care – toxic).

In actual mixing of components, it is essential that the thickener, usually diluted with water, is added with careful stirring to the polymer and not the other way around – which will cause lumps to form. A production mixer is shown in Fig. 2.5. Stirring is always started slowly, and speeded up when a stable mix is obtained. Before any bulk mixing of polymers and compounding ingredients is undertaken, it is vital that small scale mixes are first carried out in the laboratory to assess compatibility, stability and any other problems which may arise. There are many different water-based polymers which may be mixed together to produce a particular property. In addition, there are whole ranges of textile chemicals which may also be mixed into the compound, e.g. anti-static agents, humectants (moisturising agents), softening agents, lubricants, etc. Certain waxes, paraffin dispersions or lubricants can also be used as detackifying agents for soft resins. These chemicals may also improve the abrasion properties of coatings but, if used in excessive amounts, can cause some deterioration in other properties. The technical information sheet of each polymer or additive must be studied for pH, whether anionic, cationic or non-ionic. Mixing together an anionic chemical with a cationic may cause precipitation or lumps to form, but it may be possible to use small amounts of them if mixed in separately; however, care is needed and pre-bulk trials in the laboratory are essential. A Werner Mathis oven, shown in Fig. 2.6 and 2.7, is invaluable for trying out compound formulations on small A4 size pieces of fabric before proceeding to full width machine trials which are costly both in time and materials.

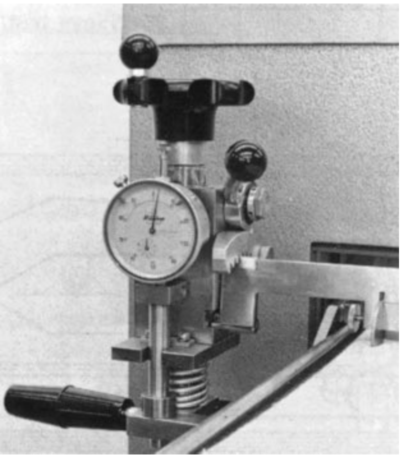
A typical recipe for a waterproof coating on woven nylon or polyester using acrylic resins could be as shown in Table 2.5. A typical formulation for crushed foam coating for curtains could be as shown in Table 2.6.

The amount of foaming agent depends very much on the individual resin. Some resins may be self foaming and require little or no foaming agent. Some foaming agents are ‘primary’ foaming agents, such as sodium lauryl sulphonate; others provide better foam stability, such as ammonium stearate. There are more specialist foaming agents for better foam stability – such as required for carpet production – and reduced side effects.

2.5 Greaves GM5 commercial mixer for water-based resins. The mixer should be capable of providing adequate agitation – paddle and disc-type impellers are not likely to be suitable. Mixing should always be started slowly and speed built up gradually. Ingredients should be added in the correct order and thickening only commenced when the mix is perfectly uniform. Photograph by Joshua Greaves & Sons Ltd and reproduced with kind permission.



2.6 Mathis Type LTE-S laboratory coating machine with knife on air, knife on roller and knife on rubber blanket facilities. Air flow can be controlled above and below and can be set to any required temperature up to 200°C. Photograph supplied by Werner Mathis AG (R Jackson Wardle) and reproduced with kind permission.



2.7 Mathis Oven coating head adjustments. The blade angle can be adjusted and the blade height can be set to an accuracy of 0.01 mm and read off the clock gauges. Photograph supplied by Werner Mathis AG (R Jackson Wardle) and reproduced with kind permission.

Table 2.5 A typical recipe for a waterproof coating on woven nylon or polyester using water-based acrylic resins

	Wet weight	Dry weight
Soft base layer:		
Plextol DV300 (very soft)	100 parts	60 parts
Rohagit SD 15 (thickener), premixed with 3 × own weight of water	9 parts	1.5 parts
Top layer ('dry', non-sticky):		
Plextol BV410 (intermediate soft)	90 parts	45 parts
Plextol BV595 (hard)	10 parts	5 parts
Gasil (silica powder – for detackifying and mattness)	3 parts	3 parts
Rohagit SD 15 (thickener), premixed with 3 × own weight of water	9 parts	1.5 parts

Thickening achieved by very gradual addition of ammonia with stirring viscosity approximately 15 000 centipoise with Brookfield Viscometer.

Excessive amounts of foaming agent may lead to poor abrasion resistance and lowering of other physical properties. Ammonium stearate can migrate to the coated surface and produce 'blooms', a discoloration effect which may be unacceptable in some applications. More effective foaming agents are based on disodium N-octadecyl sulphosuccinamate; these are more

Table 2.6 A typical recipe for producing a crushed foam coating for curtain linings

	Wet weight	Dry weight
Acrylic resin	100 parts	50 parts
Water	30 parts	0 parts
Foaming agent	12 parts	4 parts
Calcium carbonate (filler)	25 parts	25 parts
External crosslinking agent	6 parts	2 parts
Thickener (for required viscosity) approximately	6 parts	2 parts
Ammonia (0.88) approximately	2 parts	0 parts

expensive, but can be used in combination with the less expensive ones to provide a boost. Titanium dioxide could also be used if a higher standard of whiteness is required. Viscosity (before foaming) is usually 60 000–70 000 centipoise, Brookfield Viscometer model RVT, spindle 6, speed 12, and it is suggested that the resin be foamed to a wet foam density (cup weight) of about 0.2–0.6 g/cm^3). Further information is available from resin manufacturers or compounders or from the literature.[30,31]

