

## 1.1 Overview

Textile materials are used in all sports as sportswear, and in many games as sports equipment and sports footwear. Examples of sportswear are: aerobic clothing, athletic clothing, football clothing, cricket clothing, games shorts, gloves, jackets, pants, shirts, shorts, socks, sweatshirts, swimwear and tennis clothing. Examples of sport equipment are: sails, trampolines, camping gear, leisure bags, bikes and rackets. Examples of sports footwear are: athletic shoes, football boots, gym shoes, tennis shoes and walking boots.

The consumption of textile fibres and fabrics in sportswear and sporting related goods has seen a significant increase in the last decade or so. In an analysis made in 2002 by David Rigby Associates, it was stated that the worldwide consumption of textiles for sports increased from 841,000 tons in 1995 to 1,153,000 tons (projected) in 2005. The forecast made for 2010 was 1,382,000 tons. This reflects to a large extent the significant rise in interest of the population worldwide in active indoor and outdoor sports as well as in outdoor leisure pursuits. This rising interest is due to a number of social factors that include increased leisure time, increased considerations of well-being and good health, growth of indoor and outdoor sports facilities as well as the ever increasing pursuit of the adult population of activities outside the home or workplace. Textile materials in various shapes and forms are being used in a wide range of applications in sportswear and sporting equipment, and the manufacturers of these products are often at the forefront of textile manufacturing technologies for enhancing the properties of performance fabrics and sportswear in order to fulfil various types of consumer and market demands.

The strong rise in female participation in professional and outdoor sport has also been an important factor responsible for the development trends in sportswear. It was reported in *Textile Outlook International* (March/April 2003) that, in 2000, US\$36.4bn was spent on sport apparel in the USA. Of this, as much as US\$21.8bn, or around 60%, was attributed to purchases by women. According to data compiled from warranty registered cards submitted by women who have purchased Oakley

products, 25% play golf, 23% ski, 20% are involved in mountain biking, 11% snowboard and 5% surf. In the UK, consumers spent £4.05bn on sportswear in 2002, representing 10.3% of the total UK clothing market.

The sportswear and sports goods sector of the textile industry has not only seen market diversification for fibrous materials but has also contributed towards the elevation of textile science and technology to a level approaching that of other high-tech industrial sectors. New technological developments, more fragmented niche markets and increasingly demanding customer expectations are just some of the factors relentlessly driving this industrial sector. To thrive in this environment, companies are implementing radically new product development practices. Global market volume of sportswear varies depending on the type of end-use applications. High-value products exist at the upper end of the price scale, at low volumes, and these are very specialized products where performance, quality and design, and not price, seem to be the determining factors. The sportswear market occupies an important place in the total textile scene and this segment of the textile market is growing at a high rate. The producers of sportswear and sports goods have been concentrating their efforts on improving their strategic position, productivity, added-value product assortment and niche positions in order to expand their markets.

The performance requirements of many sporting goods often demand widely different properties from their constituent fibres and fabrics, such as barrier to rain, snow, cold, heat and strength, and at the same time these textiles must fulfil the consumer requirements of comfort, drape, fit and ease of movement. Among the contributing factors responsible for successful marketing of functional sportswear and sporting goods have been advances made in the fibre and polymer sciences, and production techniques for obtaining sophisticated fibre, yarns and fabrics. The finishing and coating/laminating industries have done pioneering work in the area of developing these technologies towards the needs of the sportswear and sporting goods sectors resulting in unique products.

## **1.2 Innovations in fibres and textile materials for sportswear**

### *Fibre developments*

The evolution of fibre developments has gone through the phases of conventional fibres, highly functional fibres and high-performance fibres. Polyester is the single most common fibre used for sportswear and active wear. Other fibres suitable for active wear are polyamide, polypropylene, acrylics and elastanes. Wool and cotton fibres are still finding applications in leisurewear. Synthetic fibres can either be modified during manufacture, e.g. by producing hollow fibres and fibres with irregular cross-section, or be optimally blended with natural fibres to improve their thermo-physiological and sensory properties.

Synthetic fibres with improved UV resistance and having anti-microbial properties are also commercially available for use in sportswear.

Improved fibre spinning techniques in melt spinning, wet spinning, dry spinning as well as new techniques such as gel spinning, bi-component spinning and microfibre spinning, have all made it possible to produce fibres, yarns and fabrics with unique performance characteristics suitable for use in sportswear and sports goods. New technologies for producing microfibrils have also contributed towards production of high-tech sportswear.

