5

Testing, product evaluation and quality

5.1 Introduction

Product testing is carried out for a number of reasons – the main one being to ensure complete customer satisfaction, thus making it very likely that repeat orders will follow. This is understandable, but monitoring of production during the manufacturing process is also important to ascertain if the product is suitable for the next stage in the production sequence. Value is being added all the time, and the sooner a defect is noticed the better; for example, it is wasteful to coat a fabric if colour is off-shade or it has construction faults which will lead to its eventual rejection. Testing is also carried out for safety reasons, such as FR properties for domestic furniture upholstery – labels must be displayed providing FR information. Testing survival equipment such as seat belts and life jackets is so important that it is subject to government legislation. In recent years testing for environmental friendliness and the concept of eco testing have been introduced; however, formats and procedures have not yet been standardised for every product, and so far eco testing is voluntary. It is, however, likely to grow in importance as consumers become more environmentally conscious, and especially if the proposals to offer VAT concessions on 'green' products become a reality. Eco testing is discussed further in Chapter 6.

Testing attempts to simulate the conditions of wear and tear over several years in either a single, or a series of short laboratory tests. This is not easy or straightforward, and testing must be carried out in the shortest possible time so that goods can be released for the next stage in the production process or to the customer as soon as possible after manufacture. Warehouse storage space is usually limited, and goods must be delivered to on time both for customer satisfaction and for efficient cash flow. Timing is important in the case of fashion items, and even more critical in industries where JIT manufacturing procedures are in operation, such as the automobile industry. Despite rigorous testing, however, goods can still fail prematurely in use, and much research and development is conducted to devise quicker and more reliable ways of testing materials and products. Of course determining the reasons for product failure and investigation of customer complaints are frequently the starting point for new and improved products.

There are national standards such as British Standards (BS) and German Standards (DIN), and now Euro Standards (EN) and also International Standards (ISO). Attempts are being made to standardise and rationalise these various test methods. When this has been achieved for a particular test it is renamed, e.g. for BS1000, this test is now designated BSENISO1000 and in Germany the same test would be designated DINENISO1000. In addition to these national and international standards, technical institutions and large purchasers such as the chain stores, the MOD and car manufacturers (OEMs) may also have their own standards and test methods. This causes confusion and does not only present test laboratories with additional work; it also means they have to equip themselves with all the appropriate test machinery, the purchase and running costs of which can be quite substantial.

Test methods must be realistic and must not involve factors that are not encountered in real life situations. It is easy enough to devise tests which cause rapid breakdown, but the test conditions should bear some relation to conditions of actual use. For example, in UV and light fastness testing, use of a machine which emits higher energy UV light will result in accelerated fading and separate good samples from poorer ones, but the high energy radiation could also cause damage which would not happen in actual use. Light fastness testing is complicated by the fact that conditions are different all over the world, depending to a large extent on latitude, weather and cloud cover. The additional effects of air pollution are more difficult to assess and are the subject of current research.

Certain tests carried out on certain materials, and especially clothing, are related to comfort, which has assumed much more importance in recent years. Human beings cannot function efficiently if they are not comfortable, and if a person is operating machinery or driving a car, comfort becomes a factor determining safety. However, comfort has many different aspects as summarised by one writer, 'Comfort is a complex matter, with physical, physiological, and psychological factors interrelated in an unpredictable combination which constantly undergoes variation.'[1] Comfort of clothing, in particular waterproof protective clothing and industrial protective clothing, is a well researched area and is still the subject of many textile research projects. A high standard of protection against the elements (and against chemical agents or microbes in medical outlets) combined with thermal comfort could not be obtained until the early 1970s when Gore-Tex – the first material to be both water resistant and significantly moisture permeable – was first introduced. This was followed by a whole series of waterproof and breathable materials of varying quality and gave rise to new methods of assessing breathability. The rise in living standards and increased leisure time has led to substantial demands for breathable waterproof protective clothing for walkers, sailors, golfers and other sports activities. In addition to this, employers are now required to supply their workers with protective clothing, which needs to be as comfortable as possible or more accurately as comfortable as cost allows. The medical profession is now more aware of the risks facing doctors, nurses and dentists from contact with blood from patients, and this has led to gloves being worn more frequently and the redesign of protective clothing to make it more impermeable to bodily fluids. Each product has to be tested to a particular standard of performance and, especially with the last mentioned area, new, more effective and more easily carried out tests are being developed.

When fabric volumes are high and schedules tight, it is neither physically nor economically possible to test every single roll or piece of material. The frequency of testing depends on the nature of the process and is decided after consultation with the customer. There are statistical methods to decide the number of samples which need to be taken from a particular population to obtain a representative result.[2] Results are plotted on a statistical process control (SPC) chart with maximum and minimum control limits while the process is underway. Thus the past history of a process, and any present trends in results, can be seen at a glance. Customers are informed of the results, especially if they are not precisely within the specification, so allowance can be made in the next process if necessary.

General checks for the correct construction, weight and dimensions are simple tests to carry out, but are likely to be just as important as more sophisticated tests. A piece of fabric which has passed all other tests, but which is maybe 1 cm too narrow for panel cutting, could be just as unuseable as if it had failed more technical tests by a large margin. The most relevant tests carried out on coated and laminated fabrics include: coating or lamination adhesion (peel bond), waterproofness, tear strength and durability tests which include abrasion, ageing and cleaning. Tear strength is tested after coating because the tear strength of the base fabric can be reduced by resin penetration.

5.2 Quality assurance

Quality assurance (QA) includes all factors which are relevant to quality and customer satisfaction, and has grown out of simple quality control. It goes from the earliest stages of product design, product development, purchase and monitoring of raw materials through to manufacturing, testing and inspection of the finished product. Quality assurance also involves contact with the customer, from the early stages of product design to meetings after delivery, to ensure customer satisfaction has been achieved. The QA department ensures that every member of the workforce and each member of staff is trained to regard quality as their duty and not just that of the quality department. This approach to quality management was set down in BS 5750 and CEN 2900 and further developed into ISO 9000, the standard for a quality management system. This standard is based on the concept of quality set down in ISO 8402 that refers to the 'totality of features and characteristics of a product or service that bear on its ability to satisfy stated or implied needs.' This phrase has given rise to the concept of 'total quality management'.[3]

The ISO 9000 standard consists of guidelines for choosing the appropriate system relevant to a particular company. QS 9001 is the model for QA in design, development, production, installation and servicing functions. Quality assurance systems require detailed and comprehensive specification and documentation of the product being made, the materials used, all production procedures and the machinery used, operative training, test methods, test standards, tolerances allowed and clear records of test results, and regular review and audit procedures. Only materials which have passed a certain standard can proceed to the next stage of manufacture. Test results are put on to a chart and statistical analysis is carried out The objective of the monitoring is to get things right first time by identifying potential problems and allowing corrective action to be taken before unsatisfactory products are made. The philosophy is prevention before, rather than detection and correction after. The automotive industry and others aspire to 'zero defects', i.e. giving the customer exactly what has been agreed in the sales contract. This may be for example one marked fault in every ten yards of fabric.

The automotive industry pioneered mass production with the invention by Henry Ford of the production line. The pioneering process has continued with the introduction of Japanese 'lean production', JIT and team working manufacturing methods. In mid-1994 a series of QA systems was formulated by the three largest American car makers, General Motors, Ford and Chrysler, with in-put from others including the American truck manufacturers. This system, called QS 9000, includes procedures tailored to the particular requirements of the automotive industry, and was revised in March 1998 with contributions from the European car makers. Many car makers (original equipment manufacturers or OEMs) worldwide now require their suppliers to be accredited with this system of operating and generally buy only from a supplier who has been inspected and approved. The company is also subject to random checks to ensure that it continues to comply with the requirements of QS 9000.

It is now a legal requirement under the Trade Descriptions Act to show the fibre content of textile products offered for sale. A textile product is defined as an article that contains 80% or more by weight of textile fibres, and when the textile content is stated it must be accurate to within 3% by weight. Information on washing and care is not compulsory, but is desirable. Information usually appears on sewn in labels but it can appear on the packaging.

5.3 General test considerations

5.3.1 Introduction

The standard laboratory conditions of temperature and relative humidity (RH) for textiles are generally 21 °C ± 1 °C and 65% ± 5% RH. It is interesting that the corresponding conditions for plastics are the same for temperature, but RH is 50% ± 5%, and conditions also vary for specific composites and some other materials. Test apparatus should be calibrated before use, and checked by an external certifying body at least annually and a certificate issued. Test procedures are described in detail in the various British or American (or other national or European) standards and there are articles[4] and several textbooks on the general subject of testing. Some are listed in Section 5.12, Further reading; the books by Merkel and by Saville are especially useful, and some modern specialist methods are discussed in the book edited by Raheel.

Test standards are gradually being raised as the customer demands better value for money and competition becomes even more intense. This is especially true of the automotive industry where cars being produced now are expected to last longer than before and maintain high resale values. The car interior must be in as good a condition as possible after years of use, and abrasion, light and UV degradation resistance are especially critical. Anti-soiling properties and effective cleanability are also becoming more important.

Manufacturing methods are changing, and new tests are being introduced to allow rapid and consistent operation of the new techniques. Again this is particularly relevant in the automobile industry because the component makers themselves, the Tier 1 suppliers (i.e. direct suppliers to the OEMs), have begun to set their own test methods and standards. The chain stores, the MOD and other major purchasers have for many years set their own specific test methods and standards for fabrics and materials.

The problem with so many test methods is that test laboratories must be equipped with two, three or even more different types of apparatus to measure essentially the same property. For example, there are three main testing methods for fabric abrasion in the automobile industry: Martindale, Schopper and Taber. All the time, effort and expense incurred by the multitude of different methods could be directed towards a more constructive purpose. There is some pressure from the United Nations, national governments and professional bodies to harmonise test methods and standards in general, not just in the textile and automotive industries.

5.3.2 Colour shade approval

Product lines may involve many hundreds of thousands of metres of dyed fabric and continue for several months. However, dyebatch to dyebatch shade variation is inevitable and difficult to eliminate even within the same dyehouse, let alone in different dyehouses, possibly in different countries. It is, therefore, important that the customer and dyer agree on what is acceptable and what is not. Nowadays, this is usually assessed objectively on a 'pass or reject' basis using quantitative colour information obtained with colour measurement instruments. This procedure removes human error and subjective assessment variations, which used to present so many problems in the past.

Two types of instrument, the spectrophotometer and the tristimulus colorimeter, both measure colour, from which quantities known as the chromaticity co-ordinates are calculated. This information is measured from an agreed standard master shade and also from the submitted test pattern. A colour computer then processes the data from both sets of measurements and calculates the differences between them. These differences can be mathematically processed and represented by a single figure, delta E, which can be used for pass–fail decisions. The size of this figure relates to the magnitude of the colour difference between the submitted pattern and the standard master shade. To be acceptable the submitted shade should be inside an agreed tolerance figure. There was more than one method of processing this information, however, which led to problems. Eventually work was carried out by a team which included colour instrument makers and major purchasers who worked under the auspices of the Society of Dyers and Colourists (SDC). The CMC(2:1) equation was the result, and this has proved to be a significant improvement on the original CIELAB 1976 for acceptability decisions. This equation, adopted by both ISO and CEN, is published as the International Standard for Colour-difference Measurement (BS EN ISO 105-J03:1997).

It is possible to calculate a value for delta E which represents the actual difference perceptible by the human eye, but this is complicated because the human eye is more sensitive to certain colours, not to mention all the other human limitations, including fatigue. The situation is still not completely resolved because not all dyehouses use CMC(2:1). However, the ultimate decisions are made on the basis of *visual* assessment under specified lighting conditions, and negotiation between the dyer and the customer.

The acceptance tolerances vary from industry to industry; slight colour variations may be acceptable in industrial protective clothing, but not for fashion anoraks sold in a chain store. The coating or lamination process in many cases involves heat, and shade changes may occur, especially if the process stops and material is exposed to more heat or to a higher temperature than normal. In addition, the coating may either cause colour changes during the coating process or catalyse shade change or fading later. All of these factors should be investigated before products are released to the customer.

5.3.3 Durability testing

There are many tests carried out to evaluate durability when used by the customer. These tests try to simulate wear and tear caused by actual use, sometimes over long periods of time, using short laboratory tests. For coated and laminated fabrics, one of the prime considerations is bond strength, i.e. the strength of the adhesive bond between the coating or laminated material to the base textile fabric. It is important to measure the initial bond strength after manufacture, but the article may be subject to continual flexing in the case of a garment, exposure to the elements in the case of a tarpaulin and UV light in the case of a car seat cover. The effect of UV light is discussed in Section 5.6. Inside cars the combined effects of UV radiation, heat and high relative humidity are probably the main factors determining durability. There may be lessons to be learnt from these factors with other materials.

Household goods and apparel have the added requirement of durability to repeated washing which is, in many cases, more ‘wearing’ than actual use. Tests must, therefore, be carried out after simulated washing and cleaning as well as simulated wearing, which in the case of coated fabrics is achieved by flexing and crumpling tests. A standard durability test for all textiles used for apparel and upholstery is abrasion resistance, but there are different methods for doing this. Those used for car seat covers are discussed below. Properties such as hydrostatic head to assess water resistance are invariably re-assessed after flexing, washing and abrasion.

All materials are also subject to ‘ageing’, which means the combined effects of time and the ambient conditions under which the article spends its working life. Most materials are exposed to oxygen and daylight, and these two agents cause fading of colour and eventual loss of mechanical properties. Heat and humidity usually accelerate the breakdown process, which is generally a combination of oxidation and hydrolysis reactions. Ageing tests for coated fabric (BS 3424 Part 12; 1996) involve storing the article under test in an oven for prolonged periods varying from, say, several hours to one week at elevated temperatures and high relative humidity. Car manufacturers have their own procedures, some of which are more exacting than those in BS 3424. More details are provided in Section 5.6.11. The objective is to simulate the effect of several years 'ageing' during normal ambient conditions within the space of a short period of time. Some materials 'age' because of loss of additive chemicals, such as plasticiser in PVC coatings, which migrate to the surface and evaporate off or are leached out by some fluid. Most chemical and physical reactions proceed faster under the action of heat, and this of course is the reason why the ageing tests are carried out at elevated temperatures.

A further consideration which has become more relevant in recent times is atmospheric pollution. It is not easy to measure or simulate this factor because it can vary so much from place to place. The main pollutant is traffic fumes which can include oxides of nitrogen and carbon, certain hydrocarbons, oxides of sulphur and particles of soot. Industrial pollution can consist of oxides of nitrogen and sulphur – especially close to power stations. These pollutants can give rise to acidic species and ozone which can have damaging effects on materials exposed over long periods, such as tarpaulins and building material. The effect of atmospheric pollution is being studied by some research workers.[5]

5.4 Testing of coated fabrics

5.4.1 Introduction

The 'parent' standard for coated and laminated fabrics in the UK is the BS 3424 with its 25 or so parts. The corresponding standard in the USA is ASTM D751-98 with 90 paragraphs. This section details the tests common to most coated or laminated fabrics. Specific tests relevant to more specialised end uses or major applications of coated or laminated fabrics appear under the appropriate heading. Amongst the main tests applied to coated fabrics are adhesion, which measures the bond strength between the base fabric and the coating (or material to which it is laminated), water penetration resistance, and various methods to assess the wear and ageing of these properties, including flexing and abrasion of the actual coated surface. Other physical tests, such as tear, tensile and bursting strengths, are also relevant as they influence the performance of the coated article, and also because coating may change some of these base fabric properties. Tests such as colourfastness, etc. of the base fabric are usually carried out before coating or lamination. With increased medical knowledge and higher standards of living, society has become more aware of biological infection, and tests have been developed – and continue to be developed – to test for barrier properties against these agents. Table 5.1 lists some of the funda-

Table 5.1 Selected British and related test methods associated with fabric coating and laminating

Property	British Standards	Other related standards
Coated fabrics (general standard)	BS 3424 (25 parts)	ASTM D 751-98 (90 sections)
Adhesion (peel bond)	BS 3424-7:1982 (1996) Method 9	ASTM D 902 AATCC 136 DIN 53357 ASTM D 751-98 (para 46–49)
Abrasion resistance	BS 3424-24:1990 (1996) Methods 27A and 27B BS 5690 (Martindale)	ASTM D 3389-94 (rotary) ASTM D 4966 (Martindale) ASTM D 3884 (Taber) ASTM D 3885 (Flexing, Stoll) DIN 53864/2 (Schopper) DIN 53528 (Frank Hauser)
Accelerated ageing tests	BS 3424-12:1996	ASTM D 751-98 (para 73–80) Auto companies tests SAE tests
Tear strength	BS 3424:1982 (1996) Methods 7A, 7B, 7C	ASTM D 1424 (Elmendorf)
Fusion of PVC/state of cure of rubber	BS 3424-22:1983 (1996) Method 25	
Elongation and tension set (stretch and set)	BS 3424-21:1993 (1999) Method 24	
Flexing resistance	BS 3424-9 (crumple)	
Low temperature resistance	BS 3424-8:1983 (1996) Methods 10A, 10B, 10C	ASTM D 751-98 (para 62–66)
Dimensional stability to water	BS 3424-17:1987 (1996) Method 20	
Wicking/lateral leakage	BS 3424-18:1986 (1996)	
Air permeability	BS 4443 pt 6 (method 16) BS 6538 pt 3 (Gurley) BSEN ISO 9237: 1995	ASTM D 737-75
Water resistance – spray rating	BSEN 24920:1992 (BS 3702)	AATCC 22-1989
Water resistance – rain tests	BSEN 29865 (Bundesmann) BS 5066:1974 1993 (WIRA)	AATCC 35-1994 AATCC 42 (impact)

Table 5.1 (*Continued*)

Property	British Standards	Other related standards
Water penetration resistance (waterproofness)	BSEN 20811:1992 (BS 2823:1982)	ISO 811-1981 ASTM D 3393-91 (1997)
Hydrostatic head test	BS 3424-26:1990 Methods 29A, 29B, 29C, 29D	ASTM D 751 (para 37)
	BSEN 20811 (dense fabrics)	AATCC 127-1989
Water vapour permeability (breathability)	BS 3424-34:1992 (1999) BS 7209:1990 BS 3177 (desiccant, packaging)	ASTM E 96-95 (procedures A, B, BW, C, D, E) DIN 53122 (desiccant, packing) CGSB4-GP-2 Method 49 (Turl) EN 31092 (sweating hotplate) ISO 11092 (sweating hotplate) ASTM F 1868-98 (sweating hotplate) Gore Cup
Blocking resistance		ASTM D 751-98 (para 81–85)

N.B. These are a selection of the more important and general test methods and standards. The BSI and ASTM Annual Books of Standards are recommended for product development. Automotive companies and large chain stores will have their own test methods and specifications.

mental tests applied to coated fabrics. Table 5.2 lists some of the standards and test methods applied to specific products.

5.4.2 Adhesion (peel bond)

This is carried out by measuring the force necessary to pull the coating, film or attached material away from the main base fabric. Specimens 5 cm wide (or 2.5 cm wide) are prepared, and the coating or attached material is peeled away manually to a distance sufficiently far to allow the two components to be clamped into the jaws of a universal tester, Fig. 5.1. The jaws are computer controlled and separate at a specified speed, and the force needed to separate the components is recorded. From this result the ‘peel bond’ per 5 cm width (or 2.5 cm width) is determined, usually by calculating the average of the test results of five specimens taken from the warp direction

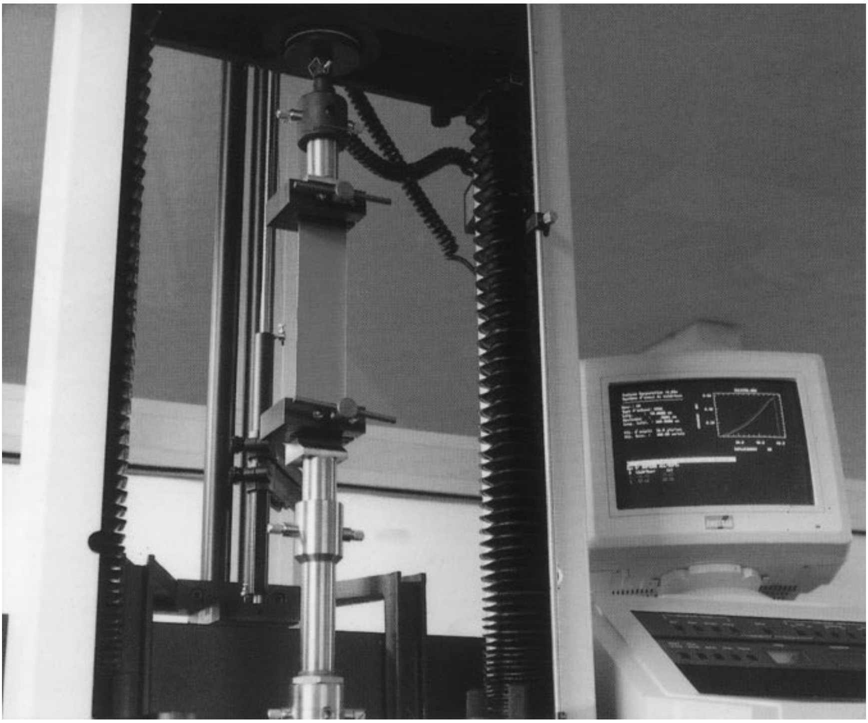
Table 5.2 Selected British and related standards associated with products or properties

Product	British Standard	Other related standards
Water penetration resistant clothing Waterproof protective clothing 'Foul weather clothing'	BS 3546 (coated fabric for use) BS 3546-2:1993 (non-water vapour permeable fabrics) BS 3546-4:1996 (water vapour permeable fabrics) BS 3546-5:1995 (immersion suits)	(ASTM D 751-98) MOD specifications ASTM D 2724 (laminated) EN 343:1996
Architectural uses		ASTM D 4851-97
Mattress covers	BS 5455:1977 (polyurethane) BS 5223-4 (hospital)	
Tarpaulins	BS 3408:1992 (1995)	(ASTM D 751-98)
Upholstery	BS 5790 (PVC)	ASTM D 4852 (attached) ASTM D 3690 (PU/PVC)
Venetian blinds	BS 3415:1986	
Buoyancy aids, rescue devices	BSEN 12628:1999	UL 1123
Life jackets and personal buoyancy aids	BSEN 393:1994 to BSEN 396:1994	
Recreational inflatables		UL 1180
Chemical protective clothing	BSEN 368:1993 (resistance to liquid chemicals) BSEN 369:1993 (liquid chemicals breakthrough) BSEN 374:1993 (gloves – resistance to chemicals/micro-organisms) BSISO 1817 (vulcanised rubber)	ASTM F 739-91 (permeation by liquids/gases – continuous exposure) ASTM D 3132 (solubility of resins and plastics) ASTM F 1001 (battery of chemicals for chemical protective clothing) ASTM F 1383 (permeation by liquids/gases – intermittent exposure) National Fire Protection Association (USA) Standards: NFPA 1991 NFPA 1992 NFPA 1993
High visibility clothing		EN 471

Table 5.2 (*Continued*)

Product	British Standard	Other related standards
Luminescent fabrics		ASTM E 2072 (specification) ASTM E 2073 (test method)
Conveyer belts	BSEN 28094 (adhesion test) BSENISO 252 (adhesion) BS 903 Part A12 (adhesion)	ISO 36 (adhesion of rubber to textile)
Air bags		ASTM D 5428-93A (evaluation of performance) ASTM D 5446-94 (physical properties determination) ASTM D 737-96 (air permeability) ASTM D 5427-93A (ageing) OEM (environmental age tests) 'Scrub' test for adhesion (Swiss test)
Automotive carpets		ASTM D 2646-96 (test for backing fabric) ASTM D-1175 (abrasion resistance) SAE J1530 abrasion and fibre loss AATCC Method 121 soiling
Aero standards	BS Aero F131 (wind socks) BS Aero F136 (rubber coated nylon) BS Aero F139 (aluminised rubber coated nylon) BS Aero F 127 (elastomeric coated nylon)	

N.B. These are a selection of the more important and general test methods and standards. The BSI and ASTM Annual Books of Standards are recommended for product development. Automotive companies and large chain stores will have their own test methods and specifications.



5.1 The universal tester is used not only for fabric tear and tensile strength determinations, but also extensively for coating and lamination adhesion testing (peel bond). The apparatus is also used for stretch and set testing which has become more important for moulding and automated manufacturing operations. Photograph supplied by Bobet Coated Fabric Company and reproduced with kind permission.

and five from the weft direction. The actual test procedure and the standard required (expressed in Newtons per centimetre width of sample) are specified by the customer, but are likely to be based on BS 3424 or ASTM D 751-98. For coating adhesion the level required is generally at least 50 N per 5 cm width. Peel bonds are also usually carried out with wet samples and somewhat lower figures are generally acceptable, say 35 N per 5 cm.