2.6.3 Compounding of solvent-based resins

The common solvents used in coating resins are DMF (di-methyl formamide), MEK (methyl ethyl ketone), toluene and iso-butyl alcohol. All mixing apparatus should be of the appropriate type as a precaution against fire, the mixing area should be well ventilated and protective clothing worn. Safety precautions are especially relevant when isocyanates are being handled because they are known to be irritants and respiratory sensitisers. Fire precautions must be taken and resins and mixed compounds stored in a cool and safe area; any residues should be disposed of correctly through a registered disposal contractor. Solvents evaporate quickly and must be stored in sealed containers or a skin will rapidly form on the surface. External crosslinking agents and catalysts are generally supplied in solvents compatible and miscible with the main resin solvent. Polyurethane polymers are formed by the combination of a polyol and a crosslinking chemical of which isocyanates are probably the most used. Because of the potential health risk, isocyanates are supplied in a ‘blocked’ form and only become reactive when unblocked by heating in the drying oven. There are several sources of information giving details of polyurethane resin properties as determined by their chemical nature.[9–11,26,28] In general, aromatic isocyanates have good chemical resistance but are prone to yellow discol-

Table 2.7 A typical recipe for waterproof coating using polyurethane solvent-based resins

Base layer:	
Polyurethane resin	100 parts
Polyisocyanate crosslinking agent (or melamine formaldehyde resin)	9 parts 5 parts
Acid catalyst	2 parts
Top layer:	
Polyurethane resin	100 parts
Gasil	3 parts

Viscosity 10 000 centipoise, Brookfield Viscometer model RVT.

oration; aliphatics have less tendency to yellow but are more costly. Considering the polyol part, of which there are two main classes, ether derived or ester derived, ethers have the greater hydrolysis and anti-microbe resistance of the two, while esters are physically tougher with better chemical resistance. The viscosity of solvent-based resins depends on the solids content and, in compounding, the usual need is to thin the mixture rather than thicken, which is the case with water-based resins. Thinning is easily achieved by the addition of solvent. If thickening is necessary, addition of silica is possible, but this has a matting effect and too much may affect physical properties. Solvents have different boiling points, for example MEK (80 °C), toluene (110 °C) and DMF (153 °C), and they may be blended, if necessary, to produce a steady rate of evaporation to form a good film in a particular drying oven. A too rapid evaporation rate causes blistering, and this may be controlled by increasing the boiling point of the compound by adding a higher boiling solvent to the mixture. Further discussion on solvent coating is given in Section 3.4.5.

A typical formulation for a waterproof coating on woven nylon or polyester could be as shown in Table 2.7.

Polyurethanes, especially those based on polyethers, are susceptible to microbiological attack and the inclusion of a biocide should be considered. Transfer coated fabrics seem to be more vulnerable to microbe attack than direct coated materials.

2.6.4 Compounding of PVC plastisols

The main commercial outlet for plastisols in fabric coating is the production of tarpaulins and other associated covering material, the main physical requirements of which appear in Chapter 4. Raw PVC is generally supplied in powder form and, to convert this to a useful material for coating, it is necessary to prepare a plastisol, which is a complex mixture of PVC, plasticiser and several other specialist chemicals – all required to do a specific job. Great care is needed because the chemicals selected must not have any harmful effects during either mixing or use. For example, an effective heat stabiliser may not have the necessary health and safety approvals. Compounds considered toxic cannot of course be used for materials that will come into contact with food or children's toys, for example. PVC has so many applications, and this has resulted in a very wide choice of chemical additives. In recent years, the added constraints of recyclability and environmental friendliness have also been imposed. In addition articles such as toys, which will be used by children, need much care in plastisol formulation and are subject to both government and EC regulations and scrutiny. For automotive interior applications, plasticisers and other additives should not cause 'fogging', i.e. they should not migrate to the surface and vaporise and deposit themselves on the interior of the windscreen.

There are two separate tasks, formulation of what is included in the plastisol and then the actual mixing process. The first decision is which base PVC polymer or blend of polymer to use; this is followed by choice of plasticiser or mixture of plasticiser. One of the main characteristics of a PVC polymer is the molecular weight – or, more correctly, average molecular weight. PVC polymers are specified by their '*K* value', which is obtained from viscosity measurements and is an indication of the molecular weight and, therefore, of the basic physical properties. A PVC polymer made by the emulsion process with a *K* value between 70 and 80 is generally suitable for flexible coatings. Rigid PVC goods are likely to be made from polymer made by the suspension process with a *K* value around 57 to 68. The manufacturers of PVC polymers supply details of the optimum grade of polymer for a particular application.

Pure PVC is hard and brittle and, for textile coating and lamination purposes, it must be softened by the addition of plasticisers. The PVC is supplied as a powder and this is mixed with the plasticiser which is generally a liquid. The plasticiser is an important component, which determines many of the important properties of the plastisol, such as viscosity and processability. It also influences properties of the resultant coating, including tensile strength, tear resistance, temperature resistance, toxicity and chemical resistance and, therefore, has to be carefully chosen. PVC itself has excellent FR properties, but plasticisers vary in their individual FR nature; different ones require FR chemicals in different formulations. Many of the plasticisers are liquids, and the most common and economical ones tend to migrate very slowly to the surface of coatings and slowly evaporate. This loss of plasticiser from the PVC material causes stiffening and embrittlement of the coating leading to breakdown by cracking. It is this vaporisation of plasticiser which causes 'fogging' on car windscreens. Phthalates, such as dioctyl phthalate, and phosphates are amongst the more common plasticisers which have the basic requirements of good processability and compatibility with the PVC polymer combined with low cost. More specialist plasticisers such as sebacates and adipates are used for good cold temperature flexing; phosphates and chlorinated hydrocarbons give good FR properties. Food contact products require very careful consideration to meet the regulations governing the specific product. There are plasticisers available which meet the American Food and Drug Administration (FDA) requirements for use under specific conditions. Other plasticisers are available for specialist chemical resistance and specialist physical properties, good electrical properties, low odour, etc.