By using the conjugate spinning technique, many different types of sophisticated fibres with various functions have been commercially produced which has resulted in fabrics having improved mechanical, physical, chemical and biological functions. The technique of producing sheath/core melt spun conjugate fibres has been commercially exploited for producing added-value fibres. Unitika produced the first heat-regenerating conjugate fibre with a core containing zirconium carbide (ZrC). Since ZrC absorbs sunlight (visible and near-infrared radiation) and emits far-infrared radiation, one feels warmer when one puts on a jacket made from such fibres. Other types of heat-generating fibres contain ceramic micro-particles.

### *High-performance fibres*

Today, a wide range of high-performance fibres is commercially available for technical and industrial applications. These types of fibres are used in sports protective wear/equipment developed for impact protection and in textile reinforcement in sports products for different applications. Among the speciality fibres already established are the following:

- *Aramid fibres:*
  - *p*-aramid fibre to provide high strength and ballistics
  - *m*-aramid fibre to provide flame and heat resistance.
- *Ultra-high tenacity polyethylene fibres (UHMWPE).* Gel spun, ultra-high molecular weight polyethylene fibres with extremely high specific strength and modulus, high chemical resistance and high abrasion resistance.
- *Polyphenylene sulphide fibres (PPS).* Crystalline thermoplastic fibre with mechanical properties similar to regular polyester fibre. Excellent heat and chemical resistance.
- *Polyetheretherketone fibres (PEEK).* Crystalline thermoplastic fibre with high resistance to heat and to a wide range of chemicals.
- *Novoloid (cured phenol-aldehyde) fibres.* High flame resistance, non-melting with high resistance to acid, solvents, steam, chemicals and fuels. Good moisture regain and soft hand.
- *PBO (p-phenylene-2,6-benzobisoxazole) fibres.* The strength and modulus of this fibre exceed those of any known fibres.

*Highly functional fabrics*

There has been a strong growth in the development and use of highly functional materials in sportswear and outdoor leisure clothing. The performance requirements of many such products demand the balance of widely different properties of drape, thermal insulation, barrier to liquids, antistatic, stretch, physiological comfort, etc. The research in this field over the past decade has led to the commercial development of a variety of new products for highly functional end-uses. By designing new processes for fabric preparation and finishing, and as a result of advances in technologies for the production and application of suitable polymeric membranes and surface finishes, it is now possible to combine the consumer requirements of aesthetics, design and function in sportswear for different end-use applications. The fabrics for active wear and sportswear are also specially constructed both in terms of the geometry, packing density and structure of the constituent fibres in yarns and in terms of the construction of the fabric in order to achieve the necessary dissipation of heat and moisture at high metabolic rates. Many smart double-knitted or double-woven fabrics have been developed for sportswear in such a way that their inner face, close to human skin, has optimal moisture wicking and sensory properties whereas the outer face of the fabric has optimal moisture dissipation behaviour.

In addition to the innovations in highly functional man-made fibre-based fabrics, advances have also been made in cotton and wool fabrics for sportswear. An example is the development of 'Sportwool' weatherproof technology, where the constituent fibre, yarn and fabric properties and the fabric finishes of 'Sportwool' are supposed to create a drier and cooler microclimate.

Since the introduction of Gore-Tex fabric in 1976, a variety of lightweight breathable highly functional fabrics have been developed worldwide. Highly functional fabrics are generally characterized as being waterproof/moisture permeable, sweat-absorbing and with high thermal insulation at low thickness values. These fabrics are now extensively used in making sportswear and sports shoes. One can say that these products are basically complex materials with diverse functions. In many of these products the requirements of comfort and fashion have successfully been integrated with segmentation in uses.

Important developments are envisaged in making multifunctional coated or laminated fabrics for different applications. For example, some new innovative functional textiles for protective clothing were recently introduced by W. Gore and Associates. Gore-Tex Airlock is a functional textile which was developed by Gore for the special needs of firefighters. The concept of this product is to eliminate the conventional, bulky, thermal insulation layer and substitute it by a protective air cushion. Dots consisting of foamed silicone are discontinuously applied to a fibre substrate and anchored within the microporous Gore-Tex membrane. They measure only a few millimetres in height, creating a defined air cushion between the adjacent flame-retardant face fabric and the inner lining.