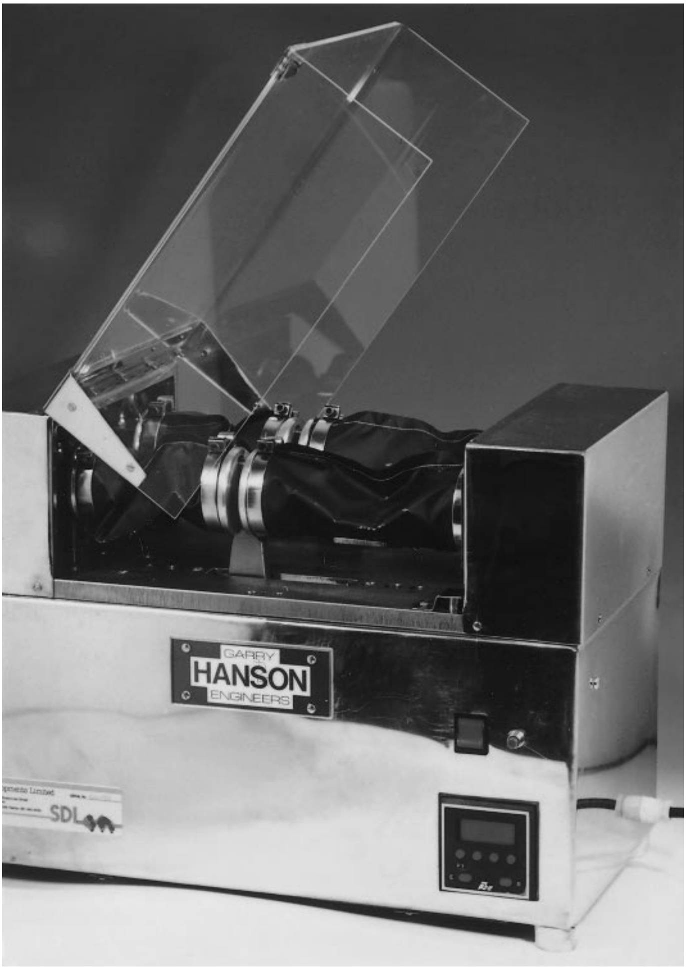
When a foam backed laminate is tested, the bond between the foam and the fabric may be stronger than the tear strength of the foam. The result is normally recorded as a 'foam tear' which generally implies more than satisfactory. However, if the foam is very thin and unsupported, i.e. a bilaminate, the actual tear strength of the thin foam may be less than the required peel bond. If the test result is recorded as a foam tear, this statement is misleading, and it may be necessary to modify the test procedure, for example by sticking a supporting material to the foam (to form a trilaminate), so that the actual foam to base material bond can be determined. The same considerations apply to thin films laminated to one fabric only.

For coated fabrics where the actual coating itself cannot be peeled away to insert into the jaws of a universal tester, two samples are joined coated face to coated face with a strong adhesive. A short distance at one end is not joined because, when the adhesive has dried and fully bonded, the sample is held in the universal tester using the loose ends in the same way as a laminate, and the adhesion test is done in the same way as before. If the adhesion of a fabric intended for water-resistant clothing is to be tested, and the face side of the material is treated with a silicone water repellent, care must be exercised. The silicone finish can mark off and contaminate the coated sides which are to be joined together to carry out the peel bond test, and this will affect the result. The best practice is to take the sample for peel bond testing before silicone is applied. Fluorocarbons generally reduce peel bonds much less than silicones, and it should be possible to do peel bond tests on fabric which has been fluorocarboned – although pre-testing is best to confirm this.

Peel bond tests on car seat cover laminates, face fabric to foam and foam to scrim, are important to ensure that delamination does not occur in the car during use or during downstream processing. To simulate possible conditions which may be encountered during the life of the car and during subsequent processing, the peel bond test is carried out as received, and also after heat ageing, while wet, and sometimes after treatment with solvents. The new manufacturing technique of direct joining seat cover to the foam squab and cushion may necessitate higher peel bonds, because there are fewer sew lines to help hold the laminate components in place.

5.4.3 Flexing tests

These tests are a further means of assessing coating adhesion by flexing to simulate the mechanical action encountered by garment materials during wear, especially at elbows and knees. The Crumple-flex tester twists fabric samples made into a cylinder through 87° and stretches and crumples them at the same time. The flexed samples are examined for delamination or other damage, and in the case of water-resistant material the water resistance is assessed after a specified number of cycles. The test procedure is in BS-3424-9, see Fig. 5.2. The Schildnecht Flextester is a similar machine, but does not twist the fabric. More samples can be tested at the same time using a Schildnecht machine, but the sample specimens are smaller. Flex requirements specified by the customer may vary considerably with the article

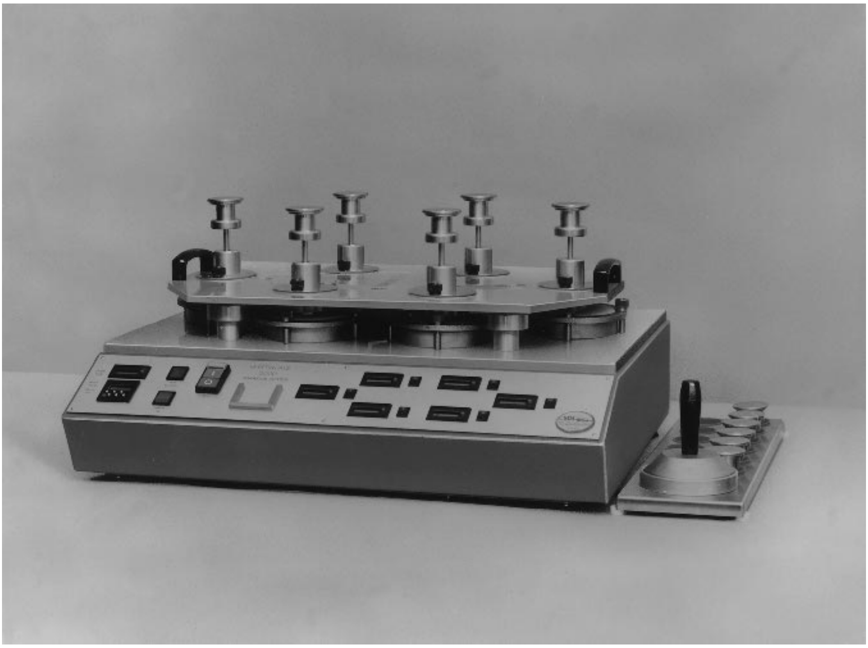


5.2 Crumple-flex testing is important to assess coating adhesion and quality under simulated wearing conditions. A tube of fabric is repeatedly flexed, stretched and compressed and twisted through 87°. Suitable for BS 3424, ISO 8096 and other tests. Photograph supplied by SDL International Ltd and reproduced with kind permission.

being tested, e.g. (Schildnecht) 200 000 flexes for garment material, 500 000 flexes for a tarpaulin.

5.4.4 Abrasion resistance

In the case of a coated fabric, abrasion has two meanings, the abrasion resistance of the coated surface, i.e. the resistance of the resin to damage, and also the abrasion resistance of the face fabric. The face fabric abrasion



5.3 Martindale abrasion test apparatus. This is only one of several methods in use. The automotive industry also use the Taber and Schopper test methods. Photograph supplied by SDL International and reproduced with kind permission.

resistance of woven fabrics can be improved significantly by coating the back, but of course the material becomes stiffer and less flexible. While this is sometimes unacceptable for apparel fabrics, it is less of a problem with upholstery fabrics or fabrics which are laminated, especially those laminated to a rigid material. Coating fabrics also improves the associated problems of pilling and snagging because the resin helps to lock fibre in place. This aspect of coating and abrasion resistance is discussed in Section 5.6.6, although many of the factors involved are also relevant to domestic furniture.

The abrasion resistance of the coating on a coated fabric could influence the performance of waterproofing, and therefore requires assessment. This is accomplished by use of the Martindale apparatus, see Fig 5.3, placing the coated fabric to be tested on the base of the machine and abrading it with a piece of wool held in the abrading head. This test uses the machine the other way round compared to normal procedure, but it does allow a test sample large enough for waterproof testing after abrading. The material should still be waterproof after say 5000 rubs. There are a number of other abrasion tests, such as the Taber, the Schopper, etc, some of which measure the amount of material abraded away from the test sample by weight reduction.

5.4.5 Waterproofness (water penetration resistance)

Resistance to penetration by water, the ability to provide protection against water or rain, is measured by the hydrostatic head apparatus that essentially attempts to force water through the fabric, the pressure being measured by a column of water, see Fig. 4.11. Details of the test are given in BS 3424 Part 26; 1986 which mentions three procedures, Methods 29A, 29B and 29C. The new procedure for 29A is the method now most widely used and is generally in accordance with BS 2823; 1982, the hydrostatic head test. Method 29A uses a fabric sample of 100 cm^2 area (11.3 cm diameter), and water pressure is applied to one side at the rate of increase of 10 cm per minute until 'the first damp patch' appears. Because this procedure can be very time consuming, many laboratories increase the pressure to the standard level required within one minute and, in addition, may follow the procedure described in BS 2823; 1982, i.e. pressure is increased until the third growing drop appears. Work carried out by Wenzel as far back as 1936 showed that results recording the third drop were more reproducible than those recording the first.[6] The average result of five individual test specimens is taken as the hydrostatic head. Standards have risen since this time, and up market manufacturers may reject an entire batch of material if a single test result fails to meet the minimum. The reason is presumably because a garment needs only a single weak spot to leak water. It should be appreciated that different results may be obtained with different rates of increase in water pressure. The standards do require that the rate of pressure increase be recorded with the test results. Older laboratories may still possess apparatus which uses test fabric samples 5 cm in diameter, as stated in Method 29C. The intention of BS 3424 Part 226; 1986 was to phase this out by the early 1990s.

A height of 100 cm is generally regarded as the absolute minimum for a fabric to be termed waterproof or water penetration resistant. Many quality manufacturers, however, require more than this, up to and exceeding 200 cm. In practice, the higher the better, because if the initial hydrostatic head was 250 cm and during use over six months, or after washing, the performance is reduced by, say, 50%, the article is still water penetration resistant – and so the higher the initial hydrostatic head, in general, the higher the durability. It is usual to test the hydrostatic head after flexing and after abrasion testing; some customers accept a hydrostatic head of 70 cm after these tests, others require considerably more. The term 'waterproof' is discouraged in this test because it implies that the 'waterproofness' is equivalent to the hydraulic bursting strength of the material, and also that the material is completely impermeable to water. This term appears still to be used in the USA; ASTM D 3393-91 (1997) is the Standard Specification for Coated Fabrics – Waterproofness. However, the term is avoided in ASTM

D 751-98 ('hydrostatic resistance' being used). The unit kPa is now being used in place of cm (head) of water; 1 cm 'head' of water pressure is equivalent to 0.098 kPa (1 inch 'head' = 0.25 kPa). BS3546, the standard for water-resistant coated fabric for clothing, states that the term 'water penetration resistant' should not be applied to any coated fabric with a water penetration pressure of less than 10 kPa 'as received', i.e. before any flexing or ageing test. As stated above, however, 'waterproofness' is used in the trade and is therefore used in this book.

Many performance specifications for waterproof protective clothing include requirements of hydrostatic head after simulated wear tests such as flexing, abrasion testing and cleaning. An allowance is normally made for these tests – the hydrostatic head is not expected to be the same as it was 'when received'. Abrasion tests on coated fabric have already been described above. Different customers require differing standards of performance and different tests. The MOD specifications are amongst the most demanding, requiring 700 cm hydrostatic head after the durability tests.

5.4.6 Fabric handle, drape and stiffness

Coating fabric causes stiffening by penetration of the resin into the fabric structure, and generally the more penetration the more stiffening is caused. This is invariably accompanied by a reduction in tear strength, and can also affect the appearance and aesthetics of the face side. Under a microscope, 'grin through' can be seen. In general, the more penetration is controlled, the less the stiffening effect on fabric handle. Sometimes a fluorocarbon finish is applied to a fabric before coating to help control resin penetration. However, the less penetration, the lower the resin adhesion, and in some cases a balance or 'trade off' needs to be established. The stiffness of coated woven nylon for waterproof clothing has always been something of a problem, although anorak fabric is significantly softer than it was in the 1980s. The MOD find the rustle of garments a problem – disruptive print uniforms are designed to conceal the presence of soldiers, but the noise caused by garment rustle may negate this to a certain extent!

Fabric stiffness can be assessed by a bending length tester of the type designed by the Shirley Institute (now BTTG). The Cusic drape tester is a quick method for assessing the drape of light weight material, but it is possibly not suitable for some coated fabrics. Some efforts have been made to quantify surface touch using the Kawabata system, which has had some success in the clothing industry.[7–11] The influence of different finishes on fabric handle has been researched and quantified. Research on fabric handle of apparel and household textiles has revealed national preferences for touch properties and softness. For domestic and contract upholstery, and automotive textiles where the fabric is fixed to a seat or rigid component such as a wall, door casing or headliner, the only relevant mechanical properties out of the five specified by Kawabata are compression and tactile surface touch properties. The other Kawabata properties relating to drape and flexing do not apply in these cases. Kawabata investigations were done on car seat fabric by a research institute, but do not appear to have been followed up by an OEM or seat maker.

5.4.7 Fabric strength – tear and tensile

Good tear strength and resistance to tear propagation is a fundamental property of all fabrics, and is central to good durability and performance. Car seat fabrics are expected to last the life of the vehicle, and torn seat fabric would deter prospective purchasers and significantly reduce the resale value of used cars. The tearing strength of a fabric is influenced by the smoothness and the construction, as well as by the thickness of the yarns. Coating can have a significant influence on fabric tear strength. When a force is applied, if the construction is rigid and inflexible, the applied force breaks the threads one at a time, and low tear strength is obtained. A fabric coating which penetrates the fabric structure and holds the treads in place will generally cause a lowering of tear strength and also, as has been discussed, fabric stiffening. If the threads move under the tearing force and bunch together, several threads will be broken together, producing a higher tearing strength. Some fabric lubricants will allow this to happen, and it is more likely if yarns have a smooth surface. Care must be exercised, however, because lubricants and finishes can reduce peel bonds if the fabric is to be laminated. Silicone finishes and coatings, in fact, very significantly improve tear strength and puncture resistance – but these are *not recommended* on fabric to be coated or laminated. They may be applied after coating or laminating, but with care because, as has already been mentioned, a finishing process on a coated or laminated fabric could reduce bond strength. Silicones are especially not recommended on automotive fabrics, not only because of their effect on adhesion but also because they can contaminate surfaces to be painted, i.e. the car body, and cause resist marks.

Certain constructions such as twill weaves and basket weaves allow threads to group together more easily and thus tend to have better tear resistance than plain weaves. The yarn and fibre type also determine fabric strength; polyester is stronger than wool, and continuous filament yarns will be stronger than those made from spun staple fibre. The use of 'rip-stop' constructions to improve tear resistance has already been mentioned. Tear strength testing is also sometimes required after exposure to UV light. Polyester fabric tear strength is generally satisfactory after exposure, but that of wool fabrics and especially nylon fabrics may be significantly lower. Yarn lustre has a significant effect because of the effect of titanium dioxide – bright yarns with no titanium dioxide are generally much more resistant to UV light. Acrylic fibres have the best resistance to UV degradation.

There are a number of tear tests in use, single rip, wing tear and Elmdorf tear. The wing tear avoids transfer of tear, whilst the Elmdorf method measures energy loss during the tear process. Care must be exercised in clamping the specimen in the jaws of the test machine, because any slippage could be mistaken for a tear or a failure of the test specimen. Jaws and clamps of different designs are available for testing different types of materials. Straight load or tensile strength tests on strips of fabric are useful for investigating the effect of a material or process change on fabric properties. BS 3424-5; 1982 (1996), Methods 7A, 7B and 7C details three methods for determination of tear strength for coated fabrics. Certain knitted fabrics may distort or unravel, and bursting strength tests are likely to be more reliable (BS 3424-6; 1982 (1996), Method 8B).

5.4.8 Bursting strength

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

5.4.9 Dimensional stability

These are tests for garment shrinkage on washing or during use by the customer. They also check suitability for downstream processing such as panel cutting and sewing or, in the case of the automotive industry, lamination to door casing. Dimensional stability tests involve measuring the percentage shrinkage after soaking in cold water or after heating in an oven at various temperatures. Effective heat setting during fabric finishing significantly reduces the possibility of shrinkage. Figure 2.1 shows the general relationship between heat shrinkage and heat setting temperature with polyester fabric. However, if fabric has been subject to high tension during the coating process, shrinkage may occur when panels are cut or when the material is relaxed. These tests have assumed more importance recently with newer methods of manufacture and tight production schedules, which do not allow for continual machine adjustments. Lamination must be carried out under conditions of no tension if the products are to pass these tests consistently. This is especially relevant if any of the laminate components are stretchy.

5.4.10 Other general tests

Cold cracking tests carried out at, say, –20 °C are specially relevant to PVC coated fabrics such as tarpaulins, because if not appropriately formulated PVC may crack when cooled to temperatures below 0 °C. Tests for dimensional stability under water immersion are also routinely carried out to simulate washing and generally getting wet by exposure to the elements. Stretch and set tests are important for laminates, especially when one or both components have a significant amount of stretch. Lamination must not be carried out when the materials are not in a relaxed state, because this may result in the laminated material curling and not lying flat on the cutting table. In addition, cut panels may distort or even change dimensions slightly, which can cause serious problems if they are used in an automated process such as those used in the automotive industry for door panels, headrests, etc. These factors are discussed further in Section 5.6.9.

5.5 Thermal comfort of apparel

5.5.1 Introduction

Garments produced from coated or laminated fabrics are worn for protection from the elements, or from some specific agent such as heat, microbes, chemicals, radiation or even molten metal splashes. One important factor common to all garments is comfort. The human body cannot function efficiently for any length of time if it is uncomfortable, and hence comfort is a factor determining safety. In some cases the person is so uncomfortable in a particular garment that he or she will remove it and thus be exposed to the danger against which the garment is designed to protect. The main problem is the inability of body perspiration to evaporate to cool the person who will generally be involved in some form of activity.

Thermal comfort is defined in ASHRAE Standard 55–56 as ‘that condition of mind that expresses satisfaction with the thermal environment’. Generally, this means that the person does not know whether he or she would prefer a warmer or a cooler environment. Clothing comfort has already been discussed in Section 4.1.

5.5.2 Energy balance of the human body

As long as a human being is alive, he or she is producing heat. Even when sleeping the human body is producing 80 W of heat; when walking at a leisurely pace, this rises to about 210 W; and it can exceed 700 W when walking up a steep hill. In high activity work or sport it can rise to well over 1000 W. However, human body core temperature must always be constant at about 37 °C, and there are automatic body mechanisms which try to maintain this. If we are too cold, the body shivers in an involuntary action to generate heat by muscular contraction – if we are too hot, sweating occurs which causes cooling of the skin by evaporation of the liquid sweat. Water evaporating has a cooling effect because it takes away its latent heat. Heat is lost from the human body by four principal methods: conduction (physical contact), convection (by air or wind), radiation and evaporation of sweat from the skin. The main mechanism for loss of excess heat is by sweating, and if the human body surroundings reach or exceed 37 °C in temperature (the inside of a car on a sunny day), then this the only way the body can lose heat.

At the other extreme, if body core temperature begins to fall below 37 °C, the person begins to suffer from hypothermia.[12] At 35 °C, the person shivers violently and has poor co-ordination. If the body temperature continues to fall, the person becomes incoherent and confused and falls unconscious when 30 °C is reached, death soon follows if they are not warmed and revived. Wind can increase the heat loss by convection and by evaporation of sweat or water from rain on the skin. The effect of a strong wind at a low temperature, the 'wind chill effect', can have a much greater cooling effect than still air at an even lower temperature. Water conducts heat away about 25 times faster than air at the same temperature, and so apart from the discomfort, wetness substantially increases the loss of body heat. In addition, wet clothes have much reduced insulation properties and lose much of their ability to keep the body warm. Waterproof clothes are therefore not only important in keeping a person comfortable and protected from the elements, but are also necessary for survival in extremely cold conditions. At the other extreme, if the human body generates more heat than it can lose to the surroundings, the person becomes uncomfortable and stressed. This can also induce fatigue and cause the person to function inefficiently and become more accident prone if doing a job of work. However, if a person is wearing waterproof clothing, it is important that as much perspiration as possible is allowed to escape and induce body cooling by evaporation. The rate of liquid perspiration exuded from the skin can be related to the work rate in watts, for example gentle walking with a work rate of 200 W produces an equivalent liquid perspiration rate of 7600 g in 24 hours, and active walking on the level carrying a heavy pack with a work rate of 500 W produces an equivalent perspiration rate of 19 000 g in 24 hours.[13] These figures are of course only general, and will vary according to individual body metabolism and ambient atmospheric conditions.

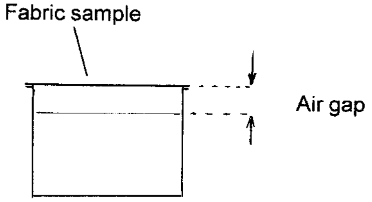
5.5.3 Measurement of water vapour permeability–'breathability'

Most waterproof materials which do not allow the passage of liquid water do not allow perspiration to pass either, i.e. they do not 'breathe'. Breathability is a more difficult quantity to measure to the satisfaction of all customers and of the general public. One of the main reasons, of course, is that everybody has their own particular metabolic rate of producing perspiration and their own particular 'comfort threshold'. In addition, the rate of production of perspiration depends on the level of activity – the more strenuous the activity, the higher the level of breathability required in the garment material. It should be remembered that even an unclothed body would perspire if working hard. Also an unclothed body at rest would perspire if situated in a room at a temperature higher than body skin temperature. Breathability tests seek to assess the amount of perspiration which can pass through the garment material under controlled laboratory conditions which bear some relation to conditions of actual use.

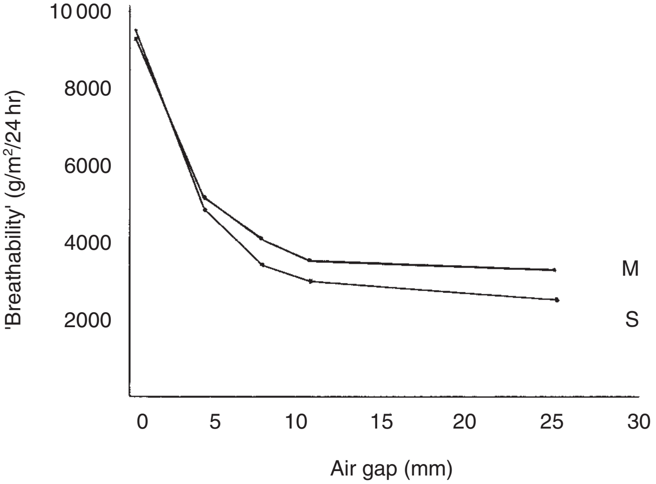
Non-coated fabrics are generally breathable, but they are not water resistant (i.e. do not have a hydrostatic head of 100 cm of water), but most regular, water resistant, coated fabrics, e.g. PVC, Neoprene, regular polyurethane and acrylics, do not breathe appreciably. Coated fabrics which do not have a good hydrostatic head, for example about 30–40 cm of water, will give more protection from the rain than a non-coated fabric. They cannot, however, be classed as 'waterproof', but they are likely to be appreciably breathable. A truly 'breathable and waterproof' fabric should be 'breathable' and also have a hydrostatic head of at least 100 cm of water. An acceptable level of 'breathablity', however, is a little more difficult to define than waterproofness as will become clear over the next few paragraphs.

There are various methods of measuring breathability, the units of which are grams of moisture transmitted through a square metre of the fabric in a given period of time, usually 24 hours. Other more academic methods measure water vapour resistance, i.e. millimetres of still air or other units – see later in this section. Tests generally fall into three categories: desiccant methods such as BS 3177, ASTM E96-95 Procedures A, C or E, and DIN 53122; 'inverted water' methods such as the Gore Cup and ASTM E96-95 Procedure BW, and finally evaporative methods such as BS 7209 and ASTM E-96-95 Procedures B and D. The desiccant methods are used mainly in the films and packaging industry for measuring relatively low levels of water vapour permeability. There is an extensive range of literature on products, test methods, results and discussion of results.[13–18] Chapter 4 discusses waterproof breathable products.

Evaporative tests are probably both the easiest to carry out and the most easily understood by the layman. They are, however, extremely sensitive to test conditions, experimental procedure and error, and inter-laboratory agreement can be poor even when tests are carried under apparently 'identical' conditions. Essentially, they measure the amount of water evaporated through the fabric under a given set of conditions. A small vessel is partly filled with water and the top sealed by the coated fabric being tested, Fig. 5.4. It is then weighed accurately to at least two decimal places, placed on a hot plate set at the test temperature, left for the prescribed period and then re-weighed. From the weight lost and the surface area of the vessel, it is possible to calculate the amount of water vapour transmitted through the coated fabric per square metre in 24 hours – the breathability of the material. This can be done at different temperatures; Procedure B of ASTM E 96 95 uses a temperature of 23 °C (73.4°F), Procedure D uses a temperature of 32.2 °C (90°F). Presumably this temperature was chosen because it is approximately the inside temperature of a garment. The actual temperature of course depends on a number of factors including the layers of clothing worn in between the skin and the outer garment. The higher the temperature of the water inside the test vessel, the higher will be the figure of breathability obtained, because the 'driving force' is the difference between the temperature of water inside the vessel and the outside ambient temperature. The level of water in the vessel, i.e. the air gap between the sample and the top of the water, is very critical – the smaller it is, the higher will be the figures obtained. A difference in air gap of 5 mm within the range 0–10 cm can double 'breathability' results, see Fig. 5.5. The reason for this is believed to be the resistance to water evaporation of the air in this gap. Needless to say for reproducible results, sample temperature, the ambient laboratory temperature and relative humidity should be as constant as possible. Another factor influencing results is efficiency of sample vessel sealing. Table 5.3 shows some figures obtained on a range of products using an evaporative method with an air gap of one inch (25.4 mm).



5.4 The evaporative (cup) method of breathability evaluation. The test variables are air gap inside the test vessel, water temperature inside the vessel, and temperature (and relative humidity) of the outside (ambient) atmosphere. The difference between the two temperatures is the 'driving force'. ASTM E 96 Procedure D recommended cup water temperature is 32.2 °C (90 °F). BS 7209 cup temperature is the same as external ambient temperature, 20 ± 2 °C.
N.B. For information on effect of temperature variation on 'breathability' see Ref. 62.
Desiccant methods use the same cup, but with calcium chloride or silca gel inside to reduce humidity.