PVC is vulnerable to heat degradation at processing temperatures during manufacture and also during the lifetime of the product. It is also degraded by light and UV radiation, and both heat and light stabilisers must, therefore, be added to the mixture for protection. There are vast ranges of heat stabilisers and stabilisers for other specific purposes. These are now usually barium/zinc compound and calcium/zinc compound mixtures, but some heavy metals have been used and these are a cause for concern for environmentalists, especially at the end of the life of the product. Some fillers are added in order to reduce cost, but others are intended to impart a particular property, such as opacity, and to modify the physical properties. The tensile strength of the coating obtained can be reduced significantly if the wrong filler is used. Fillers, depending on particle size, usually increase the viscosity of the plastisol paste which then has to be readjusted. The filler, in effect, absorbs the plasticiser leaving less for the PVC, thus increasing the viscosity. The tendency of a plasticiser to do this is measured by its 'oil absorption' capability; water-ground mica and fine China clay have high 'oil absorption'. For low oil absorption, the filler particles should be as spherical as possible. Extender polymers, which are low molecular weight PVC materials, are sometimes used to help with processing – making the mix flow better and reducing viscosity if necessary. These are also specific viscosity modifiers which are used to increase viscosity, e.g. aluminium stearate, or to decrease the viscosity, e.g. derivatives of polyethylene glycol. Viscosity can also be lowered by the addition of a solvent, but this increases the fire risk and some processing machines may not be designed to cope with this.

To produce a pore-like structure or a very flexible coated material, a 'blowing agent', such as an azo-dicarbonamide (decomposition range 190–230 °C), is mixed into the plastisol. These agents decompose during processing to produce small voids in the coating giving a sponge-type structure and a soft touch to the surface. The factors to consider in choice of blowing agent are decomposition temperature, particle size distribution and volume of gas liberated, because these variables will determine the pore structure and other properties. Special heat stabilisers are available which can also decrease the decomposition temperature and provide a kicking action to the foaming process.

PVC plastisols require adhesion promoters to improve the adhesion of the base layer to the fabric, particularly with polyester and nylon. Different fabrics need slightly different ingredients and, if the fabric construction allows significant mechanical interlocking, the amount of adhesion promoter may be reduced. Adhesion promoters can be applied to the fabric beforehand by impregnation during the heat setting process or by addition to the plastisol used for the base coating layer.[57,58] For some grades of PVC it is necessary to include an emulsion of a plasticiser into the priming system. As discussed above, adhesion promoting systems are generally not required for cotton and the use of continuous filament textured yarn can improve mechanical adhesion. To produce the required colour, pigments, either in liquid or solid form, are added to the mix. For ease of processing and quality results, the correct viscosity, rheology, flow properties and a completely uniform mixture are essential. Ideally, viscosity should be measured at different rates of shear, so that some idea can be obtained of the performance of the plastisol in actual use on the coating machine, and it can be modified if necessary.

A good stirrer is required for actual mixing, but it is very important that it does not create bubbles or cause air to be drawn in and entrapped. Ideally, mixing is best done under vacuum which would minimise air entrapment. There are air release agents which help, but silicone types may reduce adhesion to the fabric substrate and are generally not recommended. Entrapped air can be minimised by a period of very slow stirring at the end of actual compounding, when all the ingredients have been added. If the viscosity of the paste is low, simply leaving the material to stand for a few hours will remove much of the entrapped air. Entrapped air can cause small pits or blemishes in the surface of the coating. Mixing in of pigments requires special care, especially if they are in solid form. Some compounders first produce a pre-mix by grinding and mixing the solid in a small amount of liquid plastisol, and then mix this pre-dispersion into the main mixture. Generally, pastes should be stored at room temperatures, but preferably below about 23 °C; however, they should be protected against frost which is likely to cause them to go solid and become unuseable even when brought back to room temperature. Poor mixes may well separate out at room temperature within the expected shelf life and, even if only partially separated out, are likely to give very unsatisfactory results if used.

On heating, a PVC resin does not strictly speaking ‘crosslink’, but passes from the fluid phase to a solid material by a fusing or gelling process, the precise mechanism of which has not yet been elucidated. The transition temperature is about 160 °C, but to achieve optimum physical properties requires heating to at least 170–180 °C for a minimum of 1–1½ minutes.

Table 2.8 A typical formulation for a PVC tarpaulin

PVC plastisol	100 parts
Plasticiser	70 parts
Filler	25 parts
Heat stabiliser	2.5 parts
Light stabiliser (if necessary)	1.0 part
Pigments	10 parts
Dispersing agent	1.0 part

Gelling at lower temperatures produces inferior physical properties. Unlike the crosslinking process, the material must be heated for this length of time for the gelation process to proceed properly. Simply hitting 180 °C for an instant does not 'kick off' crosslinking in the case of PVC, because there is no crosslinking process to take place. PVC is subject to environmental scrutiny at the present time and this is influencing the choice of which additives and plasicisers to use. This aspect is discussed in Chapter 6. Guidance on resin selection and compounding is available from PVC manufacturers, suppliers of compound and the literature.[22–24]

A typical formulation for tarpaulin material could be as shown in Table 2.8.