This laminated fabric is characterized by thermal insulation, breathability, perspiration transport, absorption and quick-dry properties.

### *Biomimetics and textiles*

The structure and functions of natural biological materials are precise and well defined. The imitation of living systems, 'biomimetics', could make it possible in future to replicate the molecular design and morphology of natural biological materials since their structure and functions are related. Already in many laboratories around the world, R&D work is going on in the field of biomimetic chemistry and fabric formation. A typical example is the development of water- and soil-repellent fabrics produced by imitating the surface structure of a lotus leaf. Water rolls like mercury from the lotus leaf, whose surface is microscopically rough and covered with a wax-like substance with low surface tension. When water is dropped on to the surface of a lotus leaf, air is trapped in the dents and forms a boundary with water.

### *Intelligent textiles*

There have been some interesting developments taking place regarding intelligent textiles and interactive materials with great market potential in the sportswear sector. These materials readily interact with human/environmental conditions thereby creating changes in the material properties. For example, the phase-change materials and shape-memory polymers embedded in fabric layers will be able to interact with a human body and produce thermoregulatory control by affecting the microclimate between the clothing and the human skin. In addition to the two dimensions of functionality and aesthetics, if 'intelligence' can be embedded or integrated into clothing as a third dimension, it would lead to the realization of protective and safety clothing as a personalized wearable information infrastructure.

## **1.3 Design considerations in sportswear/footwear**

Design requirements of active and performance sportswear have produced designers with skills and knowledge in graphics, textiles and fashion to conceive aesthetically pleasing and ergonomically viable ranges which take advantage of the latest advances in functional and 'smart' textiles. Leading fashion designers have been quick to realize that the performance has actually become the aesthetics in sportswear. It is the fabrics and technology that set the trend. Incorporation of microfibrils, breathable barrier fabrics, innovative stretch materials, intelligent textiles, interactive materials such as phase-change materials and shape-memory polymers, and wearable technology as a part of the functional design system in sportswear, will become routine in the product development process.

The development of new materials and designs for sports footwear has created an extremely competitive market for footwear design. The needs of consumers for active sport and leisure are performance, protection and comfort related. The design concepts are based on biomechanical analysis related to the knowledge of foot morphology, anatomy and lower extremity mechanics. The use of lightweight, durable, and energy-absorbing and moisture/heat-regulating materials is becoming a critical factor for functional design in sports footwear. Microfibres, breathable membranes and coatings, moulded polyurethane, air cushions and various forms of gel capsule, elastomeric fabrics and phase-change materials (PCM) are becoming common features promoted in shoe design.

Advances in innovative highly functional uncoated and coated textiles and coatings as well as in garment manufacturing technology have resulted in more sophisticated sportswear and footwear specifically designed for different user categories of performance sports and outdoor leisure activities. All this helps to speed the runner, keep the jogger dry and cool, streamline the swimmer, protect the cricketer, hockey player and snowboarder, keep the football player and cyclist dry, and keep the user comfortable and warm in extreme weather conditions. The functional design of newly developed sportswear and sports footwear has a strong impact on leisurewear and leisure footwear as well.

## 1.4 Sportswear and comfort

In active and endurance sports, the performance of a sportswear is synonymous with its comfort characteristics. In active wear for outdoor use, the clothing should be capable of protecting the wearer from external elements such as wind, sun, rain and snow. At the same time, it should be capable of maintaining the heat balance between the excess heat produced by the wearer due to increased metabolic rate on the one hand, and the capacity of the clothing to dissipate body heat and perspiration on the other.

Over the past two decades significant advances have been made in the technologies for spinning fibres and yarns, the production techniques for functionally designed knitted and woven fabrics as well as in the highly functional coating and laminating technologies. All these efforts have resulted in some of the most interesting fabrics which possess the desired characteristics of good tactile properties, thermal insulation, stretch, quick liquid absorption, ability to evaporate water while staying dry to the touch, and being capable of transporting perspiration from the skin to the outer surface and then quickly dispersing it. The performance category that has seen a large number of innovations is that of moisture management, which is directly related to comfort.

Highly functional coated and laminated fabrics are now commercially available which are aesthetically attractive, breathable yet with the desired barrier characteristics against the external elements. These fabrics are engineered by using either microporous or hydrophilic membranes, and the

water vapour transmission through these membranes is achieved by the physical processes of adsorption, diffusion and desorption.