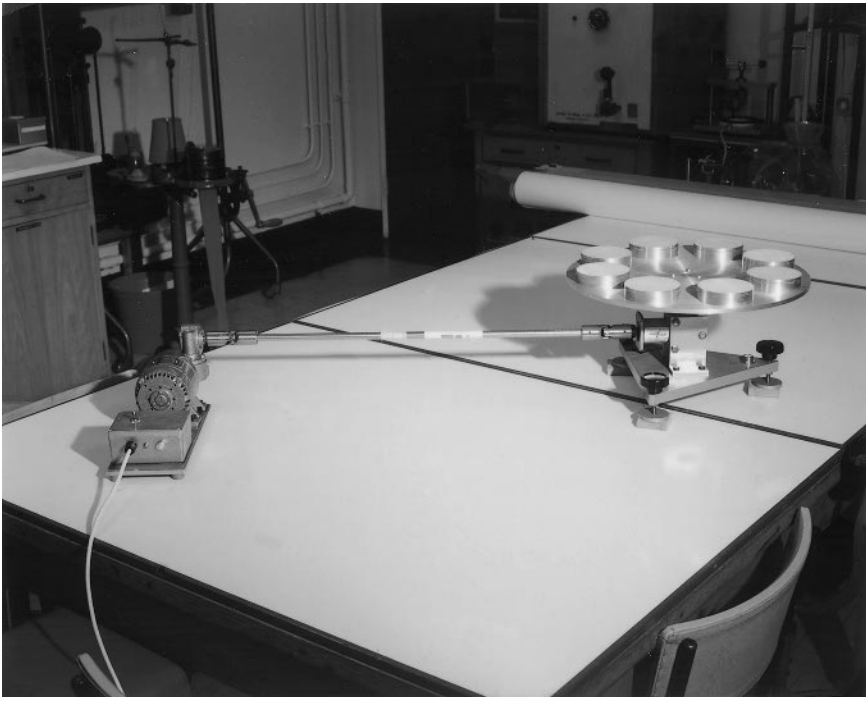
5.5 The effect of the air gap in evaporative or 'cup' tests. This is extremely significant in the 0–8 mm range. These results were obtained using a vessel 3.5 cm wide. The temperature of the water inside the vessel was 37.5 °C and the ambient laboratory conditions were 21 °C and 50–55% relative humidity.
N.B. M = PTFE microporous laminate, S = solid film coating.

When waterproof breathable fabrics were first introduced in the early 1980s, several test methods were used by individual manufacturers, each of whom used methods and test conditions that enhanced the performance of their own product. In addition, even when a particular test was performed by different laboratories using apparently identical conditions, the agreement was poor. As related in Chapter 4, a standard evaporative test procedure was developed under the auspices of the BSI. This was BS 7209, which does not actually heat the water. The test vessels were placed on a turntable which rotated slowly to remove any stationary layer of air which might sit over the surface of the fabric samples and hence influence test results, see Fig. 5.6. The test results were expressed as a percentage of the result obtained with a standard uncoated polyester fabric woven from a mono-filament yarn. This technique improved inter-laboratory agreement, and the results of samples tested by the method detailed in BS 7209 are referred to as the water vapour permeability index (WVPI). Up market, waterproof breathable materials are expected to have a minimum WVPI of 80%, lower grade products a value of at least 50%. As already stated, breathability is meaningless without a high standard of waterproofness, and quality products should also have an initial hydrostatic head of 500 cm of water (50 kPa) while lower grade products should have a minimum of 150 cm (15 kPa).

Table 5.3 Some breathability figures obtained using an evaporative method

Sample	Total fabric weight (g/m^2)	Waterproofness Hydrostatic head (cm of water)	Breathability (g/m^2/24 hr) HDF conditions 37.5 °C	Breathability (g/m^2/24 hr) LDF conditions 21 °C
PTFE 3-layer laminate	200	700+	3600	585
Microporous PU coating (1)	120	560	3300	1009
Microporous PU coating (2)	97	280	3627	942
Microporous PU coating (3)	158	700+	2707	456
Solid PU film hydrophilic coating (1)	150	700+	2900	420
Solid PU film hydrophilic coating (2)	165	700+	2700	266
Solid PU hydrophilic polyester film laminate	140	700+	3890	594
Standard 4 oz polyurethane coating	156	700+	400	163
Closely woven cotton uncoated (commercial product)	202	89	4400	1061
Non-coated woven nylon	123	0	4571	962
Polyethylene film	41	356	143	0
Open test vessel		—	10654	2075

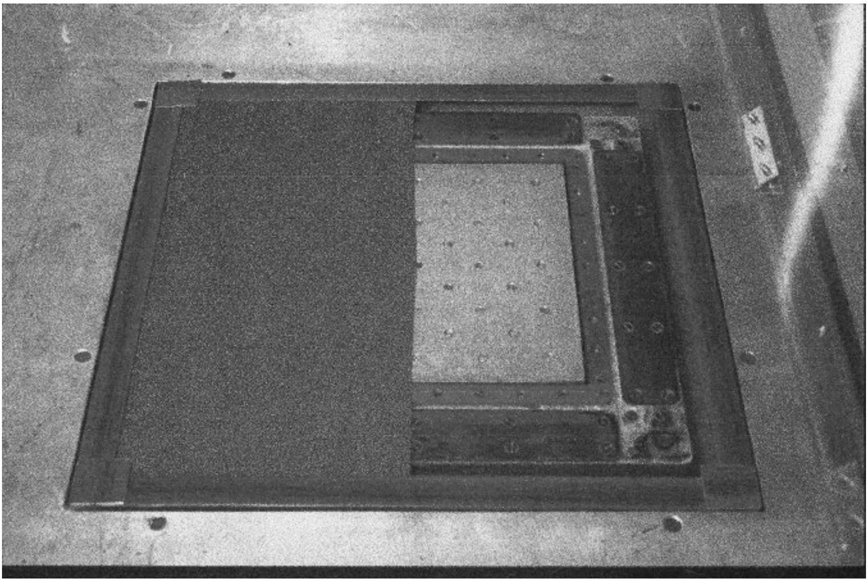
Test conditions:
Test vessel diameter 3.5 cm; air gap 2.54 cm (one inch); relative humidity 50–55%.
HDF = high driving force of 37.5 °C inside test vessel and 21 °C ambient outside.
LDF = low driving force of 21 °C both inside and outside.
N.B. These samples, all on nylon base fabrics, were commercial products on sale at the time of testing (1986) by Courtaulds Research at Spondon, Derby.



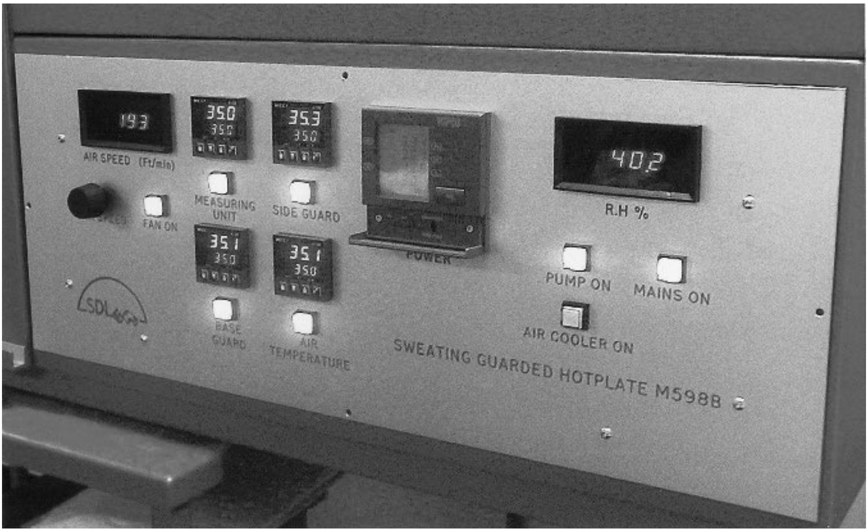
5.6 Shirley Water-Vapour Permeability Tester. The apparatus was developed from the Canadian Government specification CGSB4-GP-2 Method 49 and is suitable for BS 7209 and BS 3424–34. Photograph supplied by SDL International Ltd and reproduced with kind permission.

Meanwhile more academic research continued, the objective being to produce a laboratory test which correlated with actual outdoor wear trials. The Hohenstein Institute have been successful in this exercise and have developed the Sweating Guarded Hotplate method, which has now been adopted as a European and international standard test method (EN 31092 and ISO 11092), see Fig. 5.7 and 5.8. The main drawbacks to this method are that the apparatus is expensive to buy, that it needs skilled operatives to carry out the test and is probably not suitable as a quick quality control test. Some results obtained using the Sweating Guarded Hotplate method appear in Table 5.4. A Canadian Government test called the Turl Dish is an evaporative method and measures resistance to evaporation of the test fabric together with the air layer inside the air gap. This test is also believed to agree well with actual outdoor wear trials.

Even now, nearly two decades later, the confusion over breathability figures still persists, with various figures quoted by manufacturers many



5.7 The Sweating Guarded Hotplate. Photograph supplied by the Hohenstein Institute (Germany) and reproduced with kind permission.



5.8 A commercial Sweating Guarded Hotplate test rig. Photograph supplied by SDL International and reproduced with kind permission.

Table 5.4 Breathability results obtained using the Hohenstein Institute Sweating Guarded Hotplate

		Water vapour resistance Ret (m^2 Pa/W)
1.	Non-breathable (standard) polyurethane coating	164.7
2.	Woven microfibre (not coated)	1.45
3.	Woven polyester microfibre (not coated)	2.30
4.	Tri-laminate with hydrophilic polyester membrane	15.49
5.	Bi-laminate with hydrophilic polyester membrane	5.12
6.	Bi-laminate with microporous PTFE membrane + hydrophilic surface layer	2.58
7.	Bi-laminate with microporous PTFE membrane	2.88
8.	Hydrophilic polyurethane coating on polyester non-woven	12.05

Notes:

1. Samples were measured by the Hohenstein Institute using their Sweating Guarded Hotplate method which is now an international and European test standard, ISO 11092/EN 31092. The results obtained are valid only for the samples actually tested.
2. The two 'extreme' samples are sample 1, which is standard, non-breathable polyurethane and samples 2 and 3, which are non-coated fabrics woven from microfibres.
3. The higher the water vapour resistance, the lower the breathability.

Source: Dr V T Bartels, 'Survey on the moisture transport properties of foul weather protective textiles at temperatures around and below freezing point', Technical Report AiF 11674, Hohenstein Institute for Clothing Physiology 2001 (in German). Reproduced with kind permission of the author.

of whom do not provide precise details of the test method or conditions of test. The procedures used are sometimes quick in-house methods. However, scientific research into fabric and garment comfort has continued and investigations into comfort in real life dynamic situations and whole clothing assembles are being conducted.[19–21] Thermal comfort depends not only on the ability of materials to allow the transmission of water vapour, but on all other factors which have a bearing on moisture management, e.g. wetting out of textile surfaces, wicking of liquid moisture and the capacity and speed of moisture absorption. Also, as has been mentioned, garment design is relevant too, and some writers have commented that more research should be devoted to this than to the actual fabrics.

5.6 Testing of automotive products

5.6.1 General comments

The automobile industry is the largest user of coated and laminated textiles. In many ways the industry is also the most demanding in terms of both consistent quality and production requirements, because of its highly competitive nature and JIT requirements. The exacting durability requirements of car seat fabric are quite unique for such a large volume material.[22–29] Production must be monitored for two main reasons, first to determine suitability for the next process, and secondly to simulate actual conditions of wear during the life of the car. Simulating actual conditions of use over a period of years with accelerated laboratory tests is neither easy nor straightforward, and each OEM has its own methods of doing this. In addition, climatic conditions around the world vary significantly. Test methods depend on the physical conditions which will apply during the next process, and on where in the car the fabric will be situated. Car seat covers have the highest abrasion resistance requirements, while parcel shelves and dashboards have the highest light fastness and UV degradation resistance requirements. The shade of dyed fabrics must be examined, because two pieces of fabric used together in the same car may have been dyed in different dye lots or even different dye works, and the shades may appear slightly different. In addition, if the fabric is used in conjunction with a coloured plastic foil or dyed leather the colours may again not be exactly the same. Care must be taken to avoid the occurrence of metamerism.

Some properties such as weight and thickness can be monitored automatically by microprocessors. However, the final fabric examination, generally carried out manually, is a slow, relatively costly process, and even experienced examiners miss significant numbers of faults. However, customers now call for ‘zero’ defects in goods received, i.e. the exact standard agreed in the sales contract. At the time of writing, zero defects allows for one marked fault in typically 10 m of fabric. Existing automatic examination systems are not sophisticated enough to cope with the whole multitude of factors which result in second quality material. The technology is probably available, in theory at least, but the cost is prohibitive.

New specialist vehicles such as SUV, ‘recreational vehicles’ (RV), ‘multipurpose vehicles’ (MPV), and in the USA pick-up trucks and mobile homes, are creating new requirements associated with the intended use of the vehicle – or the image it creates. An example is the pick-up truck, the ‘cowboy’s Cadillac’, which conjures up the idea of a robust utility vehicle (Ford advertises their product as ‘built Ford Tough’), and it is likely to be treated as such! In the USA car leasing has become more widespread and so the ‘private life’ of the car does not start until it is, say, two years old.

It must not only be in almost showroom condition after this time, but it is also going to have a longer life. The American OEMs are expected to push up the specifications of light and UV degradation resistance and also that of abrasion.[30] In addition, the move towards three-year warranties on new cars by European and American OEMs (to match the Japanese and Koreans) is also likely to lift standards all round. Test methods and standards required by individual OEMs or Tier 1s are generally confidential between themselves and their suppliers. They are, however, usually based on national, international or institutional standards, e.g. BS, DIN, ASTM or SAE. Table 5.5 summarises the main test methods used for seat fabrics and interior trim. Performance standards as well as test methods, however, can vary, and what is acceptable for one OEM may not be acceptable to another. Some attempts have been made to harmonise test methods both in the USA and Europe, which can only be good for the industry as a whole.[31–33]

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

5.6.2 Processability quality checks

The main properties required for downstream processing include the following: consistent dimensions of width and thickness; porosity; stretch and set; dimensional stability; elongation; ability to lie flat (not curl); cold water stability; peel bond (lamination adhesion); heat/humidity ageing. Panel cutting, usually on a cutting table, precedes all making up procedures. Many layers of fabric are cut at the same time, and the laminate must lie flat for accurate cutting. There must not be any inherent instability to cause the laminate to distort or alter its shape in any way. If the seat cover laminate has been laminated with any one of the components under tension, it may alter slightly in dimension when unrolled or cut. Large cut panels may stretch under their own weight, especially knitted fabric laminates. This is inevitable, but they must all stretch by a consistent amount within close limitations. Mass production methods and getting the process right first time, every time, requires starting materials with consistent properties. Pour in foam methods require consistent porosity, so foam does not strike through

Table 5.5 Some selected important automotive seat fabric test methods

	British Standard test methods	Selected related test methods
Colour fastness	BS 1006:1990 (1996) Methods of determining colour fastness to about 70 different agencies BS 1006: Grey scales for assessing changes in colour A02 BS 1006: Grey scales for assessing staining A03 BS 1006: BO1 Blue wool scales	AATCC Test method 16 ASTM test methods DIN 54022 (fastness to hot pressing) DIN 54020 (rub fastness)
Light fastness	BS 1006:1990 (1996)	SAE J1885 Mar 92 Water cooled Xenon arc SAE J2212 Nov 93 Air cooled Xenon arc SAE J2229 Feb 93 Outdoor under glass variable angle SAE J2230 Feb 93 Outdoor under glass sun tracking DIN 75202 FAKRA 7/91
Abrasion	BS 5690:1991 (Martindale) NB sometimes tested after UV exposure	SAE J365 Aug 1994 Scuff resistance (Taber) SAE J2509D ASTM D 3884-92 (Taber rotating platform) ASTM D 3885 Flexing abrasion (Stoll) ASTM D 3886 Inflated diaphragm DIN 53863 3/4 Martindale DIN 53863/2 Schopper DIN 53528 Frank Hauser, loss in mass for coated fabrics DIN 53754 Taber
Pilling	BS 5811: pill box (BS 5690: 1991 – Martindale)	ASTM D 3511-82 Brush ASTM D 3512-82 Tumble ASTM D 3514-81 Elastomeric pad
Frosting		AATCC Method 119 screen wire AATCC Method 120 emery
Snagging		SAE J948 Aug 94 (also abrasion of vinyl/leather) ASTM D 5362-93 bean bag ASTM D 3939-93 mace test

Table 5.5 (*Continued*)

	British Standard test methods	Selected related test methods
Tear strength	BS 4303:1968 (1995) wing tear BS 3424 Pt 5 for coated fabrics BS 4443 Pt 6 Method 15 for foam laminates	ASTM D 2261:96 tongue tear-single rip CRE ASTM D 1117:95 trapezoidal tear DIN 1424-96 Elmdorf tear apparatus DIN 53356 tear propagation
Tensile strength/ breaking and elongation	BS 1932 for yarns and threads BS 3424 Pt 5 for coated fabrics BS 2576 woven fabric/ strip method BS 4443 Pt 6 Method 15 for foam laminates	ASTM D 751 for coated fabrics ASTM D 1578-93 yarns by Skein method ASTM D 5034-95 Grab method DIN 53857 for non-wovens DIN 53571 tensile and elongation
Stretch and set	BS 3424 Pt 21 But BS 3425 Pt 24 still in use	SAE J855 Jan 94 DIN 53853 DIN 53857
Dimensional stability	BS 4736:1996 cold water	SAE J883 Jan 94 cold water SAE J315A DIN 53894
Compression (for foam laminates)	BS 4443 Pt 1 Method 5A stress strain characteristics BS 4443 Pt 1 Method 6A compression set	ASTM D 2406-73 Method B DIN 53572 compression set DIN 53577 stress strain
Air permeability	BS 5636:1978 now BSENISO 9237 BS 4443 Pt 6 Method 16 BS 6538 Pt 3 (Gurley method)	ASTM D 737 DIN 53887
Fogging	BS AU 168:1978	SAE J1756:1994 ASTM D 5393 DIN 75201
Flammability	BS AU 170 1979:1987	FMVSS 302 SAE J369 DIN 75200
Accelerated ageing	BS 3424:1996 Pt 12 coated fabrics BS 4443 Pt 4 Method 11 foam BS 4443 Pt 6 Method 12	ASTM D 2406-73 DIN 53378 Tests of individual auto companies sometimes as pretreatment for further tests e.g. peel bond, effect on appearance. Cycles can range from –40 °C to as high as 120 °C.

For further information see References 22–30 and Further reading 8 and 19.

to the fabric face, and in addition laminate thickness must be within certain limits for some moulding techniques.

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

5.6.3 Customer satisfaction quality checks

The more familiar tests associated with fabric include the following: uniformity of shade; regularity of pattern; abrasion resistance; light fastness; wet perspiration dye fastness; dye crocking fastness; tear strength; bursting strength; laminate peel bond; crease recovery; cleanability/soil resistance; 'environmental' tests; flame resistance. Test specifications may seem unrealistically high to the layman, but it is easy to misjudge the wear and tear over several years of daily use and the combined effects of high temperature, varying humidity and UV radiation. Cars produced in, say, the UK must generally be capable of withstanding climatic conditions in any part of the world. In recent years the following factors have grown in importance or become more critical: fogging; odour free; cleanability; anti-static properties.

5.6.4 Colour fastness and crocking

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

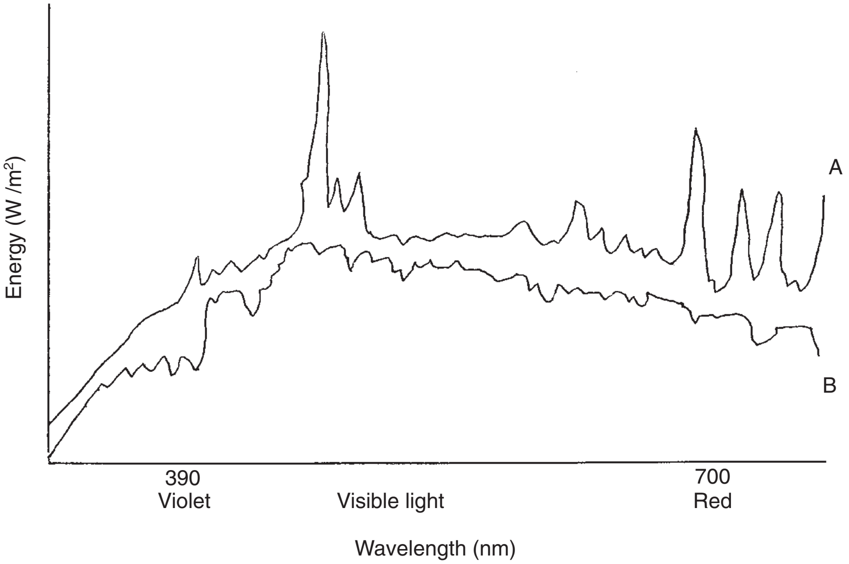
Rub fastness, both wet and dry, is assessed using a Crockmeter, a machine with a wooden peg around which is fastened a piece of white cotton fabric. The machine action is to rub the fabric sample ten times with the cotton fabric covered peg, after which any staining off of dye is assessed using grey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

5.6.5 Light fastness and UV degradation resistance

This is probably the single most important test and also the most difficult to reproduce; consequently much research has been carried out.[34–41] One of the reasons, of course, is simply that sunlight conditions vary not only according to location in the world, especially latitude, but also at any given place according to the position of the sun in the sky and therefore the time of day. The weather and cloud cover are also relevant factors in addition to variations in actual solar UV radiation, see Fig 5.9. The large amounts of glass in modern cars allow the entry of substantial amounts of sunlight, which heat up the confined space of the car raising the temperature to as high as 130 °C in extreme conditions in the Arizona Desert. On normal summer days in the UK, the temperature of car interior surfaces exceeds 70 °C with ambient exterior temperatures of only 23 °C. As the sun sets, the temperature will fall and this will significantly affect the relative humidity and cause dampness. Some test procedures attempt to reproduce all of these conditions. The daily cycle of heating and cooling could be influencing rate of colour fade and fabric degradation. Some tests, such as the American standard SAE J1885, include a period with the light switched off to simulate this. If the procedure involves the sample becoming wet, the test is best described as a weathering test rather than a light fading test.

Sunlight is a mixture of all the colours of the rainbow plus IR, UV and other radiation. The UV rays are the shortest in wavelength and, having the most energy, are by far the most damaging to fabrics. Whilst much of this radiation is filtered out by car window glass some of the longer UV rays still penetrate. The thickness of the car window glass will have an effect – the thicker the glass, the fewer UV rays will enter the car. Tinted glass also reduces the amount of radiation, including visible light, but there are safety limitations on the degree of tint permissible.

Following investigations over a number of decades, researchers agree that, amongst other factors and combinations of factors, the three most important single ones causing degradation by sunlight are UV radiation, heat and dampness. To obtain test results which will give accurate information on likely performance over several years, of actual use in the



5.9 Spectral energy distribution of daylight compared to that obtained with artificial xenon arc light with filters. Diagram produced from information supplied by Atlas Material Testing Technology BV.

A nanometer (nm) is one millionth of a millimetre. Visible light, made up of the colours violet, blue, green, yellow, orange and red, is in the region of 390–700 nm, with violet (390–430 nm) and red (610–700 nm) at each end. Beyond the range of visible light is UV (30–390 nm) and IR (700–3000 nm).

The shortest wavelengths have the most energy, and the UV is the most damaging radiation to textiles. However, windscreen glass filters out some parts of it.

Sunlight is a mixture of all radiation, but clouds have a filtering effect. The extent to which clouds do this depends on thickness and type of cloud. White light is a mixture of all colours and includes UV and IR. The relative amounts of all the colours and the infrared and ultraviolet, depends on several factors: the position of the observer on the Earth's surface (latitude and whether facing north or south); the time of day (i.e. position of the sun and whether high or low in the sky); the degree of atmospheric pollution; and the amount of cloud cover.

For an accelerated light fading test, it is first necessary to obtain an artificial light source – preferably one which reproduces sunlight as closely as possible. This is neither easy nor straightforward, for the reasons stated. The carbon arc is very rich in UV – much more than in natural sunlight. The best artificial source so far achieved, which closely reproduces natural sunlight, is the xenon arc with filters.

N.B. A = Xenon arc with filters, B = average daylight in Miami.

car, the test machines use these three factors at extreme, but realistic levels, mainly running all together at the same time. It is important that these conditions are comparable to what is observed in actual daylight, because if they are not, misleading information could result. For example, using substantially higher levels of radiation could cause other types of degradation, which would never actually occur under natural conditions. However, it is important that the test is completed in the shortest possible time so that fabric can be released for use as soon as possible after manufacture.

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

The first lamp developed was the enclosed carbon arc (Atlas in 1920s) which was used in the Fade-Ometer. The spectral distribution of this lamp was very different to sunlight; in particular, UV rays, which are responsible for much of the damage caused by sunlight, were absent. The sunshine carbon arc, which was used in the Weather-Ometer was an improvement. This lamp had a better resemblance to sunlight and did produce accelerated fading, but it contained certain bands of UV radiation not present in natural sunlight, and was judged to be too severe. Furthermore some visible light was absent from its spectrum. Maintenance was expensive because the electrodes of the carbon arc lamps had to be changed daily, and test machines using fluorescent lamps appeared as cheaper alternatives. Whilst fluorescent lamps do give accelerated fading, they are now considered unrealistic because, while their spectrum is rich in UV radiation, other wavelengths are absent.[35]

The latest developments involve the xenon arc lamp, which is at present the best reproduction of natural sunlight commercially available. The first machine of this type, which was introduced during the 1950s by Heraeus, was an air-cooled model. A water-cooled model produced by Atlas followed shortly after, and both types are now in widespread use. However, it is important to specify the method of cooling and which filters are to be used, because the spectral distributions of the two types are not the same. Results of fading tests will be different for the following reasons. The Atlas model has two glass tubes around the xenon lamp, which act both as filters and as part of the cooling apparatus. The spectral distribution of the light is, therefore, the same in all directions. The air-cooled Heraeus model, on the other hand, uses a combination of filters to produce an overall spectral distribution. The carbon arc lamp is still used, but this is declining in favour of the xenon models. Some researchers believe that the whole spectrum of sunlight should be reproduced to give the most accurate accelerated results. For these reasons the OEMs specify the test method and the type of machine. A typical test requirement includes the following information: test machine model and lamp; filter system; humidity; test chamber temperature (ambient inside the apparatus); black panel temperature (temperature of the actual test sample); and exposure time.