2.6.5 Compounding of rubber compounds

This is a very large and specialised subject area, because there are so many different types of rubber and additives used in many thousands of applications. There are over a dozen different grades of Neoprene (DuPont polychloroprene rubber) alone, for example, and there are very many different ingredients in a recipe, each ingredient being necessary to do a specific job or to provide some specialist property. The rubber compounding industry began with the discovery of vulcanisation in 1839, and the industry's expertise today is the cumulative result of the work of thousands of rubber technologists working on countless applications since that time. Rubber is processed both from water-based lattices and from solvent-based compounds. Dipping for the manufacture of items such as gloves is generally carried out from lattices. As well as specialist additives, there are certain ingredients included to make the various chemicals compatible with each other. In addition, the many different types of rubber can themselves can be blended to optimise a particular property requirement. The compounder's job is to produce a rubber compound to do a specific job at the lowest possible cost.

The adhesion principles discussed above also apply to rubber coatings, cotton not requiring any adhesion promoting system. There are well over a dozen different classes of rubber, each with its own special properties, and each type of rubber itself has numerous variants. The essential constituents of a rubber compound are: the rubber itself, vulcanising agents, fillers, oils, antioxidants and plasticisers. Frequently, inclusion of one particular chemical improves one property at the expense of another, and a balance must be reached. Finally, the mix must be processable on the apparatus available, produce the specified properties and be at the correct price to be commercially viable.

The compounder's first task is to select the rubber type (see Table 2.3) and, if necessary, consult manufacturers and specialist papers on the subject. [30,31,40–45] The next essential component is the vulcanising agent, or activator, the most common one of which is zinc oxide. In practice, this universal vulcanising agent is usually used together with an additional agent to 'tailor' the properties to meet the requirement. Vulcanisation is the term used to describe the crosslinking process which converts raw rubber into a more useful state, one having elastic properties and more durability. The accelerator is used in conjunction with the vulcanising agent to increase the rate of cure and to produce other improvements. There are many different chemicals used as accelerators, and it is possible to vulcanise rubber under almost any conditions of time and temperature. A compound containing only these basic ingredients may be difficult to process, and fillers and processing aids are also required. These also reinforce the rubber.

The fillers are powders and the processing aids, which may also be plasticisers, are needed to disperse the solid particles and to help control the viscosity. Fillers are sometimes referred to as black or white, the black type being invariably carbon black. Some specialist grades of carbon black can confer significant anti-static properties to the article being coated, e.g. carpets. White fillers can be calcium carbonate, clay, silicates or titanium dioxides, etc. The size and shape of the filler particles can influence the properties of the rubber, and careful consideration is needed in the choice of chemical type. For example, if the rubber article is to come into contact with acids, calcium carbonate would not be used as a filler. There are dozens of different grades of carbon black used, each one producing slightly different properties in the rubber.

Antioxidants are necessary to protect the rubber from atmospheric oxygen and to improve the ageing properties. Here again, careful selection is important in order to prevent discoloration and other adverse effects. In addition to the essential ingredients, there are FR agents, pigments, specialist heat stabilisers, blowing agents for 'soft touch' and bonding agents to join the rubber to the textile and other materials. There are also dispersing agents, thickeners, wetting agents, emulsifying agents, gelling agents, deodorants and other additives to impart special physical and chemical properties.

A typical basic formulation would include:

- rubber polymers
- vulcanising agent/sulphur
- zinc oxide
- accelerator (catalyst)
- fillers
- antioxidant/stabiliser
- softener/lubricant

There are numerous other 'standard' formulations depending on the type of rubber and the end use properties required. Some recipes may contain 20 or more different ingredients.

2.7 Adhesives

2.7.1 Mechanisms of adhesion

There are four basic mechanisms by which adhesion is believed to take place.[59] These are: mechanical interlocking of the materials; diffusion of polymer molecules across the interface; electrostatic forces; and, lastly, interatomic and intermolecular attractions between the atoms and molecules of the materials being joined, i.e. the adhesive and one of the substrates. The adhesive acts as a 'go between' between the two substrates being joined together. The last named group includes chemical bonding, which generally produces a strong and durable bond. Mechanical interlocking and electrostatic forces are physical bonding mechanisms. All types of bond require clean surfaces, free from dirt, grease and other contaminants, especially silicones. Increasing the surface roughness generally improves the bond strength. There are general accounts of adhesives and their properties.[59–62] When bonding problems with films and plastics are experienced, surface treatment of the film or plastic with corona discharge or a plasma process sometimes help, see Section 2.7.3.[63–66] Chemical cleaning or pretreatments with flame are also reported to be helpful.

Mechanical interlocking, especially with rough, natural short filament fibres such as cotton, is an important means of adhesion and, as discussed above, textured yarns also provide facilities for mechanical bonding. Much development has been necessary to improve the bonding of rubbers and plastics to smooth continuous filament synthetic fibres by the use of adhesion promoters and priming materials. The application of adhesive must not affect the appearance, colour or surface texture of the fabric being joined, and should have minimum effect on the handle of materials, especially those which are to be used for further processing. Thus, adhesive must be controlled; it should first 'wet' and flow to cover the surfaces of the materials being joined, and then penetrate to a certain extent, but not so much that it will cause stiffening or penetrate through to the fabric or material face. 'Wetting' depends upon surface energy of the materials; the solid surface being 'wetted' should have a higher surface energy than the wetting agent for it to spread over the surface. Once applied, the second material substrate must be introduced, and the two substrates should be held together in intimate contact until a strong bond is developed. If there is any delay, the adhesive could lose some of its effectiveness, by cooling, premature crosslinking or evaporation of the carrying liquid. If the freshly laminated materials are disturbed before a strong bond is formed – for example by a sudden change in material tension – the final bond strength may be lower than expected. Further processing factors influencing adhesion are discussed in Chapter 3.

2.7.2 Surface tension

'Wetting' is used in a broad sense and does not refer just to water 'wetting' – the liquid can be a water-based adhesive, a solvent-based adhesive or a liquid, hot melt adhesive. Surface tension is the physical property which determines the ease with which the 'wetting' will occur. If the surface tension of the liquid is greater than the surface tension of the solid, the liquid will not 'wet' the surface, but instead will form beads, i.e. small spherical droplets on the surface. If the surface tension of the solid is greater than that of the liquid, the liquid will wet out and spread over the surface of the solid. When fabric is involved, the situation is slightly more complicated because of the 'holes' in the surface, but similar considerations apply. In this case, the surface tension of the fibre – or more correctly that of the finish on the fibre – affects the wetting. All fabrics and fibres will have a finish of some description on them. Even 'pure' finished fabric will have some residual dyebath chemical on it, or the yarn will have residual spin lubricant or finish applied to it during yarn manufacture. As previously mentioned, fabric or yarn with absolutely nothing on it would be almost impossible to process, because of the significant build up of static which would cause it to cling to rollers and other surfaces.

The same surface tension determines whether a fabric will have water or shower repellency. Fluorocarbon finishes on fabrics impart a very low surface tension to the fabric surface, thus conferring shower or water repellency to the material. Certain wax finishes and silicone finishes also have low surface tensions and impart water repellency, but these finishes also attract oil-based soiling, because the oils have an even lower surface tension.

2.7.3 Modification of surface properties

The first fabric used for coating was cotton, which has a naturally rough surface and is made from short staple lengths twisted together to make a continuous yarn. There were few problems with resin–polymer adhesion, partly because of the mechanical locking made possible by the rough fibre surface, but, more importantly, because of the very large number of short staple fibre ends embedded in the resin. When viscose was first used for car tyres, intensive research work needed to be carried out to find a chemical means of improving rubber adhesion to the smooth continuous filament viscose yarn. Most modern coated fabrics are produced from nylon and polyester yarns, frequently high tenacity varieties, and are smooth continuous filament. In addition, for specialist end uses, aramids are used which are also generally smooth continuous filament. Work has been done to try to improve the adhesion of polymers and rubbers to industrial synthetic yarns, using surface treatments such as plasma and corona discharge. In recent work in the USA the surface tension of plastics and fibres has been increased by plasma treatments in the laboratory to 70 dynes/cm (erg/cm^3) which would allow better 'wetting' out of adhesives.[64] Some researchers believe that, in addition to lowering of surface energy, some surface roughening and cleaning results from these treatments. Hence there is more than one reason why adhesion is improved.

The breakdown of the fibre–polymer bond is believed to be the cause of premature failure of many rubber coated articles, including tyres and hoses. Initial strong bonds are essential if tarpaulins and garments are to withstand the flexing encountered during their lifetime and, in the case of the garment, multiple washings. In some cases the fabric substrate surface is buffed or slightly raised before coating in efforts to improve coating adhesion. Sometimes this is done to obtain a softer and more flexible handle, especially with transfer coating.

2.7.4 Adhesive type

Adhesives are available as solutions in solvent or water, or as dispersions in water, or as solids, which melt under the action of heat, see Table 2.9. A variety of different chemical types are available, each with their own properties such as suitability for specific substrates and durability to water, humidity, solvents, heat, etc. The chemical nature generally determines the property, for example polyurethane adhesives are flexible and stretchy, but some may discolour. Polyvinyacetate adhesives are relatively inexpensive, but generally have limited water or washing resistance. There are mixtures of different chemical types that produce specific properties, for example a hot melt adhesive may consist of a blend of copolyesters and modified

Table 2.9 Summary of adhesive types

	Water based	Solvent based	Hot melt
Form supplied	Solution or dispersion in water	Solution in solvent	Powder (various particle size) Granules Gel Web Film
Advantages	Non-flammable Generally safe to use Easy clean up Easy storage Fewer health and safety problems	Generally good tack/grab Quick dry off Good water resistance 'Wets' surfaces easily	Clean No dry off necessary No fumes Instant bond in many cases Storage generally easy
Disadvantages	High energy required to dry off water (latent heat of evaporation is 539 calories per gram) Process may be slow Generally low solids content Limited durability to washing and moisture 'Wetting' of surfaces and spreading sometimes not easy	Fumes potentially toxic Extraction/ emission treatment necessary VOCs environmentally unfriendly Legislation requirements Careful storage is necessary Fire risk Health and safety requirements	Initial plant may be expensive Heat necessary to activate the adhesive which may damage substrates (e.g. pile crush, glazing, stiffening, discoloration) Short 'open time' and loss of tack on cooling Certain operations require high operative skill
Cost	Inexpensive to moderate	Moderate to expensive	Granules generally inexpensive Powders vary from inexpensive to moderate Webs vary from moderate to expensive Films vary from expensive to very expensive

Table 2.9 (*Continued*)

	Water based	Solvent based	Hot melt
			Gels vary from expensive to very expensive – but may be cost effective if optimised

Flame lamination: Expensive initial plant, operating costs high for small volumes, low to very low cost for high volumes. Regular foams are inexpensive but specialities may be very expensive (the melted foam, 'burn off' is the adhesive). Fumes are potentially toxic and abatement is essential. Alternative methods being sought for environmental reasons.

Notes: Polyester, polyamide, PVC and polyurethane materials are generally relatively easy to laminate but adhesive selection is necessary for the required level of durability (mechanical flexing, wash/dry clean resistance, heat and heat ageing), handle, ease of processing, cost and other specialist requirements. Plasticisier resistance needs to be considered for PVC. Polyolefins are generally relatively inert and require more careful adhesive selection, and substrate pretreatment may be necessary. Bicomponent hot melt adhesive films are available for specialist applications.

polyethylenes. All adhesives must have some affinity for both the materials being joined. As just mentioned above, they must first of all 'wet', cover and penetrate the surfaces to be joined, and then solidify by evaporation of the carrier liquid to form the permanent bond by the mechanisms already mentioned. In the case of a 'hot melt' adhesive, the bond is formed on cooling. Hot melt adhesives are available in several forms; as a 'web' (resembles a net curtain), as a continuous film, or in powder or granular form. Some adhesives are also available as a liquid or jelly; these are 100% (or nearly) active material which does not contain any solvents or water. The earliest use of a hot melt adhesive is probably sealing wax for envelopes.