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

There are additional factors influencing reproducibility. The test substrate itself may not be completely uniform and may have varying amounts of chemical finishes, UV absorbers or other substances on it. In addition, fabric samples could have been produced under varying conditions of scouring, stentering or lamination, etc. Laboratory reproduction of several years exposure to air pollution and traffic fumes, the composition of which will vary widely with location, is especially difficult. These factors may also be playing a part in conjunction with the combined effect of all the other variables, not to mention the surface abrasion and other factors associated with the car occupants sitting on the fabric.

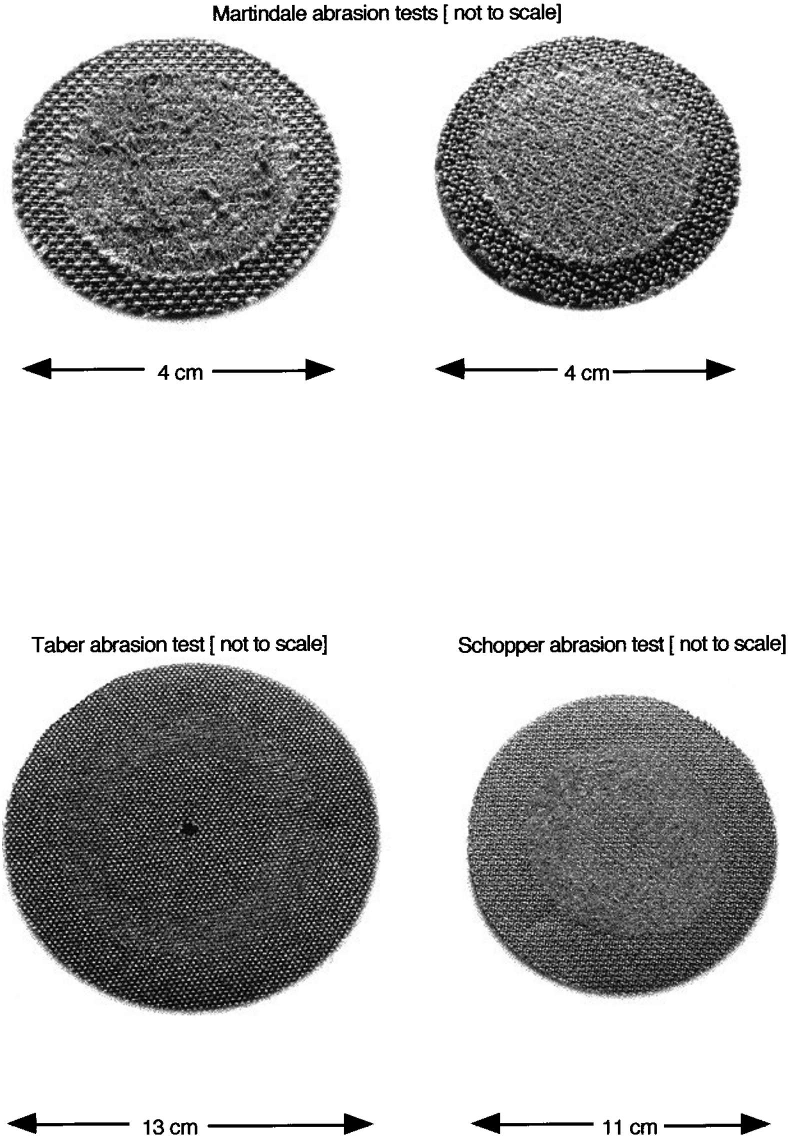
Fibre lustre, or the titanium dioxide delustrant added to the yarn during manufacture, has a very significant effect on UV resistance. Matt yarns, which contain the most delustrant, break down significantly faster than bright yarns. This is thought to be due to the titanium dioxide photosensitising degradation,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

When fabric is tested for light fastness and UV degradation, it is important to test it either in the laminated form or with polyurethane foam underneath it. The foam is believed to act as a heat sink, hence more accurately reproducing the conditions actually prevailing inside the car. Different OEMs specify different test conditions, but there are steps to standardise procedures in order to reduce the number of test methods, especially in the USA and Europe. In Germany there has been some successful harmonisation with the Fachnormenausschuss Krafflahzeuge (FAKRA) test procedure, DIN 75202 being widely used, while in the USA, the SAE J 1885 test is widely used. Harmonisation should result in some savings, because at present fabric producers supplying several OEMs must possess every machine necessary and these are expensive to buy and to run.

5.6.6 Abrasion resistance and associated factors

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

There are three main test methods for abrasion resistance in use: Martindale (using 12 kPa, 28 oz weight), Schopper and Taber which *very generally* agree with each other – but certainly not always, see Fig. 5.10. The three test methods actually represent different types of abrading motion as well as using different abrading materials. The Schopper machine operates with a reversing circular motion, while the Taber motion is a little more complicated with two circular wheels rotating in opposite directions. Martindale operates in a multi-directional manner, the abrading heads moving in a Lissajous pattern. The Taber uses an abrading wheel made from rubber/aluminium oxide abrasive particles (Calibrase), the Schopper uses fine emery paper, while the Martindale uses a standard grade of woven



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

wool. Many researchers regard the Martindale multi-direction action and use of wool as the abrading material as the most realistic of the three tests, but it does take substantially more time than the other two. To reproduce significant wear in actual use, a minimum of 50 000 Martindale rubs are necessary, taking about 16 hours to complete. In comparison, a similar Taber test only takes 15–30 minutes and a typical Schopper test requires 1–2 hours.

Abrasion resistance is influenced by the fabric construction, yarns used, finishes applied and amount of coating on the back. Yarns of higher dtex/filament generally have better abrasion resistance than yarns made from finer filaments. Highly textured yarns usually have slightly lower abrasion resistance than yarns with a lesser degree of texture. Excessive wet processing, prolonged dyeing or rigorous reduction clearing can all reduce abrasion resistance, and in some cases spun dyed yarns may have better abrasion resistance than yarns of the same shade, which have been aqueous dyed. Fabric construction can have a substantial effect on surface abrasion. Those constructions with long 'floats', or which otherwise provide points for frictional stress, have the poorest abrasion resistance. Fabric finishes can significantly improve abrasion resistance, by acting either as a lubricant in the abrading action, or as a barrier between the fabric and the abrading material. However, they are rarely used on automotive fabrics, because of the risk of fogging and also because they could lead to the development of unsightly or sticky deposits on fabric surfaces over a period of time. This is probably caused by degradation of the chemical by the heat, humidity and light radiation to which car interiors are subjected. In addition drops of water could lead to the appearance of 'tide' marks or discoloration. Certain waxes and silicones in particular must be avoided, because they can affect adhesion of coatings or materials during lamination. They can be applied after coating or lamination, but care is required because the heat or liquid involved in the finishing process can loosen the polymer or adhesive bond. After testing by the prescribed method, the abraded samples are inspected for wear or broken threads. A certain amount of wear is usually acceptable, but most OEMs will not accept a broken thread in car upholstery.

5.6.6.1 Frosting

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

5.6.6.2 Pilling

Also associated with abrasion resistance is pilling, which is the formation of little circular clusters of fibre on the surface of the fabric, produced as a result of the fabric being rubbed against itself or against some other material, see Fig. 5.10. Fibre ends become tangled and twisted together, sometimes with the fibre ends and broken threads of the material it is being rubbed against.[42–45] Unsightly pilling can occur where the seat occupants' clothing is perhaps more to blame than the seat fabric itself. This is sometimes referred to as 'foreign' pilling.[42] Fabrics constructed from spun yarns are significantly more prone to pill than continuous filament, and the problem is probably more pronounced with polyester than wool. Wool is an inherently weaker fibre and pills can break off from the fabric surface before the end of the test cycle. This does not always happen with polyester because of its higher strength, and the pills grow larger, become more conspicuous and unsightly, and unlike wool are present at the end of testing and are assessed. Thus, misleading results which do not reflect actual wear may be obtained.

Pilling can be minimised by chemical finishes, increasing the yarn filament thickness, use of higher twist yarns and by brushing and cropping of the fabric. However, any one of these factors may change the handle and other qualities of the material. Fabric can be tested for pilling using a pill box of the type designed by ICI which consists of twin wooden cubic boxes, each with sides about 25 cm long, the inside walls of which are lined with cork. Fabric samples are wrapped around rubber formers and placed inside the boxes, which are then rotated around a common axis for a measured length of time. The samples are assessed against masters and the degree of pilling assessed on a scale of 1 to 5, the higher the rating the less the pilling. In an alternative test method, the so-called Random Tumble Pilling Tester Method (ASTM D 3512), cotton fibres can, if required, be added as a source of foreign fibre. The Martindale tester is also used to assess pilling by subjecting the test fabric to cycles of, say, 1000 or more rubs and counting the number of pills.

5.6.6.3 Snagging

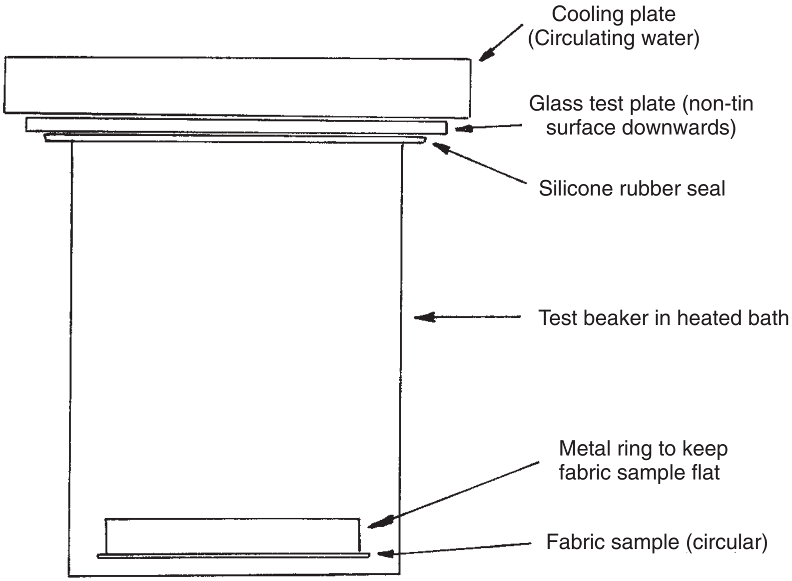
Snagging occurs when a sharp point or rough surface catches a thread in a knitted or woven fabric. Constructions incorporating long floats are especially prone to this problem. The thread is pulled out of the fabric forming a small loop on the surface, while the thread still in the fabric is stretched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

5.6.7 Fogging

Fogging is the mist-like deposit that forms on car windscreens reducing visibility and which is sometimes difficult to remove, even with soap and water. Fogging is caused by volatile materials vaporising out of *all* interior trim components, such as plastic foils and polyurethane foam, and not just the fabric. Modern polypropylene foils hardly fog at all, but PVC, if not formulated with suitable plasticisers, can fog quite badly. Fabrics, if not stentered well or scoured, can fog very markedly owing to the multiplicity of lubricants applied during dyeing, yarn doubling, warping, weaving, knitting and finishing. Because of the much larger surface area of yarn on the face, velvets or other pile fabrics can fog significantly. Results of chemical analysis of the fogging deposits have been published along with other findings.[46–52]

The fog test is carried out by putting a specified amount of fabric into a beaker, which is covered and sealed by a glass plate, see Fig. 5.11. The light reflectance of the glass plate is measured beforehand. Because the 'non-tin' side of the glass plate must face downwards towards the material being tested, which side is which must be labelled by the supplier. This glass plate is cooled by a metal cooling plate which rests on it, and cooling water is pumped through it at a specified temperature, usually room temperature. The beaker is heated at 90–110 °C for three to six hours, the actual conditions being specified by the OEM. After this time, the light reflectance of the glass plate is re-measured to determine the reduction in reflectance which has been caused by condensation of the volatile materials from the test sample. This is usually expressed as a percentage of the original reflectance, and a good result is generally anything over 90%, although some OEMs may accept less than this value. The three main test parameters, i.e. temperature of sample heating, time and cooling water temperature are specified by the OEM. The apparatus is calibrated by measuring the fogging obtained with DIDP (di-isodecyl phthalate), a plasticiser used in PVC, which should give a fog value of 76–79%, depending on the information supplied by the manufacturer, e.g. Merck. This check should be carried out periodically about once a month, but some test houses include a DIDP standard with every test batch.

Inter-laboratory reproducibility may not be satisfactory, and much discussion has taken place to standardise procedure in order to improve this.



Main Test variables are: Heated bath temperature
Cooling plate temperature
Length of test period

5.11 Automotive fabric fogging testing.

Cleaning of the glass plates is generally believed to be critical. A gravimetric method, which weighs the volatile deposits, has been put forward as more satisfactory, but it relies on a balance capable of weighing to five decimal places. Recent work has focused on the formation of crystals on the glass plate, which may still reduce visibility but give a high reflectance reading. Two test rigs are widely used, those made by Haake and by Hart, but the test specifications are written in such detail that self assembly is possible. Operative procedure is believed to influence the accuracy of the test substantially, and the recommended methods are detailed in the test specifications. A training video has been produced by the Industrial Fabrics Association International (IFAI) for SAE J1756. Fogging has assumed more importance recently and is related to the problem of malodours in new cars, both being associated with volatile materials.

5.6.8 Anti-static properties

The occurrence of static shocks when getting out of cars has been known for some time, and some OEMs require anti-static finishes on their car seat covers.[53–56] The static electricity is generated by the person's clothes rubbing over the polyester car seat cover, especially when he or she stands up to get out of the car. Some individuals are especially prone to static shocks, which are also influenced by clothes and shoes worn and the ambient air conditions inside the car. The polyester seat cover is hydrophobic, i.e. containing very little moisture to conduct away or help dissipate the static electricity. Anti-static properties are easily conferred on to the fabric by application of an anti-static finish by padding, or by foam coating, but these are not permanent and eventually wear off. Their efficiency is measured by surface conductivity methods and they work simply by their hydrophilic nature.

The conductivity meter actually measures surface resistivity in units of ohms per square. A resistivity of about 1×10^{10} ohms per square is considered a reasonable level of anti-static behaviour, but the lower the better. Padding a fabric with a good anti-static agent can easily give a figure of 1×10^7 ohms per square. The surface conductivity method has its limitations, and some researchers question its suitability for car seats. Some OEMs and research institutions, such BTTG and John Chubb Instrumentation, have developed whole chair tests using human subjects wearing specified clothing. Recently, the possibility of static electricity interfering with electronic equipment controls in the car has been raised, along with the possibility, in extreme cases, of its igniting petrol vapours.[55] There has been renewed interest in development work using conductive yarns such as Negastat and R. Stat. products which can confer permanent anti-static properties. These specialist yarns are very expensive, but only small amounts are required in a fabric to confer some measure of durable anti-static behaviour.

5.6.9 Stretch and set

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

5.6.10 Soiling and cleanability

These factors are assessed by the application of materials likely to be accidentally spilt on to the surface of car seat fabric. They are applied to test pieces of fabric in the laboratory and then cleaned off using a specified procedure. The degree of soiling left behind is assessed under a standard light source such as CIE (Commission International d'Eclairage) D65 (chosen as closely resembling natural daylight), and either compared to standard patterns or assessed using grey scales. Rating 5 of the grey scale records no noticeable staining, 4 records slight staining, descending down to rating 1, which records very significant staining. The soiling agents include materials such as chocolate, coffee, tea, ice cream, hair-dressing fluid and engine oil. A brand name or chemical type of soiling agent is usually specified for the tests to be reproducible. Anti-soiling seems to be an increasing concern, and there have been recent reports on the subject.[57,58]

The problem of 'linting', or the appearance of white specks of fibrous material on the car seat, is well known and is quite difficult to overcome. These 'lints' are not easy to remove by brushing, and tests have been carried out to minimise the problem using certain soil release agents. Associated with linting is 'minking', the removal of hairs from fur coats by abrasive action of the car seat fabric.

5.6.11 Environment and ageing

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

5.6.12 Air porosity and permeability

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

5.6.13 Car seat comfort

Many factors directly or indirectly influence car seat comfort, and much work has been done.[59–65] Thermal comfort has been discussed in some detail above, and everyone is aware of the thermal discomfort which is experienced in hot weather inside a car. The 'greenhouse effect' is primarily to blame, but the car seat contains thick layers of foam, which is an insulating material and acts like an additional layer of clothing in the restricted area inside a car. If the seat fabric is coated, this is going to restrict the evaporation of perspiration making the seat occupant thermally uncomfortable. Leather and especially PVC seat covers can produce very thermally uncomfortable seats for the same reason. For a short while some car seats were made by laminating a film of polyurethane to the fabric and sewing the car seat cover into a 'bag' into which was poured a liquid which reacted to form the solid foam inside. The film was needed to stop the liquid foam from seeping through the fabric before it reacted and became solid. This led to seats which were thermally uncomfortable because the film was a barrier to the passage of perspiration. If a film of higher permeability to perspiration, such as Gore-Tex or Sympatex, had been used the seats would have been more comfortable, but this was not generally possible because the higher specification material was much more expensive. As has been discussed, there are methods for measuring breathability of films, but more realistic tests are best carried out on the seat as a whole. At present, there are no requirements for water vapour permeability for car seat fabric laminates, although OEMs may test the seat as a whole for thermal comfort during development. Air conditioning in cars, however, is likely to alleviate this problem.

5.6.14 Odours in cars

This has become a problem in recent years, and test methods are being developed.[66–68] At present, some OEMs simply state that the fabric must be free of any unpleasant odours, while Ford have introduced an 'electronic nose' to detect and measure odours. Odours could be related to VOCs and would therefore have health and safety implications. They may in some cases be associated with coatings on fabric or carpets.

5.7 Flamability (FR) testing

5.7.1 General comments

The importance of FR has already been discussed in Chapter 2, and testing articles for accurate information on FR properties is essential. The correct terminology must be used, because sellers of products labelled 'fire-proof', 'flameproof' or even 'low flammability' may leave themselves vulnerable to legal proceedings. Only approved and defined terminology should be used, and reference should be made to the BS or ISO test that establishes the terminology, e.g. 'does not sustain flame' (BS 6336). 'Flame retardant' (FR) has come to be widely used as a useful general term. Because of both the legal and the moral implications, the articles offered for sale must pass the appropriate tests using the procedure set down. Needless to say, laboratory staff should be trained both in carrying out the FR test and in interpreting the results, and commercial test houses are generally validated and accredited in the UK by the National Measurement Accreditation Service (NAMAS). Many papers are available on FR testing and standards in domestic, industrial and transportation situations.[69–78]

5.7.2 FR properties of coated fabrics and laminates

A coated or 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 will have its own properties that must be determined by testing. The FR property of the plastics coating will be made more complex by the fabric construction, which may shrink back from an applied flame and not 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, become ignited and thus display very different FR characteristics. A resin formulation which may pass an FR test on a particular fabric substrate, if it is applied to another fabric which in fact is less flammable than the first, may in the second case burn and fail the test. The reason could be that the supporting fabric of low flammability does not shrink back, or melt and drip away, but instead stays rigid and supports the resin, allowing it to burn. Foam burns more readily than solid material because of the greater surface area available for a given weight.

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 that 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. The factors mentioned above add further to the complexity of FR testing which both research and quality control staff are only too aware of. The FR properties of a coated fabric are thus influenced by the FR nature of the base fabric and by the resin material and its formulation, i.e. FR chemical concentration and type. The FR properties of a coated fabric will also be influenced by coating technique, resin add-on, penetration and the many factors and inter-relating factors which depend on these variables, including fabric handle, drape and flexibility. Mention has already been made in Section 2.8.1 of a statistical study of the effect of coating parameters on FR properties of a cotton fabric coated with a phosphorus FR compound.

5.7.3 FR testing of products

Coated and laminated fabrics which require FR testing include domestic upholstery, curtains and carpets. Any material used in transportation applications or buildings open to the general public is likely to be required to pass stringent FR tests. Flame retardancy requirements are especially important in aircraft, and recent train disasters involving fires in tunnels have highlighted the need for rigorous FR standards for passenger trains. The FR properties of seat covering materials, especially in aircraft, are tested very rigorously because of the foam material used beneath. If ignited, copious potentially toxic fumes may be emitted, but low FR foams are now also used. Fireblocker materials are used as a barrier, and tests are carried out on the whole seat assembly. Fireblockers which are made from fibres of high inherent FR properties, such as Nomex, Panox, PBI and Inidex, are now being used increasingly in trains and coaches. These fibres are, of course, very expensive and could not be used in private cars. In fact the FR requirements of car seat fabric are not especially high, presumably because the risk of a fire inside a car is probably quite low and there are at least two doors for a rapid exit.

For car seat fabric the test used by OEMs is the USA standard FMVSS 302, a horizontal burn method, but the test performance standard required varies according to the OEM. Generally, this test is not especially difficult to pass, but sometimes an FR coating is needed on the fabric or an FR foam is necessary. In certain cases, the fabric alone could pass the FR test, but FR chemicals are required in the coating to reduce its flammability. Sometimes both FR coatings and FR foam are required to satisfy the test standard. Flame retardant chemicals both in the foam and the coating add to the cost, and for commercial reasons the concentration levels in both foam

Table 5.6 Selection of FR test standards and methods associated with coated and laminated fabrics

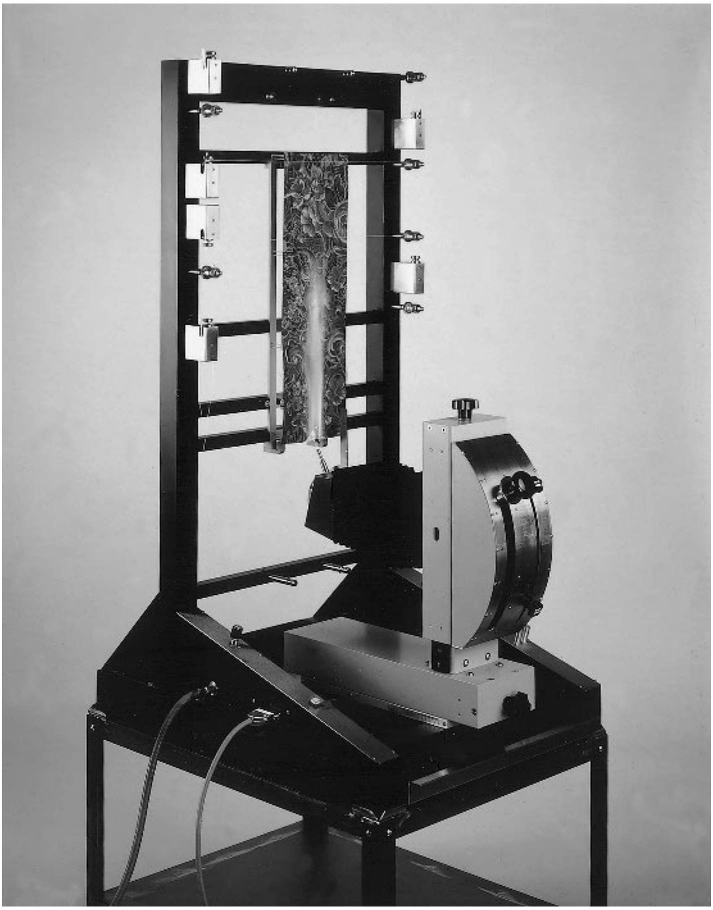
Product	Standard	Comments
Clothing	BS 6249 Part 1:1992	Performance standard based on Test 2 method in BS 5438:1976, three flammability indices
	BSEN 469:1995	Firefighters' clothing
	BSEN 470-1:1995	Welders' clothing
	BSEN 531:1995	Industrial workers' clothing
	BSEN 532:1995	Protection against heat and flame
	BSEN 533:1997	FR fabrics
Furnishings	BS 6807:1986	Ignitability of mattress and bedding materials
	BS 7176:1995	Spec for resistance to ignition of upholstery for non-domestic seating
	BS 7177:1996	Spec for resistance to ignition of mattresses, divans and bed bases
	BS 5852 Part 1:1979	Test for ignitability – different sources for different articles – fabrics coated for FR are subject to water soaking before testing
Upholstered furniture (domestic)	BS 5652:1979 BS 5652:1982 BS 5652:1990	Test methods for ignitability and performance standards. Domestic furniture must meet certain specifications in the Furniture and Furnishings (Fire) (Safety) Regulations 1988/89. Covers beds, sofa-beds, futons and other convertibles, nursery furniture, furniture in new caravans, etc, but not carpets and curtains
Curtains and drapes	BSEN 1101:1996	Burning behaviour of curtains and drapes
	BS 5867:Part 2:1980	Ignition of vertical specimens by small flame
Textile floor coverings	BS 4790:1972	Hot nut test
	BS6307:1982	Methenamine Tablet test
	ISO 6925:1982	
	BS 476 Part 7	Surface spread of flame
Tents and marquees	BS 6341:1983	Camping tents – 10 grades – flammability requirements
	BS 7157:1989	Ignitability of fabric used in large tent structures
	BS 7837:1996	Spec for FR properties for marquees and similar
Motor vehicle seat coverings	FMVSS 302	Each manufacturer has their own performance specification

Table 5.6 (*Continued*)

Product	Standard	Comments
Automotive carpets		ASTM D 4723-90 method and specs for heat and flammability ASTM D 2859-96 FR test method
Pile fabrics	BS 4569:1983 (1990)	Ignitability of fabrics with pile on surface (surface flash)
Ventilation ducts	BS 476-24:1987	Determination of fire resistance
Railways	BS 6853:1987	Code of practice for fire precautions for railway passenger and rolling stock
	BS 5852, crib 7	Railway seats in UK
	UIC 574-2 DR	International Union of Railways Specification
Marine	IMO Regulations e.g. IMO Resolution A471 (XII) for fire resistance	
Aircraft	FAR 25 853b	Ignition and propagation
	FAR 25 853c	Paraffin burn test and weight loss
	ATS 1000.001	Smoke opacity and toxic gases
Other tests		
	NBS Smoke Chamber	Smoke release
	NFX 70-100	Test for a series of toxic gases
	OSU 65/65	Ohio State University test for heat release

N.B. These tests are a selection and a summary. Certain tests are in the process of revision, and standardisation of test methods in Europe is being carried out.
For further information see References 69–77 especially the papers by Eaton (69), Johnson (71), and Bagnall (75) and the textbook by Troitzsch (76).

and coating are kept to a minimum. A fabric coating can cause stiffening as well as adding to the overall weight and cost. Flammability is assessed by the burn rate, which is the distance in centimetres burnt in one minute. The burn rate regarded as acceptable varies according to the OEM. Door panel fabric is usually assessed on the actual door panel itself. Variations in flammability test results are sometimes caused by uneven up-take of fabric finishes, or by variations in scour or stentering. Stentering may influence the flammability of stretchy knitted fabrics, because it could affect the manner in which the fabrics shrink away from the flame. Some OEMs require that pile fabrics be brushed in a particular way before testing.