2.7.5 Solvent-based and water-based adhesives

Solvent-based adhesives are generally environmentally unfriendly, see Chapter 6, and, in addition, many are flammable and their fumes can be harmful to health if breathed in. Solvents are also more expensive than water. In general, however solvent adhesives 'wet' the surfaces to be joined better than water-based adhesives, have more 'grab', and they also dry off faster. Solvent-based adhesives are reported to have a better shelf life than water-based ones, because the organic ingredients are more stable as solutions in solvent than they are as dispersions in water. Water-based adhesives are safer to use and pose less of a problem to the environment, but drying off water (latent heat of evaporation is 539 calories/g) is expensive both in terms of energy and time. Because of the hydrophilic nature of water-based adhesives, many are not, in general, as resistant to water or moisture as are solvent-based types.

2.7.6 Hot melt adhesives

Because of the factors stated above, hot melt adhesives are gaining in popularity, but they need to be carefully selected. For good durability their softening and melting point must be well above the temperature to which they will be exposed during use, e.g. inside a car interior. Other performance factors which must be considered, as with all types of adhesive, are bond strength, resistance to moisture, humidity, heat ageing, light and UV degradation, and any effect on fabric colour. The nature of the materials to be joined, where they will be used within the car, and their physical form, all need to be taken into consideration when deciding which adhesive and which lamination machine to use.

Choice of hot melt adhesive affects the handle for two reasons. The first is the physical property of the adhesive material itself, i.e. if it is hard or soft. The second is the degree to which it sinks into the fabric. The melting characteristics, flow properties and viscosity of hot melt adhesives are important considerations. If too much heat is applied they can flow away from the surfaces to be joined, hence producing a poor bond. This excessive flow may also cause stiffening of the laminate and penetration to the face of the fabric being laminated. The adhesive manufacturers offer advice on which chemical class of adhesive to use, and the best one for the job in hand. They should also have information on adhesive properties, including recommended temperature of bonding, heat resistance, resistance to water and solvents, etc. Manufacturers should also be able to advise on resistance to PVC plasticiser migration, when PVC is being joined, and should have information on adhesive viscosity at the recommended bonding temperature. Of course it is always sensible to get at least a second opinion, and to carry out impartial trials. The manufacturer being consulted may not actually sell the best product or even the best chemical type for the job. They may judge that it is not in their best interest to recommend a competitor's product! But this applies to all products in all industries!

Chemical types include polyethylene, polypropylene (the two chemical types merge and are often referred to as polyolefin), polyamide, polyester and polyurethane, see Table 2.10. There are copolymer varieties of each chemical type, allowing a wide range of properties including melting points, durability to washing and dry cleaning and heat resistance to be obtained. Polyolefins tend to be the most economical, but tend to have lower

Table 2.10 Hot melt adhesive chemical types

Chemical type	Comments
LDPE (low density polyethylene)	Low cost, inert material. Used for fusible interlings, automotive carpets
HDPE (high density polyethylene)	Generally higher melting point that LDPE with better temperature resistance. Low cost. Used in carpets and for fusible interlings, shirt collars and cuffs
Ethylene vinyl acetate (EVA)	Good adhesive properties (tack). Low cost. Used in footwear and to bond leather and paper. Good flexible properties
Polyamide (and copolymers)	Wide range of products and temperature melting points, generally higher than PE and EVA with better heat resistance. Used in garments and applications where solvent resistance is required (dry cleaning). More expensive than PE and EVA. Some reactive types available with high temperature resistance and high durability to chemicals, solvents and water
Polyester (and copolymers)	Wide range of properties, high temperature resistance and good durability. Some suitable for automobile interior trim. Higher cost than PE and EVA. Some reactive types available with high temperature resistance and durability
Polyurethane	Good adhesive properties and durability. Expensive. Moisture curing gels have excellent durability and high resistance to temperature. Used in automotive interior trim, laminates for protective clothing. Good flexible properties with some elongation

Powder suppliers include: Dritex, EMS-Chemie AG, Bostik
Film suppliers include: Sarna Xiro (Guttacol), Cornelius, Bostik, Protechnic, Bemis, Dow
General adhesive suppliers include: Bostik Findlay, National Starch, Henkel
N.B. All adhesive types are generally available in powder form and also as webs and films. Many variants are available from a variety of manufacturers.

durability. The polyurethanes tend to be amongst the most expensive, but they are capable of giving softer, more flexible and stretchy laminates.

2.7.7 Adhesive films and webs

Adhesives in film or web form are generally significantly more expensive than the corresponding adhesive powders. Adhesive webs are discontinuous films, rather like net curtains, and are supplied in roll form made from various chemical types with various properties and melting points. They produce laminates which are flexible and which are porous and breathable. Continuous film adhesives cause stiffening, which may not be a problem in the case of, say, demonstration or exhibition boards or car headliners. A novel product are the slit films made by Xiro^{R}. These films reticulate, i.e. the small slits open up and present a network appearance on heating, and therefore produce laminates which are porous and permeable to both air and water vapour. This is important for laminated fabric that is to be used in garments. Under the action of heat, these slit films do not shrink inwards and lose width in a similar way to some other adhesive films, and the discontinuous form produces fabric laminates which are softer and more flexible than those produced from continuous films. Film adhesives are also available with small pin holes in them; this helps to prevent the entrapment of air bubbles during lamination and would also be expected to give some measure of water permeability. Bi-component or double sided film adhesives are also available, which allow almost any material to be joined to any other material.