5.12 Rhoburn flammability tester, designed to measure the ease of ignition and flame spread of vertically orientated textile materials. Photograph supplied by James Heal and Company Ltd and reproduced with kind permission.

Coated apparel, apart from specialist protective clothing, does not generally have to pass FR tests, presumably because it is used mainly out of doors where fire risk is minimal. Certain medical products need to have FR properties, because they may be used in atmospheres rich in oxygen. Table 5.6 supplies details of a selection of FR tests applied to coated and laminated fabrics.

5.7.4 FR test methods

Flame retardancy tests now take the form of testing materials for ease of ignition, rate of propagation of flame, smoke generated and toxicity of

5.13 The BTTG Fire Technology Services RALPH manikin for full flame envelopment conditions. With each test, a burn injury prediction print-out is produced, providing information on first and second degree burn levels to allow users and garment manufacturers to evaluate performance under the most extreme of conditions. Fire-fighters' garments, FR coveralls for the off-shore oil industry and military clothing have been tested with this apparatus. Photograph supplied by BTTG and reproduced with kind permission.

fumes, opacity of the smoke and heat generated by the burning, see Fig. 5.12 and 5.13. The formation of burning debris and falling droplets is also important in some circumstances, such as in buildings. In many fire disasters, more people have died as a result of heat stress and suffocation by toxic fumes. Dense smoke can disorientate people and make escape routes difficult to see. In a real life situation, the FR tests should establish whether the persons concerned have sufficient time to evacuate the building, vehicle or vessel and reach places of safety. However, testing the individual article cannot always accurately establish the likely outcome in the event of a fire in a real life situation. Tests involving whole assembles of articles are carried out in research projects, and 'whole room burns' are sometimes conducted to observe what happens in actual domestic situations. The actual burning nature depends on the FR characteristics of the individual items, their position relative to each other, and on many other interrelating factors, including air supply and airflow and how these are affected by the positioning of furniture or other items such as doors or windows. No two fires are alike which makes the whole subject extremely complex.

For research and development, the LOI is a useful way of evaluating inherent FR properties of materials, because a quantitative figure is given. The amount of oxygen in the atmosphere is about 20% and this is a baseline. Unmodified cotton has an LOI of about 18%; treating with Pyrovatex or Proban can increase this figure to about 28–30%. Regular polyester has an LOI of about 21%, FR modified polyesters about 28%, whilst aramids have LOIs of up to 33%.

5.8 Specialist testing for chemical and biological hazards

The ASTM standard, 'Test Method for Resistance of Protective Clothing Materials to Permeation by Liquids and Gases' (ASTM-F739-91) and the 'Standard Guide for Test Chemicals to Evaluate Protective Clothing Materials' (ASTM-F1001-86) are used to evaluate material to be used in chemical protective clothing. ASTM-F1001-86 lists about 20 chemicals, including the potentially dangerous substances sodium hydroxide, concentrated sulphuric acid, nitrobenzene, and the gases chlorine and ammonia. Amongst the important factors to be considered in the test method is the 'breakthrough time', which is the time taken for the chemical agent to permeate through the test material.

In the 1980s a number of accidents occurred involving hazardous chemicals. This led to Federal involvement in the production of comprehensive standards to improve the performance of chemical protective clothing. The ASTM began to work on comprehensive specifications to document performance and manufacturer reporting requirements. The National Fire Protection Association (NFPA) set up a technical subcommittee and a draft ASTM standard, 'Standard Guide for Minimum Documentation and Test Methods of Chemical Protective Clothing', ASTM F23.50.03 (Z1416-Z), resulted. Three standards relating to vapour protective suits, liquid splash suits and suits for non-emergency and non-flammable hazardous chemical operations (NFPA 1991–3) were also issued and took effect in 1990. However, the quest for further improvements continues, and there are papers in the literature.[79–85]

Barrier textiles are also required in the medical and food industries against contamination and infection by micro-organisms, and the film and nonwoven manufacturers are putting much effort into both the development of new products and more effective means of testing. There is risk of infection of medical workers by contamination from patient's skin and blood, which is especially relevant with the presence of the AIDS virus. Test methods with a high standard of reliability are essential. However, protective clothing should be comfortable to wear and should not restrict movement. The EU is funding a project called BIOBAR for increased safety and health under its Standards, Measurement and Testing Programme, specifically to assess standard requirements and improve test methods for barrier materials to be used to protect people and goods against micro-organisms. There are four separate tasks which investigate the resistance of barrier materials to wet and dry contact with micro-organisms and also wet and dry airborne contact. BTTG is playing a leading role in the consortium of six research organisations.[84]

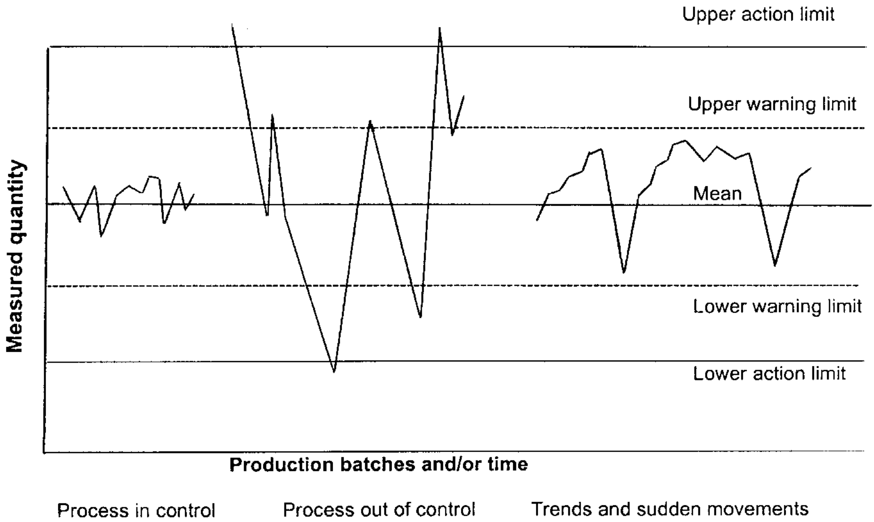
5.9 Recording of results – statistical process control

5.9.1 Process control charts

All results must be recorded and filed for a reasonable length of time so that if any problems occur in downstream processing or there is a customer complaint, the incident can be investigated. The results of individual tests are best plotted on a SPC chart where it is possible to see at a glance how consistently the product is being produced. Sudden changes in test results, trends and recurring cycles can sometimes give clues about what is happening if there is a problem, see Fig. 5.14. If the results are within acceptable limitations, it is known that the process is in control. If results begin to deviate significantly from the mean, this may be taken as a warning that something may have happened, and corrective action may be needed. Warning limits can be set, for example at the mean value plus or minus two standard deviations, while 'action' limits may be set at the mean plus or minus three standard deviations. This technique allows quality to be checked while the component is being made and not after completion, when it is usually too late. The philosophy is not one of detecting faults after production has been completed, but rather one of preventing their occurrence during production, as a means of continuous improvement with the objective of achieving zero defects.

5.9.2 Fabric examination

Every metre of coated or laminated fabric must be visually examined before it leaves the factory to go on to the customer or to the next stage of manufacture. Samples of each production batch, or whatever samples are



5.14 Statistical process control. This provides a method of detecting faults during production, as a means of maintaining continuous improvement with the objective of achieving zero defects.
N. B. Warning limits can be mean plus or minus 2 × standard deviations. Action limits can be mean plus or minus 3 × standard deviations.

decided with the customer, are sent to the laboratory for testing. Trained examiners inspect the material for width, shade/pattern regularity, visual coating or lamination faults, e.g. tackiness, delamination, oil marks or other soiling, weaving or knitting faults, handle/drape/stiffness and any other faults which could cause complaints from customers or problems in downstream processing.

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

Examination of incoming fabric before coating and lamination may or may not be carried out; the responsibility for this is generally placed on the base fabric supplier. Automatic on-line examination systems can pick out basic construction faults, tears, creasing, resin add-on, etc., but more sophisticated apparatus is necessary to identify every possible fault, especially pattern distortions.

5.10 Investigation of faulty material and customer complaints

5.10.1 Introductory comments

This subject comprises three categories: investigation of a fabric fault arising from within the coating or laminating factory; investigation of material returned from the immediate customer such as the garment maker or auto seat maker; and last, investigation of a complaint from the general public – the ultimate customer. In the last two mentioned situations, the first step is actually to confirm the identity of the material – was it actually produced in *your factory*. Is the fabric construction, colour, fibre type and chemical type of coating within your range of products?

The competent technologist will confirm everything for himself or herself. The simplest – even bizarre or banal – reason may be responsible. Every factory manager has their own anecdote which may or may not be true, but can draw attention to what is actually possible. One incidence of mass contamination of coated material turned out to be due to the cleaner mistakenly putting his floor sweepings into a Banbury mixer, believing it to be a dustbin. In another incident, a short operative, not tall enough to empty the adhesive powder from the sack into the hopper of a screw extruder, put the plastic sack in together with the contents and extruded the plastic sack in addition to the hot melt adhesive. Frequently the technologist is handed a problem which has *just started*, the base fabric is the same and it has been processed under *exactly* the same conditions – absolutely nothing has changed! Unfortunately, costs are very tightly controlled in modern industry. If a supplier admits responsibility for a particular fault or evidence is available to show that they are responsible, debit notes or even litigation for damage costs may follow. Even different departments in the same factory, each with their own individual budget, may be reluctant to admit responsibility. These factors may make the investigating technologist or quality control manager's job a little more difficult. However, it is the responsibility of higher management to ensure that accurate information is available to technical staff, because the sooner a fault is actually cured, the better it will be for all concerned. If information is concealed, the problem is likely to recur, entailing more cost in lost material and staff time.

There is no substitute for actually seeing the process at first hand. However this should not just be a brief glance, but a thorough process, actually asking the operative what he or she actually does, irrespective of what is in the standard operating procedure. The first step is to confirm that the coating has actually been produced in the factory and that it is not a case of mistaken identity, the material in fact having been produced somewhere else. The technologist should confirm details and fabric description for him or herself, leaving nothing to chance. The starting point is fibre type; is it nylon 6, nylon 66 or polyester? These three fibres account for the base fabric of well over 90% of the more common coated fabric products. Melting point determination will identify nylon 6 which melts at around 215 °C – nylon 66 and polyester melt around 260 °C. Nylon 66 should be easily stained with an acid dye, but if the fabric is already dyed to a dark shade the outcome of this test may not be easy to establish, in which case the work should be given to a fibre identification laboratory.

5.10.2 Delamination

Probably the most common problem in coated and laminated fabric production is investigating the cause of delamination of the product or insufficient bond strength. The importance of clean fabric and the factors affecting adhesion have been discussed earlier, and efforts should be made to obtain a sample of the base uncoated fabric, ideally from the same piece as the coated material undergoing investigation. Usually this is difficult, and it is only possible to obtain a piece from a 'typical' production. This is better than nothing and it should be examined for excessive amounts of finish, although it must be said that it may be difficult to draw any firm conclusions from a 'one off' incident. A laboratory coating can be carried out on the material and tested to see if it will show the same fault, and to examine closely if the resin 'wets' the fabric without any difficulty. If the problem is major, affecting a large amount of fabric, or recurrent (as problems of this type usually are), a more detailed investigation is justified. In this case, the fabric finish or lubricant content of about ten base fabric samples from different production batches from the dyeing and finishing factory, should be determined to see if it varies significantly. This exercise at least establishes the 'typical' level and may be useful for further incidences of delamination. Sometimes it is possible to establish a relationship between fabric finish content and coating or lamination adhesion levels (peel bond). Estimation of lubricant level needs careful consideration, however, prolonged extraction using solvent in a soxhlet apparatus (similar to a reflux condenser) will extract everything on the fabric, including oligomer in the case of polyester, and also some dyestuff. There are milder methods of doing this, but it may be worthwhile developing a simple 'in house' method, which is specific to a particular set of circumstances and requirements. A very simple technique is to wash 5 g samples of fabric in water (made alkali with 2 g/l sodium carbonate) for three minutes at 100 °C, weighing before and after. Care must be taken not to lose fabric by fraying, and weighing must be done after careful drying at room temperature in a conditioned atmosphere. The difference in weight is the 'level' of lubricant. Drying should not be carried out in an oven in this case, because heating in an oven will drive off further finishes and lubricants, depending on the temperature and time in the oven. Weighing samples before and after oven treatment at specific temperatures can be the basis for alternative 'in house' tests.

Fabric, especially polyester, generally requires some lubricant or anti-static finish on it for it to be processed efficiently. Static is annoying and can be quite painful to operatives, but it can also influence quality and production efficiency. For example, fabric charged with static can cling to the sides of machines causing creasing (and can also attract dust). Excessive anti-static agent is quite likely to cause poor adhesion or delamination, and it has been known for a finishing factory to increase anti-static finish levels to reduce static, thus giving rise to problems of delamination – curing one problem whilst causing another! In most cases, only a fairly low level of anti-static agent is necessary to overcome static problems, and this low level should have minimal effect on peel bonds. The best solution to the problem, however, is installation of anti-static bars after every main roller in both the finishing works and the coating and lamination plant. This can be expensive, but the most efficient bars can be restricted to those points where they are most needed, i.e. just before lamination rollers.

Lubricant levels can sometimes be checked very quickly by measuring the surface resistivity with a static meter. Many fabric lubricants are hydrophilic or, being water based, contain some hydrophilic material in them. Anti-static agents are, of course, strongly hydrophilic. The result obtained can be anything between approximately 1×10^{13} to 1×10^{6} ohms. A high level, say 1×10^{11} and above probably indicates low lubricant content, while very low levels, say 1×10^{8} and below, show a high anti-static finish level. The simplest way of *comparing* fabric finishes is by dripping water on the fabric surface. The result of course depends on the finish itself – it may be hydrophilic or hydrophobic – but this very simple test is sometimes useful because it establishes a *difference* between two fabrics which should be the same or are claimed to be the same. Another, very simple qualitative test is to try to stick office adhesive tape on to the fabric being examined and compare the ease with which it sticks with a fabric known to have given excellent or satisfactory peel bonds. The laws of adhesion apply to all adhesives, and if there is a problem sticking office adhesive tape to a particular fabric, then there could well be a problem in coating or lamination production.

In the case of a coating made up from two or more layers, the first step is to examine whether the delamination is actual separation from the base fabric or if it is interlayer delamination, i.e. one layer of coating separating from another. In the latter case, the reason is probably insufficient heat in application of the final layer, i.e. not a high enough temperature, or running the machine too fast which reduces dwell time. This particular problem is usually associated with poorer abrasion resistance, because the resin has not had sufficient heat to crosslink properly. Have the correct machine settings, as specified by the technical department, been used? Was there a stoppage or a breakdown and was coating or lamination restarted (owing to production pressure) before the ovens reached the correct temperature? Are all of the oven bays working correctly? If these enquiries draw a blank, attention must now turn to the compound itself. Did it contain everything specified in the correct amounts – especially the crosslinking agent or catalyst (if they were specified)? Other factors which may cause poor adhesion are the substrates being disturbed or moved before the bond is formed – a roller or rollers not running true may contribute to this. Nip rollers may not be parallel or pressure may vary across the width.

5.10.3 Contaminants

Another frequent problem is contaminants or marks on the coated fabric. These problems are usually due to lapses in housekeeping – but the technologist is usually asked to trace the source. Sometimes it can be established that soiling – frequently oil marks – was already on the fabric before it arrived in the coating or lamination department. Coating or laminating over an oil mark is likely to lead to poor adhesion in that particular area, and examination of peel bond could be a way of providing evidence that soiling was already on the fabric beforehand. Solid contaminants are also a problem, but are generally more easy to investigate – is it solid resin or some other substance? Chemical analysis should provide the answer quite quickly, the problem is usually explaining how it got there. Different samples of oil taken from different parts of the factory, including the weaving or knitting department, can be characterised by IR spectroscopy, or perhaps a chromatography technique. Comparing an analysis of oil taken from a contaminated area with the reference samples should quickly identify the origin. This could be extended to sampling oils in supplier factories.

Solid resin could be the deposits which sometimes build up on the reverse side of a doctor blade or on the insides of tubing or piping. Water-based resins are easy to clean until they dry, and then the only effective way is by manual cleaning. Deposits can build up unnoticed in pipework until they become sufficiently large to breakaway of their own accord. 'Foreign objects' such as fabric 'fly' or dust can cause problems, especially if there is a draught in the area. Resin can sometimes get on to the stenter brushes which are used to push fabric edges on to the stenter pins. This resin will dry, build up on the brushes and eventually become detached as a powder or small deposits; these will fall on the surface of the coated fabric as the brushes rotate. During flame lamination, ash may build up on the burner and drop on to the fabric. Some qualities of foam are more prone than others to causing this and, if this is known, suitable precautions should be taken.

5.10.4 Related faults

Many fabric faults are related to each other. In coated water-resistant protective clothing fabric, poor hydrostatic head is usually associated with low resin add-on, delamination or poor abrasion resistance of the coated surface. The same factor – insufficient heating in the last layer of coating – could cause all three faults. In flame lamination of automotive fabrics, laminates which are thicker than normal are frequently associated with poor peel bond, because of low burn off or ineffective nipping together. Stiffer than normal laminates are sometimes associated with discoloration or, if it is a raised fabric, with pile crush. All of these faults could be related to excessive heat. Sometimes during wear, a garment is rejected because of leaking through a seam which has not been taped properly. This may be due to some contaminate on the coating surface, or perhaps to some additive included in the top layer as a detackifier but present in excessive amounts. As a matter of interest, it can sometimes be difficult to establish where the water is actually coming into a garment. Sometimes a tape may be leaky at the top of a garment, but the water appears near the bottom, having run down the seam. One garment manufacturer has referred to this as the 'drain pipe effect'.

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6

Coating and laminating effects on the environment

6.1 Introduction

All human activity has some effect on the environment and the coating and lamination industry is no exception. The main effects are effluent and emissions to atmosphere during manufacture and eventual disposal of the finished article. The problems of effluent and polluting emissions to atmosphere, including VOCs, are gradually being addressed, with more effective methods of abatement and more environmentally friendly materials and methods of processing, but there is still much to be done. Coating and laminating factories are generally service industries to others, such as the clothing, automotive, furniture and carpet industries, and as such may not be directly involved in recycling and disposal issues. However, we are all living on the same planet, and the environmental issue of global warming, together with the effects of climate change and rising sea levels, affects everybody and should be the concern of all. In addition, certain chemicals are known to be harmful to human health, and others are destroying the ozone layer in the upper atmosphere. This high level ozone filters out the harmful UV radiation which contributes to skin cancer. These too are survival issues, which must be addressed.

All industrial processes require energy, generated chiefly by the burning of coal, gas or oil. All are non-renewable resources and all produce carbon dioxide and, especially in the case of coal, other harmful emissions. Many raw materials used in the coating and lamination industry, both base fabrics and coating polymers, are derived from oil. Coating and laminating thus have an effect on the environment by the depletion of non-renewable resources and by the generation of carbon dioxide, the main 'greenhouse' gas causing global warming, see Section 6.2.1.

There was a sharp increase in public awareness of environmental issues during the 1970s and 1980s, and this has been reflected in increasingly stringent UK legislation. In addition, the EU, since the early 1970s when it first adopted a formal environmental policy, has passed well over 200 laws, and further impetus was applied by the 1987 Single European Act. This act demands that full account of the environment and of the principle of 'sustainable development' is taken whenever Community policy is put forward for legislation. The term 'sustainable development,' which can be defined as 'the objective of meeting the needs of the present without compromising the ability of future generations to meet their own needs', was first put forward in the 1987 Brundtland Report, *Our Common Future*. This document was produced by a UN Conference on Environment and Development (UNCEO) and was chaired by Gro Harlem Brundtland. A European Environmental Agency has been set up in Copenhagen to provide independent, reliable, objective and comparative information on the state of Europe's environment. This unit publishes periodic reports on the state of the environment, and is examining a range of issues including air quality and nature conservation. The agency is unusual for an EU institution because it includes some non-member countries such as Norway and Switzerland.

Both the EU and the UK government have published reports defining their interpretation of and their strategies for achieving sustainable development. Most large companies want to appear environmentally friendly and socially responsible and to show that they are in agreement with the principle of sustainable development. Indeed, some have declared ethical policies, and many now issue annual environmental reports and are either ISO 14001 certified or EMAS (Environmental Management Audit Scheme) accredited, or are working towards this. In addition, an increasing number are assuming 'product stewardship' responsibility for the impact of their products on the environment based on life cycle analysis (LCA). The general public worldwide is now aware of, and concerned about, the environment, and evidence of this is the existence of over 2600 environmental organisations in more than 200 countries of the world.

As living standards increase, the populations of the world have higher disposable incomes, more leisure time and more consumer goods will be produced. There is likely to be increased depletion of the world's resources and more waste generated. Environmental problems are going to intensify, because increased living standards produce more pollution as summarised by Meadows and his co-workers[1] in the equation:

$$\text{impact on environment} = \text{population} \times \text{affluence} \times \text{technology}$$

All these three dependent factors are increasing, and without drastic action an environmental disaster seems inevitable. The management of waste is a formidable problem, and legislation has been passed to control means of disposal. However, the solutions are by no means clear, and debate continues about the best overall answers, taking into consideration environmental impact, effect on human health and social and economic factors. The existing situation in each country of the world is different, and each has its own particular needs. However, the overall guiding principle, agreed by everyone, to protect the environment is to 'reduce, re-use, repair or recycle', and actual disposal of waste should be a last resort. The issues of recycling and methods of disposal involve controversial factors that need careful examination.

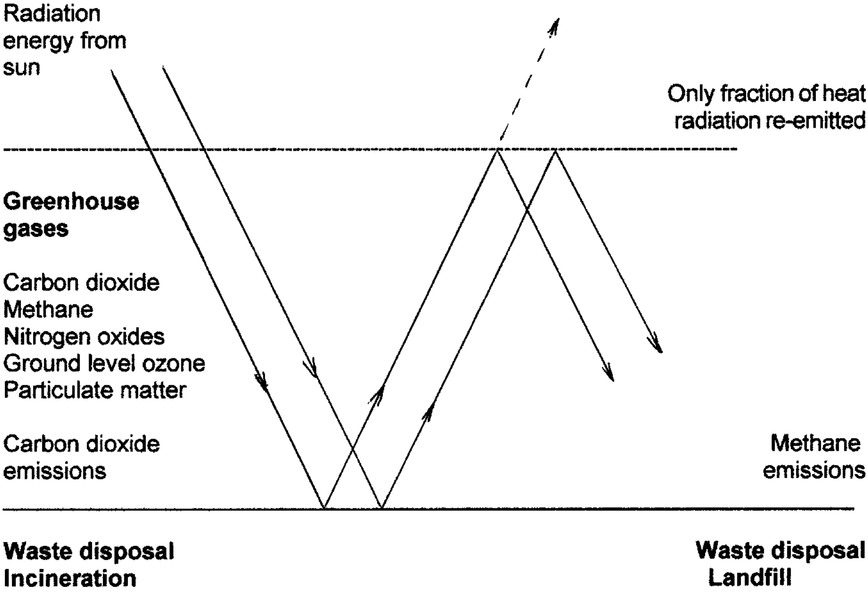
6.2 The effects of pollution

6.2.1 The greenhouse effect and global warming

Human life depends on the 'greenhouse effect', which is caused by the presence of certain gases and water vapour in the atmosphere. If they were not there, the surface of the Earth would be about 30 °C lower than it actually is. Small changes in their concentration are believed to cause changes in the surface temperature of the Earth. It is a very delicate balance, because an increase in surface temperature of only 1 °C is thought likely to change the world's ecology and cause very significant changes in climate and sea water levels.

The greenhouse effect happens because the Earth's atmosphere and surface retain heat. The atmosphere as a whole, including greenhouse gases, allows sunshine, made up of both short and longer wavelength radiation, to pass through to heat the Earth's surface. The warm Earth then radiates heat back, but this new heat radiation is at a longer wavelength, some of which cannot pass back out through the greenhouse gases to outer space. Instead, the greenhouse gases are heated up by this radiation energy, thus retaining the heat on the Earth and giving rise to global warming, see Fig. 6.1. The main greenhouse gases are carbon dioxide, methane, nitrous oxide, ozone and CFCs (fluorine compounds used in aerosol sprays and refrigeration but now banned by the Montreal Protocol). Particulate matter also contributes to global warming.

The amount of carbon dioxide in the atmosphere is increasing at the rate of about 0.5% every year, and motor vehicles are responsible for 15% of the world's total carbon dioxide emissions. Research shows that, since the middle of the nineteenth century, increased amounts of greenhouse gases have raised the average global temperature by about 0.5 °C. If greenhouse gas levels continue to increase at the rate expected, a further warming of about 1.5 °C within the next 40 years could be caused, with serious effects on global climate.[2] Global warming, in reality excess global warming, is therefore the concern of every nation on the Earth. Some researchers believe that the process has already started with extreme and unusual weather, such as the severe winter in Canada during 1997/98, the damaging



6.1 The 'greenhouse effect'. Global warming causes changing weather patterns and rising sea levels. Incineration of solvent fumes and emissions from coating and lamination operations must be carefully controlled and abatement of fumes is essential. All incineration processes, including municipal waste disposal, produce carbon dioxide, the main 'greenhouse' gas.

storms in Western Europe in 1999 and the heavy rain causing flooding in Africa and England in 2000 and 2001.

World leaders from 160 countries met in 1992 at Rio de Janeiro to discuss global warming. At a second meeting held at Kyoto in 1997, the general target was set for developed nations to reduce their greenhouse gas emissions by 5% below 1990 levels by the years 2008–2012.[3] Within the same time frame, the EU was committed to reducing emissions of six greenhouse gases by 8%, and the UK agreed to reduce its emissions by 12.5%. Although carbon dioxide is the chief greenhouse gas, responsible for approximately 75% of global warming, methane, nitrous oxide and ozone, in fact, have a far greater effect than would be expected from their relatively low concentration.[4] Methane gas is 30 times more effective at retaining heat in the atmosphere than carbon dioxide and accounts for 20% of global warming. Some CFCs are 17 000 times more effective than carbon dioxide, and if their use is unchecked they could account for 33% of global warming by the year 2030. To add to this, VOCs under the action of sunlight can react with nitrogen oxides to produce photochemical oxidants which have greenhouse effects. The control and reduction of greenhouse gases is, therefore, one of the most important issues that has ever faced the human race.

6.2.2 Air pollution

Harmful gases or vapours and solid particulate matter cause air pollution. There are many air polluting gases which are harmful to human, animal and plant life, but the main ones are oxides of sulphur, carbon monoxide, hydrocarbons and oxides of nitrogen.[5–7] The last three are present in significant concentrations in car exhaust fumes, although sulphur is being phased out of petrol and diesel. Particulate matter is also present in car exhaust fumes, especially those from diesel engines. The catalytic converter has reduced pollution, but older cars not equipped with them are still on the road. Oxides of sulphur, produced mainly from industrial burning of fossil fuels, give rise to acid rain; this is harmful to human health and also damaging to agricultural crops, vegetation and materials including buildings. Oxides of nitrogen contribute to acid rain, and produce adverse physiological conditions including eye and throat irritation if present in high concentration. Carbon monoxide is toxic to human and animal life, because it combines with haemoglobin in the blood resulting in less oxygen being carried to body organs, heart patients being especially vulnerable. Hydrocarbons, VOCs and oxides of nitrogen are the main constituents of traffic smog and under the action of sunlight they produce ozone, which is an eye and throat irritant. Their ability to create ozone is measured by their photochemical ozone creation potential (POCD). This ozone should not be confused with the UV filtering ozone layer, which is several miles above the Earth's surface. In addition, all combustion processes involving organic compounds produce carbon dioxide, the chief greenhouse gas.

6.2.3 Particulate matter

Particulate matter is mainly soot (carbon) in a wide range of particle sizes, but the most harmful to health are those which are smaller than 10 micrometres in diameter.[8–11] These small particles do not settle rapidly as dust, but stay in the air for long periods and are, therefore, more available for breathing into the human body. The American Environmental Protection Agency classified these particles as PM10s (particle matter less than 10 μm), and PM10 pollution is the total weight in micrograms of all particle matter of 10 μm in diameter or less contained in one cubic metre of air. In the USA the legal limit is 50 μm of PM10 per cubic metre of air as an average in a year.[10] Many cities of the world have peak PM10 values of 100–200. Particle size is important because particles larger than 10 μm penetrate no further than the nose or throat, but those smaller than 5 μm can enter the bronchial tubes at the top of the lungs, and the smallest, 2.5 μm and less, can penetrate into the deepest (alveolar) lung tissue where gas exchange occurs between the air and blood. If soluble, the particle matter enters the blood stream; if not soluble, it may remain in place for months or years. Particle matter is believed to be the cause of bronchitis, asthma, other chest and breathing conditions and to contribute to lung cancer. In the UK motor vehicles are responsible for 26% of PM10s.[12]

6.2.4 Land and water

Pollution of waters by the textile industry is caused by manufacturing processes such as dyeing and finishing and the washing of pesticides from cotton. Toxic liquors will harm marine life and could be harmful to humans on beaches. Pollutants are broken down chemically and biologically in the water, but both mechanisms require action by the dissolved oxygen in the water. This reduces the amount of oxygen available for fish and other marine life. Measures of these effects are the oxygen demand indices, biological oxygen demand (BOD) and carbon oxygen demand (COD).

Disposal of industrial waste by landfill is one of the least attractive options for a number of reasons, not least the appearance of such sites. Decay of organic substances results in the formation of methane gas which contributes to global warming. There is also the risk of explosion and of uncontrollable fire. Leachate from landfill could carry toxic materials including heavy metals into underground waters, which may in turn contaminate rivers and even drinking waters. Heavy metals such as lead and mercury accumulate in the body until present in sufficient quantity to act as poisons. Lead is believed to cause damage to the brain and to the central nervous system, mercury also affects the central nervous system, while cadmium is believed to produce adverse bone conditions.[13,14] Heavy metals were once widely used in PVC stabilisers and, although being phased out, they are present in articles which are still in use and which will need to be disposed of at the end of their working life.

6.3 Environmental legislation

The earliest environmental laws in the UK were passed during the thirteenth century to control the burning of coal. However, times change and accepted standards become more demanding with the increase in the quality of life. Environmental regulations have become stricter to meet new circumstances and, in addition to UK law, there is now EU legislation, which takes the form of directives and regulations. Directives are guidelines to be used by individual countries to form their own laws, while regulations are themselves legislative acts which apply across the EU without further action by individual countries. The EU in 1973 (then called the EEC) started the mechanism for programmes of action to reduce pollution and nuisances, to tackle environmental problems caused by depletion of natural resources, to promote education and awareness of environmental problems, and also to improve the natural and urban environment. Since this date the EU has been one of the leaders in the world community in protecting the environment.

There are also UN environmental initiatives, through their Environmental Programme (UNEP – founded 1973), which include the Montreal Protocol in 1987 to protect the ozone layer, and the decisions taken at the 'earth summits' at Rio de Janeiro and Kyoto. The UN was also instrumental in setting up the Convention on long-range transboundary air pollution, adopted in Geneva during 1979 and which came into force in 1983, to reduce transboundary air pollution over Europe and North America. The main concern at the time was acid rain over Scandinavia, but the Convention now also targets other pollutants including heavy metals and VOCs which have transboundary effects. Some scientists believed that emissions from UK power stations contributed to the Scandinavian acid rain.

In addition to EU and UN initiatives, there have been since 1984 meetings of countries which border the North Sea to discuss steps to reduce the build up of toxic chemicals and other pollutants in this area.[15] Measures agreed at the Third North Sea Conference in 1990, to cut levels of a number of specific chemicals and to treat sewage more effectively before discharge, became legally binding. Switzerland, which has industries along the Rhine which flows into the North Sea, attended this conference. A similar arrangement exists for the Mediterranean Sea with the issuing of the Barcelona Protocol in 1980; this banned the release of toxic chemicals such as mercury and cadmium and restricted other potentially harmful chemicals.

6.3.1 United Kingdom laws

In recent times, new laws have been implemented which update, but do not always completely replace, earlier ones. Thus a process may be governed by a series of laws applying to different aspects. The 1974 Control of Pollution Act was one of the most important environmental laws passed, although key aspects covering effluent discharges only came into force during 1985. The National Rivers Authority (NRA) created by the 1989 Water Act took over the regulatory duties of the individual (soon to be privatised) water companies. This new body tightened up on regulations, added further restrictions and set up mechanisms to monitor and control effluent discharges into inland surface waters, estuaries, coastal waters and underground waters. Clearly defined and absolute limits were set for pollutants, together with other actions to implement the new requirements which included a named manager responsible for effluent control in each organisation.[16] Much of the 1989 Act was re-enacted by the Water Resources Act and the Water Industry Act which, together with three further Water Acts in 1991, consolidated all the previous legislation involving water. The Water Acts formalised the principle of 'the polluter pays' which was a condition of the Treaty of Rome (a forerunner of the EU), but was first mentioned at a UN conference on the Human Environment in Stockholm in 1972. The NRA has also implemented European laws and North Sea conference decisions.

The Environmental Protection Act (EPA), which was first placed on the UK Statute Book during November 1990, set up an industrial pollution control system which included 'Integrated Pollution Control' (IPC) for the 5000 potentially most polluting industrial factories. The act applied to all major solid, liquid and gaseous emissions to land, waters and air. A timetable for gradual implementation was drawn up which began on 1st April 1992 with the fuel and power industries, and progressed through to November 1995 when it was extended to all other industries, including textiles. Her Majesty's Inspectorate of Pollution (HMIP) ran IPC, and all existing operators had to register and were given between three and eight years to bring their plant up to the new standards or face closure. After January 1991 all new processes and significantly modified processes prescribed for IPC had to register immediately for authorisation.

Air pollution control (APC) also became law as part of the 1990 EPA to control smaller scale polluters, which were to be regulated by local authorities. Industries such as textile finishing, coating and lamination and solvent joining operations generally came under this category. Thus the EPA was implemented by two mechanisms: IPC controlled by HMIP for large scale polluters which had national implications (so called Part A) and APC for smaller polluters regulated by local authorities so that any relevant local factors could be taken into consideration (so called Part B). Both systems applied the same regulations and used the same guidance notes. Applicants for authorisation for a process had to show that attempts had been made to prevent or minimise emissions or to render them harmless using the 'best available techniques which do not entail excessive cost' (BATNEEC). These regulations applied to both Part A and Part B processes, and to all operations including design, staff training and qualifications, operating procedures and emission levels. The interpretation of BATNEEC, however, was open to qualification and definition depending on individual circumstances.[17] If the cost of the best available technique is considered to outweigh the environmental benefit, this will be taken into account. The pollution inspectorate has drawn up technical notes for the Part A processes and the Department of the Environment and Local Authority concerned drew up the notes for the Part B processes. These notes include abatement technologies, monitoring techniques, storage, handling aspects and emission controls.

The 1995 Environmental Act established the Environmental Agency in England and Wales (EA) and the Scottish Environmental Protection Agency in Scotland (SEPA). From April 1996, the new agencies were made responsible for waste regulation and control of water pollution by combining the activities of HMIP, the NRA, some government agencies and the local authorities' waste regulation authorities (WRAs), which were responsible for regulating the handling and disposal of waste. The objective of this reorganisation into a single agency was to simplify matters for industry and to produce more effective control. The EA is responsible for air and water monitoring, and advises the government on environmental standards and the means necessary to ensure that they are met. However, some responsibility for air pollution control remains with local authorities and they have a duty to manage air quality in their own areas, which includes monitoring, modelling and establishment of emissions data bases.[18] The EA in England is now part of the Department of the Environment, Food and Rural Affairs (DEFRA).

6.3.2 European legislation

The European Integrated Pollution Prevention and Control Directive (IPPC), based on Part 1 of the UK EPA 1990, concerns major industrial operators who are to be licensed in an integrated way to control emissions to the air and water and to manage waste, in order to protect the environment as a whole. In addition IPPC is also concerned with the use and nature of raw materials, including water, energy efficiency, prevention of accidents, low waste technology, noise, and also restoration of a factory site to a satisfactory condition when production ceases. The overall concept is to make industry aware of the process as a whole, in order to ensure adoption of clean technology, careful management of resources (especially energy) and acceptance of the principle that the 'polluter pays'. This EU Directive of 1996 applied to all new installations within the EU from October 1999, and will apply to all existing installations by October 2007. It is broader in scope than IPC, which it replaces, and it is being phased in gradually. There are expected to be about 5000 major sites which will be affected – some of which fell outside the scope of the EPA.[19] The conditions of licensing are an adherence to EU environmental quality standards or laws, and a commitment to high standards of environmental protection to protect the environment as a whole using the best available techniques (BAT). However, cost and the advantages gained are taken into consideration with the EU BAT and it is, in effect, similar to BATNEEC. The monitoring will need to be done by an independent test laboratory to CEN Standard 45001.

The EU in 1997 put forward a Directive to apply a carbon dioxide/energy tax on energy in order to encourage a change to fuels emitting less or no carbon dioxide. This has appeared in the UK in the form of the Climate Control Levy on non-domestic fuel. Further detail is given in Section 6.5.

6.3.2.1 Air quality

Deteriorating urban air quality is one of Europe's two major environmental problems (the other is agriculture). The EU publish guidelines for air quality in Europe based on World Health Organisation information. The European parliament issued a Directive during March 1999 by which member states will be required to have national reduction plans for VOCs. The objective is to reduce VOC emissions by 50% when compared to 1990 levels by the year 2010. Estimates show that, on average, 24% of Europe's VOCs are from the use of solvents, which can in certain weather conditions produce 'summertime smog'. Power generation, transport, combustion processes and natural vegetation account for the rest of VOCs.

This so called 'solvents directive' is affecting 400 000 European companies, 90% of which are small or medium sized enterprises. There have been very significant contributions to clean air by voluntary actions, which have also produced cost savings. An example is the reduction of VOCs from paint spraying by energy management and use of new technology by Vauxhall at Ellesmere Port. They cut their electricity bill by 6%. Ford at Halewood reduced VOC emission by 40% and saved £60 000 on chemicals and waste disposal in the process.[20]

In the UK, air quality in the general public environment is monitored for the main pollutant gases, lead and particulate matter, PM 10, at various urban sites. This is co-ordinated by the National Environmental Technology Centre under EU regulations, and reports are available on UK Freephone 0800 556677 (or on the Internet), on levels of nitrogen dioxide, sulphur dioxide, ozone, benzene, 1,3-butadiene, carbon monoxide and also particulate matter. Under the Environmental Act 1995, air quality standards were set in the National Air Quality Strategy, and local authorities will be responsible for ensuring that the levels set are not exceeded in their area after the year 2005.

Solvents are still used in textile coating processes despite the development of water-based resins, because in some cases it is difficult to achieve the same performance at the same price or with the same add-on of compound. Factories with solvent emissions above certain thresholds have been obliged to install some form of abatement such as incineration. The actual design and type of abatement depends on the chemical nature of the emissions. Many common organic solvents produce only carbon dioxide on combustion, but if nitrogen is present in the solvent, oxides of nitrogen are produced. If the emissions produced contain anything other than carbon dioxide and water, the incinerator fumes may require treatment. The automotive interior trim industry still uses flame lamination which produces potentially toxic fumes; these are best controlled by carbon adsorption. Further details are given in Section 6.4.3.

6.3.2.2 Disposal of waste

The EU is in the process of promoting the management of waste in a way that does not jeopardise public health or the environment. The problem was identified by study of health reports on nausea, headaches, skin and eye irritation, and also by public complaints about landfill sites – 60 incidents since 1989. In March 1998, the EU ministers agreed on legislation to reduce the adverse effects of existing and new landfill sites and to encourage the development of alternative ways of disposal such as composting and incineration. Landfill safety standards would be increased and waste categorised and separated. All waste would have to be treated beforehand; other waste would be sent to specific sites for hazardous materials, and liquid and more hazardous waste would be banned altogether from landfill. Member states would have to reduce the amount of biodegradable municipal waste going to landfill to 75% of the volume of 1995 by 2006, 50% of the 1995 volume by 2009 and 35% by 2016. To meet these targets the EU has indicated that composting be increased as a way of treating biodegradable waste. The UK, which does not have the facilities at present nor the tradition of composting, is being allowed a four year extension to 2020 to meet the 35% requirement, i.e. 65% of biodegradable must be composted by this date.[21] This issue is discussed further in Section 6.5.6. Further EU Directives on waste control can be expected, and already directives on composting and the incineration of waste are being discussed and formulated.

Landfill charges are increasing in many countries of the EU and have tripled in Germany since 1992 to about 400 DM per tonne. Landfill charges were introduced for the first time in the UK in 1996. Waste classed as ‘inactive’, e.g. bricks, concrete or glass, was charged at £2 per tonne, while all other waste that decays (active) was charged at £7 per tonne. The active waste charge has now risen to £14 per tonne (March 2001) as part of a five-year programme of increases, and £25 has been recommended as a minimum to promote better waste management.[22] The Customs and Excise (with DEFRA) must now license all landfill operators in the UK.

Waste Directives have been issued since 1975 to provide a framework to reduce waste generation, encourage recycling and ensure the safe disposal of waste. The EU’s Fifth Environmental Action Programme was aimed at stabilising waste production by the year 2000 at 1985 levels. There has been much activity on reducing and managing packaging waste and scrap cars – ‘end of life vehicles’ now referred to as ELVs – see Section 6.5.2.

6.3.3 United States legislation

The situation in the USA has followed a generally similar pattern to that in the UK, with much environmental legislation activity and public concern from the about the 1970s onward.[23,24] Major acts and amendments have included the Environmental Protection Acts of 1970, 1980 and 1995, the Clean Air Acts of 1977 and 1990, the Pollution Prevention Act of 1990 and the Clean Water Act of 1987. Control details vary from state to state, but the main framework is broadly similar to Europe. Under the Clean Air Act Amendments of 1990, the US EPA developed maximum achievable control technology (MACT) standards to control hazardous air pollutants (HAP) from textile processing operations. A total of 189 HAPs were identified, and the MACT regulations apply to factories with an individual HAP emission of 10 tons a year or more, or a total of 25 tons a year of any mixture of HAPs. The MACT standard is determined by the best performing 12% of a source category. The US EPA was scheduled to issue the standards by November 2000 and factories must comply by 2003.[25]

The US also has a Climate Change Tax, and provision was made in the 2000 budget for the Climate Change Technology Initiative (CCTI) to fund research and development and tax incentives for energy efficiency improvements, renewable technologies, more efficient energy generation and carbon sequestration research. In the USA there has also been special emphasis on control of insecticides, fungicides and rodenticides with an act passed in 1988. Public concern has also been influenced by international scale disasters such as Bhopal, Chernobyl and the Exxon Valdez oil spillage; the Greens are now the third largest party in the USA.

6.4 Manufacturing concerns

In common with most major industries, textile producers take environmental and health and safety issues very seriously. All major manufacturers have established environmental policies and environmental management systems. BS 7750 issued in 1992 was designed to enable industry to establish effective environmental management systems for sound environmental performance, for participation in environmental auditing procedures and for management reviews. This standard had links with the quality management standard systems BS 5750, and it was also consistent with the then draft EC regulation to set up voluntary schemes for environmental management, which became known as the EMAS. Four years later, the first of the ISO 14000 series was published by the Swiss based International Organisation for Standardisation, which draws from 111 countries. ISO 14000 is a group of voluntary international standards, which have the objective of providing consistent and effective environmental management systems for all operational procedures. ISO 14001 is the first of some 20 separate standards, which cover all issues from environmental auditing to life cycle analysis of products. ISO 14001 requires identification of environmental aspects, policy and objectives and a commitment to comply with all relevant legislation and regulations.[26,27] Companies qualifying for ISO 14001 are audited regularly to ensure compliance, and the standard also requires continuous improvement. BSI have also issued guidelines for environmental performance evaluation (EPE), in the form of ISO 14031. EPE helps to 'describe the environmental performances of an organisation', compared with LCA which deal with products and services. Environmental performance evaluation can be used independently or to support ISO 14001.

6.4.1 Wet processing

Textile processes attempt to use the minimum amount of water for economic as well as for environmental reasons. The textile manufacturing industry is potentially environmentally polluting in two ways: discharge of effluent from wet processing and air emissions from stentering, finishing, fabric coating and lamination. Both are now very carefully controlled by the environmental pollution laws which have become progressively stricter in recent years; informative articles have appeared in trade journals.[16,28–34] Manufacturers may not discharge trade effluent into a public sewer without authorisation from the local water authority. The application form for permission should include details of the effluent, chemicals, suspended solid matter, biological content, etc. and information on the amount to be discharged in a day, including the peak rate of discharge. In April 1989 a list of 23 chemicals which were to be subject to stricter control was announced by the government, the so called 'red list'. These chemicals were already on the EC 'black list' and are now subject to control under BATNEEC to minimise input into the environment. The 'red list' includes mercury and its compounds and cadmium and its compounds. Discharge levels are also subject to agreements reached in North Sea Conferences, especially the Third in 1990 and the Fourth in 1995 at which there were further commitments to reductions.

The environmental effects of textile chemicals have come under scrutiny, and certain chemical types have had to be replaced with more environmentally friendly ones. Certain anionic sulphonates used as surfactants and scouring agents have branched molecular chains which are not biodegradable; they are, thus, being replaced by straight chain types which can be broken down by bacteria in the effluent plant. Also certain phosphate chemicals which support algae growth in rivers and waters are being phased out. The algae 'blooms' block out sunlight and reduce the oxygen content of the water – which is harmful to both plant and marine life. The chemical manufacturers have been very active and can supply much useful information. Any damage to the environment caused by harmful discharges can be made good and the bill sent to the offender under the 'polluter pays' principle. There are also restrictions on pH and temperature of effluent discharges. The rate of discharge and peak disposal rates must be notified to the local sewage undertaker. The discharge of prescribed substances, such as mercury and its compounds, cadmium and its compounds, and certain organic compounds, are very severely restricted. Consent levels are agreed with the local water company under conditions set by the EA who also set monitoring levels procedures. Process Guidance notes (PG series) are available from the DEFRA through HMSO.

Lubricant content of loomstate or unfinished fabrics can sometimes be up to 2% by weight, and much of this 'oil' is removed during scouring and stentering. Most fabric, however, is now scoured, and spent liquors should be treated before discharge to drains. pH, temperature and solids content are the usual factors requiring attention. All stenter fumes should be abated before discharge to atmosphere, and the emissions should be monitored regularly in accordance with standards arranged with the EA. Coatings applied to automotive fabrics are now invariably water based, and the material driven off during processing is mainly water, but there may be organic chemicals, which have to be removed before the emissions are released to atmosphere. Guidance Notes relating to air quality (AQ series) have been prepared by the DETR and are available from HMSO.

6.4.2 Coating and lamination

Joining methods using solvent-based adhesive spray application methods and flame lamination are potentially highly polluting, and many solvent-based adhesives have been replaced and continue to be replaced with hot melt, high solids content and water-based varieties. However, fabric coating and joining using solvent-based resins and adhesives is still widespread. In the fabric coating industry, water-based resins are used whenever possible, but in some cases it is proving difficult at present to obtain the high standards of performance and durability normally achieved with solvent-based types. However, solvent use is subject to closer restrictions, and targets have been set by the EC to reduce VOC emissions by 66% compared to 1990 levels with a compliance date of 2007.[34–37]

Textile coating factories with VOC emission thresholds above a certain level must have abatement facilities to reduce VOCs emitted to the atmosphere to within a concentration agreed by the local authority. Typically this may be 150 mg/m^3 of air. PVC factories need abatement for the fumes emitted during the gelling process. The fumes are likely to contain plasticiser and traces of the stabilisers and possibly other additives.

Flame lamination fumes are monitored and must be treated by very effective methods, if necessary by carbon adsorption techniques. Under the EPA 1990 and the Environment Protection (Prescribed Processes and Substances) Regulations 1991 Di-isocyanate Processes, operators of potentially polluting industrial plant must be registered with the EA before beginning production and must regularly monitor levels of potentially harmful substances.[38–40] Guidance notes for operators are available from government bookshops; the relevant pamphlet for flame laminators is IPR6/5, entitled *Toluene di-isocyanate use and flame bonding of polyurethanes*.

6.4.3 Methods of emission abatement

The methods of abatement fall into two categories: destructive techniques, where the undesirable fumes are destroyed by incineration into non-toxic gases and capture techniques, where the undesirable material is removed from the airstream by various techniques.[41–49] Capture techniques include electrostatic precipitation, activated carbon adsorption, filtration and 'scrubbing'. Scrubbing involves passing the emissions through water solutions, such as caustic soda to neutralise acidic material or, in the case of flame lamination, isocyanates. However, scrubbing techniques may give rise to stack 'plumes' which may consist almost entirely of harmless water vapour, but they look alarming and might, therefore, give rise to complaints from the neighbours.

PVC coatings are heated at around 200 °C to gel the PVC and plasticiser, and fumes of vaporised plasticiser and traces of other materials in the plastisol recipe are produced. The amount varies depending on the volatility of the plasticiser being used, but abatement is essential whatever the recipe. Techniques used include aerosol or electrostatic filtration and incineration, but effective incineration depends on the temperature, turbulence to ensure good thermal mixing and contact, and the length of time the fumes are actually in the incinerator. Incineration has to be very carefully controlled to ensure complete oxidation, because potentially toxic gases may be produced and released to atmosphere. This is especially relevant when chlorine containing material is incinerated, because dioxins, a group of extremely toxic materials, may be produced if the process is not at a sufficiently high temperature. Incineration temperatures must therefore be maintained precisely at the high temperature necessary for complete oxidation and to ensure public safety. This requires careful process control, especially if the waste fume stream is not consistent, and extra fuel gas is needed in these circumstances which adds to the running costs. The incineration process can sometimes be carried out at lower temperatures by the use of catalysts made from precious metals such as platinum, but they need to be protected from species which can render them inactive.