A practical problem which may arise with film adhesives is in being able to feed the film to the lamination machine without loss of width through excessive tension. Films need supporting and unrolling again without too much tension developing, which may cause loss of width and even creasing. Some adhesive films are supplied supported on, or interleaved with, a non-adhesive carrier film. The carrier film is generally there to prevent the adhesive film from sticking to itself, and is presumably used as a processing aid in the adhesive film manufacturing process. This carrier film must, of course, be removed before use, and an additional driven take-up roller may be needed on the lamination machine to do this.

Some mention must be made of pressure sensitive adhesives which are widely used on tapes. They are available on release paper for application to fabric to be used on panels, for example in automotive interiors. Pressure sensitive adhesives are based on a number of polymer types, including acrylic, and are available in different variant types for various applications and degrees of durability and heat resistance. They are relatively expensive but are clean and require no special apparatus to apply.

2.7.8 Hot melt adhesive powders

Adhesive powders are available in most chemical types and also in particle sizes ranging from very small up to about 500 micrometres or so in diameter.[67–72] The choice of size used depends on a number of factors, including the machinery available, the surface nature of the substrates and the handle and properties required. There are a number of processes by which hot melt adhesive powders can be applied, each with its own merits, which are described in Chapter 3. Sometimes adhesive powders are supplied together with, or treated with, a UV fluorescent agent and a UV lamp is positioned near the powder application point. The reason for this is so that the small powder particles treated with UV can be more easily seen, which will allow better control of application.

The smallest particle sizes, 0–80 micrometres, can be compounded into pastes which can be direct coated, usually knife over roll, or dot coated with a high degree of control, using rotary screen print application machines. These precision print machines are capable of excellent results, but require a high level of technical competence and skill to set them up and run them. They have the important advantage of being ‘frictionless’, because the screen *places* the coating on top of the material. Further details are given in Chapter 3. Dot printing of adhesive can produce breathable laminates with excellent softness and drape which are used in the lamination of waterproof breathable films to fabric.

2.7.9 Moisture curing polyurethanes

These adhesives allow strong adhesive bonds with relatively low add-on, because they crosslink in the presence of moisture. There is generally sufficient moisture in the goods themselves being processed to trigger off the chemical reaction. They are available in hot melt form as a clear jelly in sealed moisture tight drums. They have been applied by spaying, slot die extruding and also by gravure roller. Significant improvements have been made in recent years to make them more manageable and to improve initial ‘grab’ and ‘open time’, i.e. the time during which the adhesive is available for bonding once it has been exposed to the air. The ‘open time’ is believed to vary from manufacturer to manufacturer. Because they actually chemically crosslink and can form strong bonds at relatively low add-ons, durable and flexible laminates with good drape have been found to be possible. For this reason, they are used in washable garments, protective clothing and car seat covers. However, these adhesives are expensive and control of application and penetration into substrates is critical. Moisture cure polyurethane adhesives have been available for a number of years, but it is only within the last few years that significant improvements in open time and initial tack have been achieved which have increased their usefulness.[73,74] Special apparatus is required to handle these adhesives as will be seen in Chapter 3.

2.8 Flame retardancy

2.8.1 Introduction

Statistics show that a significant proportion of household fires start by ignition of textile materials and that a cigarette was the most common ignition source.[75] In the UK all domestic upholstery materials must be FR to a small ignition source, but fires have also been the cause of significant loss of life in public buildings and on trains and on aeroplanes. Flame retardancy standards for public safety are generally controlled or influenced by government departments, such as the Home Office and the Civil Aviation Authority for aircraft. The International Maritime Organisation is responsible for safety at sea. These standards are aimed at reducing ignition, flame propagation speed and the heat and smoke generated, and allowing sufficient time for people to reach areas of safety. Much literature is available on flame retardancy and test methods.[76–83] Further comments on FR testing appear in Chapter 5.

Flame retardancy is required in many coated or laminated products, and a polymer coating can hold a larger amount of FR chemical than a simple finish on a fabric. Of course the fabric will be transformed into a heavier, thicker and less flexible material, but these properties are sometimes less critical and can be tolerated to a certain extent. Examples of FR coated fabrics in the home are furniture upholstery, mattress tickings and roller blinds. Most textiles used for public buildings, such as hotels or offices, generally require quite a high standard of FR properties. Some medical textiles require FR properties because they may come into contact with lasers or are used in areas where there is a high concentration of oxygen. The FR properties of coated fabric used in any transportation application are extremely important, because of the limited means of escape within a vehicle or in the air or at sea. The highest safety requirements must be attached to any application where the general public are involved, and in transportation situations large numbers of people usually occupy a confined space, with the added hazard of panic. When many plastics burn, they give off dense smoke and large amounts of heat which are as hazardous and in many situations, more hazardous than actual flames. These properties must be taken into consideration when FR chemicals are being included in coating recipes.

The common base fabrics used in fabric coating and lamination, nylon, polyester and cotton, have no special FR properties and will generally ignite and burn unless treated with an FR chemical. There are inherently FR varieties of polyester and there are a whole variety of specialist FR fabrics, but these are expensive and most are not generally used in domestic furnishing applications. However, certain specialist fibres are used as fireblockers in transportation seating applications and specialist protective clothing, i.e. Panox (LUCF – Lantor Universal Carbon Fibres), Nomex (DuPont), Inidex (Acordis), etc. Of the resins used in fabric coating, some have relatively poor FR properties, i.e. acrylics, polyurethanes and natural and SBR rubber. Certain resins have good FR properties, i.e. PVC, PVDC/acrylic blends and polychloroprene (Neoprene – DuPont). Addition of FR chemicals can generally improve the FR properties of these resins, especially where some 'synergy' can be exploited, e.g. using the chlorine in PVC or PVDC. The fluorine-based polymers, PTFE and Viton, are extremely FR in their own right. In development work it is sometimes profitable to determine the FR properties of the coating being formulated (first cast it on to a glass plate), using the LOI test which gives results in numerical terms. The LOI is the concentration of oxygen which just sustains a candle-like flame.