Volatile organic compounds used in direct or transfer coating of polyurethane, such as MEK and toluene, are fully oxidised to water and carbon dioxide, but DMF, however, also produces oxides of nitrogen. Incineration of sulphur compounds can produce oxides of sulphur, which like oxides of nitrogen, are acidic; these could be harmful to buildings and vegetation in addition to being harmful to human health. Incineration of chlorine compounds, as already mentioned, requires special care and control to prevent the formation of dioxins, but hydrogen chloride gas or even chlorine may be produced. It may, therefore, be necessary to wet scrub incinerator fumes for acidic species using sodium hydroxide or calcium hydroxide, although oxides of nitrogen have low solubility in water and cannot be effectively removed by a wet process.

Incinerators can be designed to produce useful heat by the incorporation of heat exchangers which will contribute significantly to the running costs, but this depends on a consistently high volume of combustible organic material in the waste stream. Initial capital outlay is higher for an incinerator with primary heating, in which heat generated from the incinerated gases is used to preheat gases entering the incinerating chamber. If volumes of VOCs to be incinerated are sufficiently high, so called secondary heating may be possible. Secondary heating means that the heat from burning of the waste gases is used for useful purposes such as heating and raising steam. The DEFRA is actively promoting combined heating and power systems (CHP) because of their overall energy efficiency and contribution to reduced carbon dioxide emissions. Operators of qualifying CHP systems may be exempt from the climate change fuel levy. Some factories apparently operate very successful CHP systems.[50]

Carbon absorption is considered to be one the most effective means of abatement of fumes from flame lamination, which include iso-cyanates and hydrogen cyanide. Capital installation costs can be high, but running costs are generally moderate to low – so much depends on the production volume. Oily and particulate matter must first be removed from the laminator production fumes, because they would soon deactivate the carbon, and it is necessary to install pre-filters as part of the abatement unit. Potentially toxic gases are adsorbed on to the activated carbon, and if the unit has been properly designed and is working effectively the emissions to atmosphere should be within levels permitted by the EA. The filters need servicing and replacement periodically, and eventually the carbon will become saturated and will also need to be replaced. The spent carbon can be reprocessed under controlled conditions by specialist operators, but is believed to have been disposed of by landfill – which must now be regarded as an unsatisfactory practice.

6.4.4 Health and safety aspects

6.4.4.1 Control of hazardous substances

All chemicals and materials used in the textile and automotive industries are subject to the Control of Substances Hazardous to Health regulations (COSHH) of 1994 (which replaced the original 1988 regulations) and March 1999, which cover all aspects of purchase, handling, transportation, storage, use and disposal. The most important issue is that an employer cannot carry out any activity which exposes employees to any hazardous substance unless a 'suitable and sufficient' assessment has first been made. The assessment must be reviewed regularly and whenever any significant modification to the process has been made. Hazardous material may include gases, vapours, liquids, fumes, dusts, solids or micro-organisms. When stored or transported they are also subject to the Classification, Packaging and Labelling of Dangerous Substances Regulations of 1984. Guidance notes on safe handling, maximum exposure limits, occupational exposure limits and monitoring strategies are regularly updated, published annually under the EH40 series, and are available from the Health and Safety Executive.

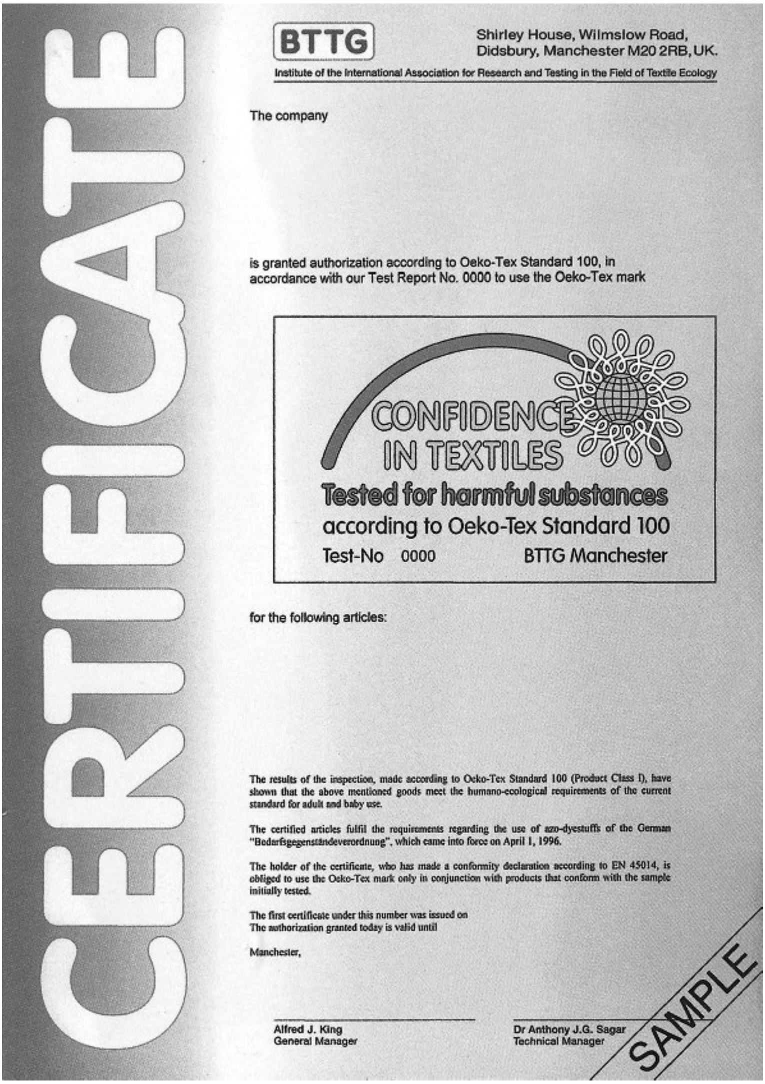
Manufacturers and suppliers must supply documented information on chemicals, adhesives and other raw materials in material safety data sheets. These documents contain information on chemical composition, physical and chemical properties, toxicological and ecological aspects, potential hazards together with first aid measures, storage and transport, protective clothing and other controls necessary for safe handling and disposal. They should conform in format and content to EC Directive 91/155/EEC. EU regulations have generally tightened control of potentially harmful chemicals.

6.4.4.2 Hazardous material content

Some environmental and customer pressure groups are now concerned about the presence of potentially toxic chemicals in consumer items, and an increasing number now require information on this. Hazardous material assessment forms are issued which list chemicals such as lead, nickel, cadmium, mercury, certain organic chemicals including bromine, etc., and their usage in the manufacturing process or concentration, in parts per million, in the finished article must be declared. There are halogen and phosphorus FR chemicals in some FR qualities of both fabric and polyurethane foam. While the risk to health from this source is likely to be quite low compared to similar chemicals in some apparel or even domestic furniture, consumer concern must be taken seriously. Considerable effort has been made by the chemical industry to replace these materials, but so far with limited success. Higher concentrations of alternative chemicals are required to produce the same performance. However, the situation is not yet clearly resolved, especially because bromine compounds have been found in the marine environment and in mammals.[51,52] Some researchers, however, believe that the benefits of FRs outweigh the risks to human health and the environment.[53–55]

6.4.4.3 *Eco-labelling*

In a strict interpretation of the term, eco-labels are applied to consumer goods as an indication that the product has been manufactured under environmentally friendly conditions, from environmentally friendly materials, and that will not pose any threat to human health or to the environment during its useful life nor at disposal. This process is a life-cycle analysis, also called a ‘cradle to grave’ approach (ISO 14040 group), but in practice is almost open-ended for many products and, at best, is extremely costly and time consuming to carry out. However, this has been the basis of the EU eco-label, which started with only a limited number of products including T-shirts and bed linen. There have been recommendations for simpler procedures, which concentrate on the more important characteristics of products. There are several eco-labels in Europe such as the ‘Blue Angel’ in Germany and the ‘White Swan’ in Scandinavian countries, while in the USA there is the ‘Green Seal’. Some of these labels are based on environmental audits of the manufacturing process alone, such as energy efficiency. Others are based on assessments of the content of hazardous material in the textile as an assurance that it will not harm human health.[56–59] One such label is the Oeko-Tex Label run by the International Association for Research and Testing in the Field of Textile Ecology, which includes the Hohenstein Institute in Germany and BTTG in England.[59] To obtain an Oeko-Tex label, textile products are analysed for content of a range of potentially harmful chemicals such as formaldehyde, cadmium and mercury. A label is granted if they are below maximum permitted levels. Well over 18000 Oeko-tex certificates have been issued, including some in the USA, the Far East, Japan and South Africa, see Fig. 6.2. It is probably the most widely recognised textile environmental safety standard.[60,61] Another example is the Toxproof mark offered by TUV Rheinland, Cologne; this is issued to textile goods only after they have been tested to TUV criteria which include heavy metals, chlorinated phenols, etc. The EU eco-labelling scheme encourages companies to design and manufacture environmentally friendly products,



CERTIFICATE

BTTG

Shirley House, Wilmslow Road,
Didsbury, Manchester M20 2RB, UK.

Institute of the International Association for Research and Testing in the Field of Textile Ecology

The company

is granted authorization according to Oeko-Tex Standard 100, in accordance with our Test Report No. 0000 to use the Oeko-Tex mark

CONFIDENCE
IN TEXTILES
Tested for harmful substances
according to Oeko-Tex Standard 100
Test-No 0000 BTTG Manchester

for the following articles:

The results of the inspection, made according to Oeko-Tex Standard 100 (Product Class I), have shown that the above mentioned goods meet the humano-ecological requirements of the current standard for adult and baby use.

The certified articles fulfil the requirements regarding the use of azo-dyestuffs of the German "Bedarfsgegenständeverordnung", which came into force on April 1, 1996.

The holder of the certificate, who has made a conformity declaration according to EN 45014, is obliged to use the Oeko-Tex mark only in conjunction with products that conform with the sample initially tested.

The first certificate under this number was issued on
The authorization granted today is valid until

Manchester,

Alfred J. King
General Manager

Dr Anthony J.G. Sagar
Technical Manager

SAMPLE

6.2 The Oeko-Tex Standard 100 is a product safety standard and prohibits or regulates the use of harmful substances such as formaldehyde, phthalates (in baby products) and emissions of volatile components. It has become the world's leading eco-label for textiles tested for harmful substances. Specimen Certificate supplied by BTTG and reproduced with kind permission.

and provides customers with information with which to choose between 'green' products and others. More notable than this could be the suggestion in an EC Green Paper on integrated product policy that there should be lower VAT on eco-labelled products.[62]

6.5 Sustainable development

6.5.1 Introductory notes

The UK and most of the other major countries of the world gave a commitment at Kyoto in 1997 to reduce carbon dioxide emissions in efforts to reduce global warming. Much is being done by the EU and the UN and by governments of the world to foster environmental responsibility and the concept of sustainable development. In recent years the world has witnessed severe weather causing loss of life and damage to property that is believed to have been caused by global warming. Environmental pressure groups call for even firmer and wide-ranging action, and much still needs to be done and done quickly.

The UK government in 1990 set non-statutory targets for local authorities to recycle 25% of municipal waste by 2000, but the vast majority fell far short of this target and mandatory targets may be necessary. Recycling has been a major cause for concern in the packaging industry since before 1990, and much progress has been made both in the reduction of packaging and in the collection and actual recycling of used packaging. Some of the lessons learnt are being applied to the automotive industry, which is now facing similar problems together with some which are unique to it. At the time of writing there does not seem to be significant pressure on the recycling of coated and laminated products – with the possible exception of car tyres, if they are regarded as being coated materials. A summary of the situation in the automotive industry is included here because the automotive industry is the largest single user of coated and laminated textiles which are used extensively in cars. The automotive industry was a pioneer of the mass production industry, and there may be lessons to be learnt in the disposal and recycling of automobiles.

The least expensive and least adverse effect on the environment is when a component can be recycled into its original product, i.e. so called 'closed loop' recycling. The second best is when it can be used in another article which usually requires less demanding properties, for example face car seat fabric being recycled into backing material. The third option is to incinerate the material to generate useful heat, but this generates the inevitable carbon dioxide and other gases and emissions, which generally have to be treated before release to atmosphere. Plastics, in fact, generally have high calorific values and are efficient fuel. The fourth and least satisfactory disposal method is landfill, which as has already been mentioned may produce environmental problems of its own. Some components consume so much energy and other resources to recycle them that it is judged more environmentally friendly overall to use the two latter options. This is why life-cycle analysis ('cradle-to-grave') is essential. Each case has to be thoroughly assessed on its own individual circumstances and merits. In some countries with a shortage of fossil fuels, such as Japan, incineration is a preferred option.

On 1st April 2001 the UK government, in line with the EU Directive of 1997, introduced the 'Climate Change Levy' on non-domestic fuel to encourage industry to use less fuel and become more energy efficient, thus reducing the amount of carbon dioxide produced. The levy could increase electricity bills by 8% and gas bills by 15%, but to avoid adding extra cost to industry, the employer's contribution to National Insurance was cut by 0.3%. Companies using approved CHP schemes are exempt, and there are also 80% discounts available for some energy intensive industries which enter into legally binding energy efficiency agreements with the government.[63,64] In addition, companies which use energy efficiently may also qualify for discounts under IPPC schemes.[65]

6.5.2 Automotive recycling

6.5.2.1 ELVs – 'end of life vehicles'

Proposed EU legislation will require a system of collection – at no cost to the last owner – and disassembly to be created for re-use, recovery and recycling at the end of the vehicle's life. An amendment states that 'producers must meet all, or a significant part of the costs'. The cost, of course, will ultimately be passed on to the consumer. Needless to say, the European car industry considers these measures unreasonable because the car is already 75% recycled by weight, and actual waste from cars represents only 0.2% of all European industrial waste.[66] However, the EU considers ELVs a priority, and these measures are likely to affect the textile industry eventually, because fabric and fabric laminates are major interior components of motor vehicles. Car industry spokespersons have commented that the new law, in effect, encourages the production of heavy cars using more metal – if the ELV directive had already been passed, the 3-litre car could not have been developed. The 3-litre car uses three litres of petrol to cover 100 km, i.e. 92 mpg, and it contains a high proportion of weight saving plastic material. Recycling analyses of automotive plastic and textiles have been carried out.[67–71]

In the UK at the time of writing about 25% by weight of the car goes to landfill with about 75%, mainly metal, being recycled. The ELV Directive requires 80% recycling and 85% recovery (5% by energy recovery) by 2006, with no more than 15% to go to landfill. These levels will be raised to 85% recycling and 95% recovery (10% energy recovery) with no more than 5% to landfill by the year 2015.[72,73] The UK government is in the process of actually detailing how the Directive will be applied. Throughout Europe there are about 12 million ELVs disposed of every year, and this is increasing at the rate of about 3% per year. The metal parts are recycled, but the remainder, about 25% by weight consisting of tyres, glass and an assortment of plastics, textiles and other materials called automobile crusher or shredder waste (ACR or ASR) mostly goes to landfill. Car seats and other interior items making up ASR pose serious challenges for the industry, and this issue will become more pressing as the deadlines for reduced landfill approach. The OEMs are supporting schemes to identify and sort scrap material and are also trying to increase the recycled material content of their cars. Some are making recycling a key design consideration and specifying that parts supplied must be made from a certain percentage of post-consumer recycled material, thus putting pressure on their suppliers.[74–77] Eventually Ford want to attain 90% vehicle recyclability (by weight), while others such as DaimlerChrysler want to do even better – 95% by the year 2005.[75] The UK government is contributing to the funding of certain projects concerned with car recycling.[78]

6.5.2.2 Automotive fabric recycling

The car seat laminate is generally made up from polyester face fabric, polyurethane foam and a scrim fabric which is either nylon or polyester. These chemically dissimilar materials are not easily separated and, therefore, cannot be easily recycled. The use of polyester scrim reduces the number of chemical types to two, but even this presents a problem. Chemical hydrolysis can be used to break down the three polymers into simpler chemicals which can be used as fresh raw materials, but at present this is not commercially feasible.[68] Several different types of nonwoven and knitted fabric (for example ‘spacer fabric’, Kunit, Multiknit (by Karl Mayer) and wool/polyester blends) have been evaluated as substitutes for laminate polyurethane foam. Karl Mayer manufacture the machines on which they are made. Some materials have been made from garment waste and are being used commercially in German made cars.[79–87] These foam substitutes do not need a scrim backing and using one made of polyester together with a polyester face fabric produces a seat cover laminate all in one polymer type.

These materials provide a soft touch to the laminate and compression properties initially comparable to foam, but they all lose significant thickness in compression and heat ageing tests.[88,89] The thickness loss would be easily noticeable with thick layers, but may be less noticeable in thinner layers. Fibre producers have demonstrated the possibility of using recycled polyester face fabric into nonwoven material. Shredded face fabric is mixed with 30% of virgin polyester polymer, melted and re-extruded into a nonwoven fibre which, although discolored, can be used as the foam substitute in a new seat cover. When this seat cover comes to the end of its life, it can in turn be shredded, melted and extruded again, but this time with a higher proportion of virgin polymer to compensate for the used polyester being recycled a second time. Alternatively, it can be used in a less demanding end-use. Thus, the same polymer is reused, but each time in a progressively lower specification application. Nonwoven polyester spun from recycled polyester bottles by Wellman is currently being used in some production models. Bottle manufacturers continue to develop and improve polyester bottles for many other end-uses, and there could soon be a surplus of polyester bottles available for recycling.

6.5.2.3 Recycling of polyurethane foam

The manufacturers of polyurethane throughout the world have responded to the challenge by showing how waste foam can be reused, recycled or disposed of with minimum environmental effect.[90–93] The methods involve shredding into crumbs and smaller particles and reprocessing by compression moulding, and adhesive or thermoplastic rebonding into useful articles, including backings for carpets, rugs and other items which make use of the acoustic and shock absorbing properties. Foam has been ground into powder and added into new compound mixes as filler. Studies have been carried out on the feasibility of chemolysis, breaking the material down chemically into the original raw materials for use in existing or new products. Composting and incineration as a useful fuel to recover the energy has also been considered. The Polyurethanes Recycle and Recovery Council (PURRC) of the (American) Society of the Plastics Industry was set up as early as 1990, and has tackled the problem of both process and post-consumer waste. In the USA there is a market for foam for recycling into new products such as carpet backing. The European Isocyanate Producers' Association (ISOPA) provides a focus for environmental responsibilities in Europe, and has issued comprehensive technical information sheets on recycling possibilities.[93]

Automotive seat makers have explored the use of ground up foam from car seats as filler for virgin foam in new seats. Physical properties appear to be reduced in quality, but may be satisfactory in actual use. The problems of interior trim foam being joined to other materials and the cost of dismantling and handling, however, remain. Foam processing waste in fabric lamination plants is taken back by certain manufacturers.

6.5.2.4 Logistics of automobile recycling

The first step in the recycling process is collection of the ELV. A single scrap car has little value to its last user, and occasionally abandoned cars are seen littering the landscape. These are not only an eyesore, but also constitute a health and safety hazard. About eight million ELVs are scrapped each year in the EU. With a certain amount of pressure from governments, voluntary accords have been set up since the early 1990s to address the problem, amongst them the Automotive Consortium on Recycling and Disposal (ACORD) in the UK, Project Altfahrzeugverwertung Deutscher Automobilhersteller (PRAVDA) in Germany, and the Environmental Car Recycling in Scandinavia (ECRIS).[94–96] The Association des Constructeurs Europeens d'Automobiles (ACEA) in Brussels promotes research to improve the design of vehicles with a view to ease of disassembly and also to the selection of materials which can be recycled and minimal use of those which cannot. The Consortium for Recycling (CARE), established in the UK in 1996,[97] works with government bodies and other organisations to produce specific results from practical work. Recytex, previously a subsidiary of the car upholstery manufacturer Viktor Achter has processed textile waste and has been co-operating with Mercedes-Benz and others on the use of recycled nonwovens for sound insulation.[98,99] Car manufacturers are co-operating with each other, for example Volvo will scrap Mercedes cars in Sweden and Mercedes will scrap Volvo cars in Germany and Toyota are co-operating with VW and General Motors.

The second step in the recycling process is disassembly, which must be accomplished quickly if it is to be economic. Plastics must be identified and sorted and different types separated from each other; this is not easy, and it may not always be economically possible. The actual impetus for recycling has arisen only since the 1990s, and many of the cars currently being scrapped were not actually designed with recycling and disassembly in mind. In addition, some components made maybe between 1985 and 1990 contain substances which are now considered to be toxic and are therefore prohibited from being used in a new car. After many years of use, seat covers are likely to be heavily soiled, which means there will be high levels of contaminants with which to contend.

The non-metallic parts of the car total about 25% of the weight and comprise glass, rubber, plastics and textiles. These materials, about 300 kg in an average vehicle, represent the biggest challenge, with adhesives, paints, coatings and fasteners further complicating matters. At present, the cost of dismantling, sorting and transporting components is not generally commercially viable, but the pressure is on to change this or to find alternative solutions. Vehicles being built at the present time benefit from these lessons, and future ELVs should gradually become more and more easily dismantled. Cars being built now will not become ELVs until the year 2010 onwards, and it has been suggested that when a polymer type is chosen for a car part, a second future use for it, at the end of the car's life, should be decided in advance. To assist with dismantling, the EU has requested OEMs to code car parts and to produce dismantling manuals. One notable exception to the trend of easier disassembly is the move towards directly joining car seat covers to the foam cushion and squab in seat making. DaimlerChrysler, Ford and BMW are believed to be planning a pilot identification and sorting plant for automotive plastic waste in Germany. Car carpets are generally one polymer, but with high levels of binders and a coating of bitumen or other material to assist with vibration and sound absorption. They can also contain very large amounts of dirt – one report records up to 1 kg of dirt per square metre of carpet.

6.5.2.5 Reduced emissions by reduced weight

Efforts are being made to reduce pollution by making the car lighter in weight. Some OEMs have requested reductions in car seat cover fabric weight of 30%. Generally this is not possible without compromising the fabric performance, especially abrasion resistance. However, the add-on of coating to the back of car seat fabric has been significantly reduced since around 1995 to reduce both cost and weight. The effect on fabric abrasion has been minimal. The car industry is responsible for 12% of all carbon dioxide emissions in Europe, and its co-operation was requested so that the EU can comply with its commitment to reduce carbon dioxide emissions. In response the ACEA proposed very significant reductions in fuel consumption. Cars are now available emitting carbon dioxide corresponding to an average fuel consumption of 4.91 per 100 km (equivalent to 48.2 mpg). Further improvements up to the year 2008 will result in car fuel consumption at levels 25% less than 1995 levels.

Textile fibre in the form of composites should contribute substantially to reduced traffic fumes by allowing considerable weight savings. However, there are technical problems to be overcome before large metal replacement composites can be made commercially in the quantities required by the high volume automotive industry. Advanced tyre cords and textile fibres/rubber combinations are, in fact, contributing to reducing rolling resistance in tyres, leading to economies in fuel consumption and prolonged tyre life. Replacement of relatively heavy fibreglass in headliners or other parts of the car by polyester, or polypropylene which is even lighter, can reduce weight further. In addition, fibreglass is unpopular because skin dermatitis is caused during manufacture.

6.5.2.6 Disposal of tyres

Coated rubber products, and tyres in particular, are difficult to recycle or dispose of on a large scale. The vulcanisation process cannot be reversed easily or economically. The tyre companies and others have researched means of safe disposal by incineration with energy reclamation. The Blue Circle Cement Company and Michelin are co-operating, under the name Sapphire Energy Recovery, to use tyres as fuel in part replacement for coal and coke in a number of Blue Circle's cement works. The plan could use half of the annual 40 million scrap tyres for useful energy by the time the EU Directive banning landfilling of whole tyres comes into effect in 2003. The Landfill Directive will also prohibit disposal of shredded tyres in 2006,[100,101] but the UK hopes to postpone this until 2009 in the case of existing landfill sites. Every year the UK disposes of 450 000 tonnes of scrap tyres, 30% by landfill, and the last few years have seen significant steps taken to solve this problem, with cement works taking tyres for incineration to produce useful energy. Two sites are in operation and trials are being conducted at three more. However, public consultative procedures, which are part of the application process, still need to be formulated by the EA.[102] The manufacture of cement requires high temperatures of about 1200 °C, and at these temperatures the risk of toxic emissions is reduced, but the public needs to be reassured.

The EA issues licences for the tyre burning process only when it is satisfied that the environmental controls are effective. Sapphire believe that their process uses the latest technology in abatement and hope eventually to have five plants operating in the UK and Northern Ireland. The UK is a leader in reclaiming energy from waste tyres. The problem of tyre disposal is also being helped by the prolonging of the service life of tyres by retreading and by more advanced design. All of these measures also conserve natural resources, and there is possibly an opportunity for parallel developments in the belting and associated industries which also rely on rubber/textile composite technology.

6.5.3 PVC recycling

The use of PVC has been questioned by some environmentalists, especially Greenpeace, because of the possible risk to health of phthalate plasticisers, and also because of the possible formation of dioxin chemicals during PVC manufacture and eventual disposal.[103–105] BMW and General Motors are reducing or have discontinued the use of PVC in cars. General Motors state that PVC is being phased out mainly on technical rather than environmental grounds. Several other car makers also intend reducing the amount of PVC, but this is likely to take some time because up to the late 1990s, PVC was used in 70–80% of car dashboards and door interior trim. Amendments to draft proposals to an ELV EU Directive which would have reduced or phased out the use of PVC in EU built cars were defeated in the European Parliament. PVC requires a whole range of stabilisers and processing aids as detailed in Chapter 2, and these add to the problems of disposal. Potentially toxic additives have been or are being phased out in current production. However, tarpaulins and other coated PVC products made maybe 10 or 15 years ago, which may still be in use or which are being disposed of at the present time, could contain additives prohibited today. Marks and Spencer, the UK chain store, is phasing out the use of PVC packaging and products by about February 2003. In response to consumer concern, the PVC industry is making efforts to remove the problems associated with PVC, and holds the view that, for many applications, there are no alternatives which pose less of a hazard. PVC is difficult to ignite, is an extremely versatile material and it is probably the most researched plastic in existence.

Disposal of PVC is difficult because it cannot be landfilled or incinerated without certain risks. The high chlorine content produces hydrochloric acid gas (HCl), and if it is not controlled, the combustion process may also produce dioxins. Many incinerators are not built to cope with large amounts of HCl gas which could not be released to atmosphere without treatment. Landfilling PVC poses the risk of additives being leached out and eventually entering water courses and even drinking water. In addition, the covering properties of discarded tarpaulins could change soil morphology, and could be harmful to earthworms and other soil dwelling creatures by reducing the level of oxygen or by restricting the flow of water. PVC coated fabric biodegrades slowly, and its disposal has become a problem which has contributed to the search for ways of recycling the material and also for alternative covering materials.

The recyclability of PVC coated polyester tarpaulins has been researched both in the USA and in Europe.[106–111] In Europe, the Solvay company has examined grinding the tarpaulin material into a powder at low temperature (−196 °C) and using the powder as a filler in new PVC plastisols. The work was apparently successful, but it was judged not to be economically feasible. Separating the PVC from the polyester has been tried using heat and using different solvents. PVC melts at 150–200 °C, which is a lower temperature than the melting point of polyester (250 °C), but it begins to decompose before this temperature is reached. Thermal methods are, therefore, not possible. In addition, the polyester becomes embedded into the PVC like a filler. Solvay examined the use of tetrahydrofuran (THF), a solvent which dissolves PVC but not polyester, but concluded that, because of the price of the solvent and its flammability and toxicity, and owing to the presence of additives and soiling material in the extracted PVC and its quality in general, the solvent route did not justify further examination. The company then explored incineration in a rotary furnace with both energy recovery and chlorine recovery in the form of hydrogen chloride. They concluded that this was economically feasible and worthy of a pilot plant. The intention is that the hydrogen chloride gas is fed to supply a vinyl chloride production plant for conversion back into PVC. Other work has examined freeze grinding, at −160 °C, and reusing the powder as filler in new PVC coatings. The Ferrari company of France, with the assistance of Solvay, have developed the VINYLOOP^R. This is a closed loop recycling process for PVC coated fabrics which first grinds the material and then separates the components by selective dissolution in different solvents. The recovered polyester fibre is claimed to be pure and reusable, while the PVC is in the form of granules which are homogeneous and also suitable for reuse. Ferrari is to build a plant at Tour du Pin, Isere in France during 2001.[109]

The University of Auburn in the USA investigated the use of separation solvents and chose MEK for more detailed work. The MEK swells the PVC and allows it to be detached from the polyester fabric by mechanical agitation. The recovered polyester fabric still had adhesive residues on it, but it retained its physical properties and it was possible to use it in epoxy composites. If the glue residues were removed with DMF solvent, the polyester fabric was suitable for the preparation of needlepunched nonwoven fabric. The recovered components were reported to be suitable for reuse in PVC coatings. A process of automated separation, the recovery of the wash liquors and the DMF/glue residues, and the design of pilot equipment are the subjects of further research at the Auburn University.[108,109] The recycling figure for the PVC industry as a whole has been quoted (at the time of writing) as between 3 and 4%, and so the amount of PVC coated fabric actually being recycled at present must be even lower than this figure. The PVC industry is committed to voluntary phasing out of potentially harmful chemicals, and it maintains that in environmental assessments, LCA methods should be used to examine items made from PVC and also to compare them with items made from alternative materials.[105]

6.5.4 Recycling of carpets

Some industries, such as the automotive industry, are high profile in environmental terms, but the problem of carpet disposal, about four million tons every year, which at one time made up approximately 2% of all landfill in the USA, has also been recognised as one that required an urgent solution. In Western Europe about 1.6 million tonnes of carpet waste are disposed of each year. The figure for Germany is half a million tonnes, but after 2005, landfill of waste carpet will not be allowed in Germany. Additional pressure was put on to producers in Germany in 1996 with the passing of the Recycling and Waste Management Act which focused the responsibility for waste on to the producer. However, industry has been working on the problem for a number of years, and as will be seen, solutions are available. As far back as 1993, the European carpet industry declared (Declaration of Vaals) that it recognised that the recycling of carpets was basic to its producer responsibility. In 1995 a three-year project was initiated to develop and introduce a closed loop production system for carpets. The necessary technology was developed by the RECAM Project (Recycling of Carpet Materials), which was supported by the EU under their BRITE EURAM (Basic Research for Industrial Technologies in Europe, European Research in Advanced Materials) Programme. Amongst the project partners were the European Carpet Industry, the German Institute for Carpet Research, DSM and EniChem.[112,113] The objectives included research into sustainable waste management, methods of treating post-consumer and industrial carpet waste to replace solid waste incineration and landfill, recovery and re-use of high quality raw materials from used carpets. Life cycle analysis of the carpet material revealed that recycling of polyamide is economically feasible because of the high energy consumption in the production of virgin polyamide. However, in the case of polypropylene the calorific value of waste is quite close to the energy needed to produce virgin polypropylene.

In 1998 five European carpet production associations formed Carpet Recycling Europe GmbH (CRE) to collect, identify, sort and market recyclable fractions. An automatic sorting plant, the world's first, has been built at Ginsheim-Gustavsburg, and processes 25 000 tonnes of carpet waste per year using fibre identification technology developed by DSM and the Dutch research institute TNO working in the RECAM Project. Waste carpet is made up of 30% polypropylene, 25% each of nylon 6 and 66, together with wool and other materials. Polypropylene is a cheap material which cannot at present be economically recycled either mechanically or chemically and is prepared for incineration. Nylon 6 can be chemically recycled back into caprolactam from which it was produced, and this is being carried out at a number of plants both in Europe and the USA.[114,115] Nylon 66, which is produced from two starting chemicals, is more difficult to depolymerise and is being mechanically recycled into a lower value material. Wool and polypropylene carpet residues are being converted into insulation material. CRE has plans to build ten sorting plants in Europe over the next five years.

Carpet Recycling Europe has a recycling contracts with the Evergreen Nylon Recycling (ENR) plant at Augusta in Georgia, USA. This plant, set up by AlliedSignal, now Honeywell International, and DSM Chemicals North America (DCNA) in November 1999, depolymerises 100 000 tonnes of nylon 6 carpet a year and produces from it 45 000 tonnes of high quality caprolactam. This is a truly 'closed loop' recycling operation and is believed to be capable of reclaiming 20% of all scrap nylon 6 carpet in the USA.[116] Evergreen Recycling is collecting old carpet in 75 US metropolitan areas, and carpet retailers are saving many thousands of dollars in landfill fees and disposal costs by participating in the collection network. DCNA and

Honeywell have developed a portable instrument called CarPID™ which quickly identifies carpet type, and which is based on near IR spectroscopy. ENR continues to improve techniques for and reduce the costs of recycling.

During 2001 Polyamid 2000 AG plans to open a 120000 tonne nylon carpet recycling plant near Berlin, where caprolactam will be produced from nylon 6 and nylon 66 will be mechanically processed. This will actually be the first carpet recycling plant in Europe.[114] In the USA, carpet recycling has been conducted in a limited way since the mid-1990s. In Europe Rhodia Performance Fibres are recycling waste nylon 6 into caprolactam and mechanically processing nylon 66 at three plants. However, carpets are not yet processed and the scrap material is waste fabric and fishing nets, but CRE are believed to be in communication with Rhodia.

Since 1994, BASF in North America has been accepting used nylon 6 carpet back under their 'Six Again-program'. Although the Canadian recycling plant capacity is only about 1000 tonnes per annum, new carpets have been produced from the recycled material for a number of years. BASF are reported to have guaranteed not to incinerate or landfill collected carpet. DuPont has been operating a nylon carpet processing plant at Chattanooga since 1995 mainly for nylon 66 using mechanical recycling. DuPont also maintains a network of franchised carpet retailers to offer services including recycling. Further development work on chemical recycling by DuPont may lead to a pilot plant at Maitland, Ontario in Canada.[112]

The problem of carpet waste disposal has been researched at a number of universities, including the Georgia Institute of Technology in the USA.[117] Polypropylene carpet waste is being examined for possible use as the thermoplastic matrix in glass mat reinforced, thermoplastic composites for use, for example, in the automotive industry. Carpet waste fibres are also being examined for use in injection and press moulding, for concrete reinforcement and for soil reinforcement in road construction. In the UK, some carpet is disposed of by incineration, for example in cement works. Despite the energy release this is now considered to be a last option because of the carbon dioxide produced and the possibility of toxic emissions. Other methods of disposal and recyling have been reviewed.[118,119] Eduard Kusters Maschinenfabrik GmbH in Germany are believed to have developed a method to process unwashed used carpet, together with wood chips, into laminated board.[120]

Amoco, which is part of BP, has developed the AdBac process which replaces latex as the backing for tufted carpets.[121] The process involves binding in the tufts with thermoplastic olefins, and is in commercial production in the USA. Several advantages over latex are offered, including energy savings in production because there is no water to dry off, weight reductions of about 500 g/m^2 with savings in transport costs, and significantly less emissions because polyolefins do not contain VOCs. In addition, the finished carpet has better water-resistant properties, and polyolefin is easier to recycle than latex and also contains no fillers to complicate issues. Latex is very effective as a tuft binder because it penetrates between individual filaments and fuzz is prevented. This penetration is more difficult to achieve with thermoplastic binders, which means powder coating as well as extrusion technology, because thermoplastic binders tend to encapsulate filament bundles. The problem can be minimised by a number of process adjustments.

Interface Inc. of Atlanta are developing biodegradable carpets using polylactic acid derived from cornstarch. This company has had a policy of sustainable development for some years now and aspires to zero emissions in manufacture. Interface is also one of the participants in a new company called WM Fibres Ltd which is setting up the first facility in the UK to recycle 12000 tonnes of carpet waste. The project, located at Knowsley, Merseyside is costing £1.5 million, and a significant feature is the ability to treat latex backed carpets. Eventually other textile waste will be processed.[122]

6.5.5 Recycling of textiles

At present, 'recycling' of textiles generally means cotton rags into paper, recovered wool (e.g. shoddy, mungo), charity shops selling second-hand clothing – a £15 million industry – and sending garments to third world countries – heavy clothing is sent to Eastern Europe, lighter garments to Africa. Clothing which is too degraded for use is made into rags for wipes.[123–126] However, these 'rags' will eventually have to be disposed of – probably with heavy soiling on them – and in addition disposable paper and non-woven textiles are reducing the need for rags as wipes. Other textile waste is shredded and used for filler and insulation in automotive components, and some is used in the flocking industry. Political problems have arisen over the export of used clothing because the EU classify ungraded mixed textiles as waste, and certain countries can impose additional import tax as waste control taxes.[127] In addition, some pressure groups believe used clothing should not be dumped on third world countries. A quality grading system for used clothing is being considered by the Textiles Recycling Association (TRA), Recyclatex, the Association of Charity Shops and other charities. There do seem to be a growing number of commercial organisations and associations concerned with textile recycling. The Bureau of International Recycling (Office in Brussels), affiliated to 600 companies in over 50 countries, has a Textiles Division. A 'Forum on Recycled Textiles' (FORT) has recently been formed by members of the TRA to discuss issues and co-ordinate effort. The Secondary Materials and Recycled Textiles Association (SMART) was actually founded in 1932, and has members from all over the world which represent a wide range of textile industries.[128,129]

Recycling of wool has been carried out for centuries, and for many years cotton rags have been made into paper. The problem of recycling of technical textiles as such does not seem to be a prominent issue at present, apart from the recycling of PVC coated fabrics. Despite work done in this area, there are as yet no actual PVC coated fabric recycling plants in commercial operation, and the recycling rate of PVC as an industry is believed to be only 3%. Light weight tarpaulins made from all olefinic material, i.e. polyethylene or polypropylene coated polyethylene or polypropylene yarns are being sold against lighter weight PVC coated material. The all olefinic material is easier to recycle than the PVC coated polyester. In another approach, research work is being conducted to develop water-based polyesters as coating resins for polyester fabric.[130] If this work is successful, the coated fabric will be made from a single plastic type and will be more suitable for recycling. In addition quicker, more economical and more convenient methods of identifying polymer type are being developed.

Recycling of coated and laminated fabrics is generally not easy, because by definition they are frequently made from at least two different polymers or materials and separation is likely to be a difficult if not an impossible commercial process for certain articles. Even standard articles of clothing such as shirts are likely to be made from polyester and cotton – two very different fibres. Much clothing and even old shoes are ‘reused’ by sending them to third world countries, and there may be some scope for this as a means to dispose of anoraks and cagoules which have become unfashionable or are only partly worn and which are still serviceable. However, the volume of coated jackets is quite small compared to the total amount of general garment waste. Some garment waste is shredded and used as sound and vibration insulation by the automotive industry and others. Coatings sometimes contain FR agents such as bromine compounds and antimony, and metallic additives and stabilisers such as those found in PVC and some rubbers. Waste material being disposed of now may have been made as early as 1990 or before when these chemicals were not considered harmful, and these materials may require special consideration. This factor could cause complications in recycling because these chemicals may now be considered harmful and their use prohibited. In addition, azo dyes were first banned in Germany in 1994 and are now also prohibited in France and the Netherlands. Clothing, especially industrial protective, may contain small amounts of potentially toxic chemicals; even smoking residues and traffic fume particulate matter may be harmful. They may have to be removed if the fibre is to be recycled into apparel, household textiles or automotive applications.

As has been seen in the case of automotive recycling, the recycling process begins with the logistics of collection, disassembly, if appropriate, identification and separation of the various fibre types, and then cleaning and disinfecting in the case of clothing. Material of the same fibre and quality has to be gathered together to make any recycling process economically feasible. Because of central government pressure on local authorities (see below), far more determined attempts are now being made to reduce the amount of waste which goes to landfill and to increase the proportion recycled and composted. The increased landfill charges, possibly £24 per tonne or more within the next four years, will change the economic feasibility of recycling and waste disposal processes. The Climate Change Levy on energy is also likely eventually to have an effect on the economics of recycling, reusing and certainly reducing. Everyone agrees that recycling, reusing and reducing are the best procedures, but they are not applicable to everything at present. As more and more articles are recycled, the issue of coated and laminated fabrics may well come under scrutiny and manufacturers of these articles could be affected under producer responsibility considerations. WRAP, a non-profit-making company, has recently been set up to create stable and efficient markets for recycled material. The government is to injected £40 million during the next three years – there may be opportunities for textiles?

6.5.5.1 Ecolog ™Recycling GmbH

In Germany VAUDE Outdoor Sport GmbH, a sportswear manufacturer, together with a number of suppliers to the garment industry, have formed Ecolog Recycling GmbH with the objective of producing an ecological and economical recycling system.[131] The system is based on the concept of producing garments made entirely out of polyester, including the buttons and cord stoppers. The polyester is thus pure and is conveniently recycled into new buttons, fleece fibre, threads and fibres. The consortium includes Sympatex Technologies, the makers of the waterproof and breathable polyester film. The Ecolog system was first formed in 1994, and a year later a subsidiary was formed in Japan which includes Toray Industries, Itochu and the Japanese Ministry of Commerce. This concept of single-fibre clothing is gradually gaining strength in the struggle to conserve non-renewable Earth resources.

6.5.6 Recycling and waste disposal

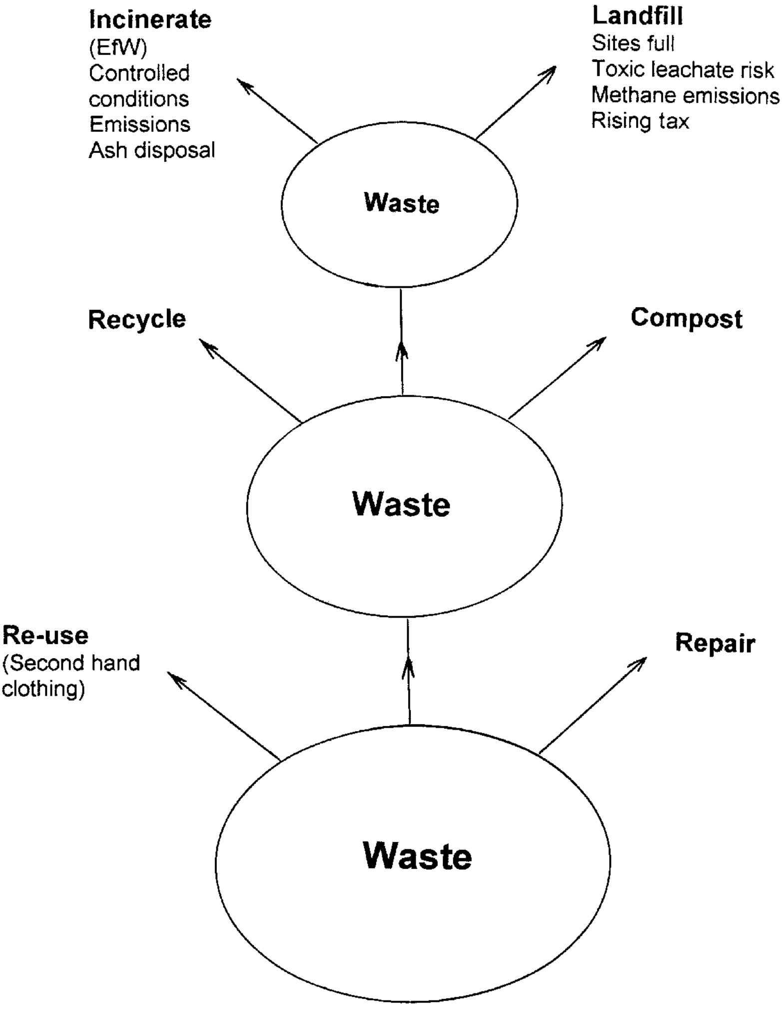
In the UK, local authorities were set a non-statutory target in 1990 to recycle 25% of municipal waste by the year 2000. No local authority actually attained this figure, and the average for England and Wales was just

9.5%. Statutory targets have now been set, and in addition to this the EC landfill directive is looming. UK landfill tax that was first set at £7 in 1996, had reached £12 by 2001 and will rise every year until 2004. Some analysts have forecast an eventual figure of £34. This policy is an attempt to reduce the amount of waste landfilled. British landfill levels are the highest in Europe; 1998/99 figures show 83% landfill, 8% incinerated with energy recovery, 1% composted and only 8% recycled. In comparison, during 1996 the figures for Germany were 34% landfill, 18% incinerated with energy recovery, 10% composted and 38% recycled.[132–134]

The EU propose a Directive on Waste designed to reduce emissions to air, water and land from the incineration of non-hazardous waste. This will tighten up and extend the scope of existing Waste Directives. An EU Composting Directive is being proposed which may include mandatory source separation of biodegradable waste, limits on contamination in composted material and possible targets for composting. An EU discussion document proposes biodegradable landfill waste to be reduced by 25%, taking 1995 levels as the baseline and 2006 as the target date. Countries such as the UK with existing high landfill levels would be allowed four extra years. A working document used by the EU suggests a hierarchy for managing waste which can be summarised as prevent or reduce, reuse, recover (when environmentally justified), compost, mechanically or biologically stabilise unsorted biodegradable waste – energy recovery is the final option. The paper suggests separate collection of biodegradable waste to maximise the scope for composting. Even composting needs careful control and siting away from residential areas because of unpleasant odours. Composting in the UK has grown by 23% per year in the last few years, and stood at about one million tonnes at the end of 2000, but of course this is still very small compared some other European countries.[135–137]

Textiles on the whole do not appear to be a major problem – from figures available, textiles constitute only about 1.5 to 2% of municipal waste. A proportion of this is likely to be carpet for which, as has been detailed above, there is a technical means of recycling. Coated domestic and apparel textiles must account for only a small percentage of this small figure, and no reference or comment has yet been seen which is specific to coated or laminated textiles. Coated PVC appears to be the only coated fabric receiving attention at the moment, and this is probably more associated with the environmental pressure groups' reservations in connection with PVC polymer material than the coated article.

The debate over whether to dispose of unuseable materials by landfill or incineration continues, see Fig. 6.3. The problems associated with incineration are greenhouse gases, such as carbon dioxide, and the possible formation of dioxins. However, if managed effectively, incineration can provide useful energy, and the process of incineration with energy release is referred



6.3 The problem of waste disposal. Material remaining after reusing (second hand clothing), recycling and composting must be disposed of either by incineration or by landfill. Incineration with energy recovery (EfW — energy from waste) requires careful control to prevent the formation of dioxins; emissions must be rigorously treated according to legislation, and preferably with the approval of local residents. Incineration residues, which may contain a high concentration of toxic substances, must be disposed of in some way. Landfill sites are filling up and landfill poses the risk of toxic leachate to underground waters, which may eventually reach rivers and drinking water. Landfill taxes are due to rise significantly. In addition, methane, a 'greenhouse' gas, is produced in landfills. The logistical problems of waste collection, dismantling, sorting and identification of different chemical types, and the transport costs are formidable. Routes may be possible, but they need to be commercially viable.

to as energy from waste (EfW). Landfill has the problems of rodents, insects, emissions of methane, the risk of explosion and possible leaching of liquors to watercourses. Leached liquors can contain high concentrations of toxic material, including ammonia and heavy metals, and can have high BOD, all of which are harmful to aquatic life and also pose risks to humans. However, methane emissions from landfill can also be used to generate electricity, and there are in fact 150 sites involved in power generation. On the other hand, the potential is likely to be reduced as less biodegradable waste is sent to landfill, and the generation of landfill gas needs 10 years for material to decay and produce useable levels of gas.

What cannot be recycled or composted needs to be disposed of in some way. If it has calorific value, incineration with energy recovery seems to be the logical means of disposal. To meet EU targets for reduced landfill, the increased use of EfW has been proposed, and this will require the construction of a number of EfW incinerators. The environmental pressure groups and others who fear toxic emissions and the effect on human health and the environment oppose this. The EU Directive on waste incineration contains a requirement that information on emissions from plants above a certain capacity, should be made public. The chief concerns of incineration are that waste not burnt at a high enough temperature could release dioxins and other toxic species into the atmosphere, and also that there is a problem disposing of residual ash which is likely to contain a concentration of toxic heavy metals. Any waste containing sulphur or nitrogen if incinerated is likely to produce the acidic emissions of sulphur dioxide and oxides of nitrogen which, as has already been noted, will require fume abatement. European Union regulations have also been applied to the technical design of municipal incinerators, and limitations have been set for toxic emissions. Incinerators are reputed to reduce waste volume by 90%, but some reports claim that the reality is nearer 50–70%, and that incinerator residual ash, which can only be disposed of by landfill, may contain toxic material in a more concentrated state than before. The emissions of municipal incinerators have been known to include dioxins, furans, oxides of nitrogen and even heavy metals, and this is one of the main reasons for the environmental pressure groups' concern. It is likely that there will be long lead times before new incineration capacity becomes available, because of the need for public enquiries and because of strong local opposition.

The UK government has set out its strategy to maximise the amount of value from the 106 million tonnes of commercial, industrial and municipal waste by increased recycling, composting and energy recovery. The amount sent to landfill must be reduced substantially, producers must increasingly expect to arrange for recovery of their material and new and stronger markets need to be developed for recycled materials.[138,139] Technical textile and coating polymer manufacturers, chemical and adhesive producers and marketing organisations way well be asked at some time in the future to contribute to disposal of coated or laminated fabrics.

6.5.7 Use of natural fibres and materials

In recent years there has been a revival of the use of natural materials in the automotive industry. The reasoning is that use of raw materials from renewable sources is more environmentally responsible than the use of synthetic fibres and plastics produced from non-renewable oil reserves.[140,141] In addition, natural materials are more biodegradable, and there are also technical advantages. Bast fibres, flax, sisal, kenaf and hemp are being explored as replacements for the more expensive glass as long fibre reinforcement in polyurethane injection mouldings for door panels and in other applications. Some products are already on the market and are being used, notably by German OEMs. Indeed the use of natural fibres in German cars quadrupled between 1996 and 2000 to 20000 tonnes and this figure is likely to double by 2005. Bast fibres are claimed to need less chemicals in growing and are therefore more environmentally friendly. Hemp is reported to grow over most weeds and can reach a height of 4m in 70 days. It is essential to use LCA techniques to determine impact on the environment; natural fibres are not necessarily the most environmentally friendly. Cotton, for example, while it is renewable and biodegradable, is believed to be sprayed with 12% of the world's insecticides and 26% of the world's pesticides, and in addition requires large amounts of water to grow.

The Crea Tech Process developed by Alpha Plastics and Haas Kunstoff uses natural thermoplastic material extracted from certain plants which is filled with derivatives from wheat, oats and soya. The resultant compound resembles and has similar properties to ABS, but will biodegrade under high humidity after 10 years. A further novel feature is that the bond between the covering decorative material and the rigid part can be controlled to be satisfactory in use, but can be separated at the end of the life of the car to facilitate recycling.[142,143]

DuPont and other major chemical companies are researching the manufacture of biodegradable polymers using plants as the starting material.[144,145] Work of this type is likely to increase, and it is possible that we will eventually see significantly less non-renewable oil being made into textiles. Already the cellulosic based Lyocell fibres, e.g. Tencel (Acordis), are being made in increasing amounts from wood grown in sustainable forests. Perhaps we should be researching biodegradable polymer materials as coatings.

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