A coated or a laminated fabric comprises at least two polymer types, and the FR properties of the combination cannot be predicted using knowledge of the FR behaviour of the individual constituent polymers. The coated or laminated fabric generally has properties of its own which must be determined by testing. The FR properties of both the fabric and the plastic will be changed when they are joined together, depending on the amount of penetration which occurs, and on other variables, among them resin viscosity and add on. A fabric which individually may shrink away, or drip away, from the applied flame and hence not be ignited, may be held to length by the coating and thus will be ignited. Another sample of the same material, but from a different batch, which has been either dyed or stenter finished in a slightly different way, may not shrink back as readily and thus will become ignited and therefore display very different FR characteristics. One researcher has pointed out that the interface of fabric and polymer is, in some ways, an entirely different material to both the fabric and the polymer coating or laminate. If an adhesive has been used, this may be a third, different chemical type which could also display different FR properties and produce further modification of the behaviour of the other two components. There will be, in this last mentioned case, two interfaces between dissimilar substances. These factors add further to the complexity of FR testing, which both research and quality control staff know only too well. The FR properties of a coated fabric will be influenced by coating technique, resin add-on, penetration and the many factors and inter-relating factors which depend on these variables. A study has been made of the effect of coating parameters on the FR properties of a cotton fabric coated with a phosphorus FR compound.[82]

2.8.2 The burning process

The stages of combustion are ignition, growth, propagation and finally decay, but every fire in real life situations is unique because the circumstances and conditions are never exactly the same. The way fabrics burn depends upon a variety of factors and combinations of factors, including fabric stiffness, drape, contact with or proximity to other materials, supply of air, draughts, etc. Smoke results from the incomplete burning of materials and is a dispersion of solid or sometimes liquid particles, together with gases, some formed by the combustion process. Fire is a hazard, not only because of the danger of contact with flames, but also because of suffocation by toxic fumes, injury from heat levels and heat stress, plus all the dangers associated with panic and the inability to escape because routes are 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 disasters. We are still learning about causes and methods of prevention – too frequently too late – despite precautions following extensive research. Flame retardancy testing of coated fabric is discussed in Chapter 5.

2.8.3 Basic mechanisms

This section attempts to explain the main principles governing flammability and its control. Many articles have been published on these aspects and also on the relevant test methods[76–83] (see also Section 5.7). 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 oxidising 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 FR agents, under the action of heat, break down producing their own free radicals. The fuel free radicals then react preferentially with the FR free radicals instead of with oxygen, thus inhibiting combustion. An uncontrolled fire with a supply of fuel is self propagating, because heat from the burning material heats up the surrounding air and the material not yet burning.

2.8.4 Mechanisms of FR chemicals

Hydrated chemicals contain significant amounts of water and, when heated, this water is released and cools the flame. 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 FR properties. Some chemicals will function by more than one mechanism.

The most effective mechanisms, however, are inhibition of the free radicals and reducing the availability of fuel by formation of a barrier or 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 combinations of chemicals prevent afterglow and re-ignition; others, on combustion, form a char or barrier which effectively reduces the amount of air reaching the burning material. An example is zinc borate, which forms a glass-like coating and is claimed to suppress smoke significantly. 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 foam-like substance.[83] This acts as a barrier and inhibits flame spread by restraining the escape of gas formed by burning and also limiting 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.

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, 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 addition of PVDC to SBR in back coatings on automotive carpets.

2.8.5 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. Products containing FR chemicals need special care when being disposed of at the end of their useful life, especially those incorporating chlorine, bromine and heavy metals. 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 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 chemicals systems for some time, but so far there has been only limited success. However, Bayer recently announced a £3 million project to develop non-halogen FR agents. Not everyone is convinced that the materials are hazardous; the bromine industry is calling for independent reports. Others believe that the risk from being burned in an accident is greater than the risk from bromine as an environmental pollutant, see Chapter 6.

Amongst 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 same performance that is obtained with a lower level of an antimony/bromine system. In certain applications, it is possible simply to 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 before the resin becomes too thick, unstable and unsuitable for coating.

2.8.6 Fireblocker materials

Fireblockers were originally developed as barriers to prevent fire ignition on aircraft seats, but are being increasingly used in other areas of public transport such as trains and coaches.[84–87] Seats are generally composed of a fabric covering a cushion of polyurethane foam which, unless highly modified, can burn and emit highly toxic fumes. Combustion modified foams are more expensive and may not have the same comfort properties and physical durability as more regular foams, hence the need for a barrier material between the face fabric and the foam. A variety of specialist highly FR fabrics may be used and these include, Nomex, Kevlar (both DuPont), fibreglass, Inidex (Acordis), Panox (preoxidised acrylic fibre from LUCF), PBI (polybenzimidazole, by Hoechst), Visil (Sateri), etc. and blends of these with other textiles. Coated or laminated fireblockers include Neoprene rubber coated or laminated to another textile (Vonar from DuPont). Fireblockers have also been produced from PVC coatings on to fibreglass. Choice of which type to use depends on various factors, including, cost, weight (important especially on aircraft), comfort considerations, the quality specification and test method to be used.

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