Thermally adaptive technology such as the incorporation of phase-change materials into sportswear and active wear is gaining momentum in different market sectors. These materials interact with the microclimate between the human body and the clothing and respond to the fluctuations in temperature which are caused by changes in activity level and the external environments. The textile structures with embedded PCM microcapsules have the following interactive functions:

- Absorption of surplus body heat.
- An insulation effect – caused by heat emission of the PCM into the textile structure.
- A thermoregulatory effect – which keeps the microclimate temperature nearly constant.

## **1.5 Sportswear and protection from injury**

Prevention of injuries is one of the primary concerns of participants in many types of sports and games and has lately attracted greater research attention. For impact protection to be provided by the clothing or sporting equipment such as protective helmets, it is necessary to use textiles and textile-based materials which possess high strength and durability as well as a high level of energy absorption. These materials are attached to the clothing in appropriate places depending on the sporting activity and the information available from injury risk analyses of different sports and games. A variety of textiles and textile composite structures are commercially available with the required mechanical properties of strength, impact resistance, abrasion resistance and tear strength for rugged outdoor and performance sports and games.

## **1.6 The sportswear and sports footwear industry**

The sportswear and sports footwear industry is one of the foremost innovators in the textile and clothing sector and has been a launch pad for many new ideas and concepts in material and product design. The industry is composed of both large and medium-sized enterprises with some of the most famous brand names, where each brand name is associated with special functional design, performance quality and the type of targeted sport or game. Well-respected branded sportswear and sports footwear companies with a global market include Nike, Adidas, Puma, Reebok, Russell Corporation, Umbro, Berghaus, Scanda, Arena, Paramo, Salomon, Rukkla, Sprayway, Helly Hansen and Oscar Jacobsson. We have been noticing a strong trend towards the combination of multi-functionality of materials and fashion in many items of sportswear and leisure clothing. The

result has been the emergence of many different types of high-tech fabrics and garment designs with some remarkable performance properties.

The sports clothing and footwear business have become very technically oriented, using highly functional textiles for specialized performances in different sports, e.g. good thermal properties for cold-weather sport; aerodynamic properties for downhill skiing and swimming, breathable waterproofing for outdoor pursuits; strength and durability for sails. With the advent of intelligent textiles, functional design and wearable technology, innovative solutions have become the name of the game for the sportswear businesses. The performance sportswear of today has become a truly engineered product designed to fulfil the consumer's requirements of light weight, softness, injury-preventive, thermoregulatory, elastic, anti-microbial, durable, aesthetic, etc. This book brings together information about the state of the art of textiles in sportswear and about the future trends in this important business sector.

## 1.7 About the book

The objective of this book is to describe the developments in textile fibres and materials with specific reference to their use in sportswear and sporting goods. The sixteen chapters cover the following five general topics of interest:

- Current sportswear market
- Innovative fibres and fabrics in sports
- Sportswear and comfort
- Protection
- Specific applications.

The contributors to this book represent a team of international experts at the cutting edge of textile research and clothing design relevant to sportswear and sporting goods.

In Chapter 2, David Buirski gives an overview of the sportswear and sporting goods market. This chapter is written as a personal view of how the author sees the market with the benefit of the hindsight. In addition to containing facts and figures, the chapter tells us about the extraordinary development of sport itself and how textiles are used to serve this market. It also describes the future of this market and where the market will lead as far as textile developments are concerned.

In Chapter 3, Sophie Bramel has covered the key trends in sportswear design and describes in detail how advances in fibre and textile engineering offer great opportunities for new creative garment design and enhanced wearer comfort. Innovations in textiles influence sportswear design at two basic levels: from the technical perspective, new materials enable improved performance regarding protection as well as athletic performance and achievement, and at an aesthetic level they facilitate the introduction of new styling options.



In Chapter 4, Jane McCann has written about functional design of sportswear and material requirements for the design of performance sportswear. Developments in sport-specific clothing from postwar to present day are described, keeping in mind the needs of the end-user. The topics covered include material developments, commercialization of sport, sportswear for women, trends/styles and fashion, fibre branding and garment development. This is followed by a description of the design development process addressing the functional needs of the end-user, the demands of the sport, and form and style considerations. The author then describes some emerging trends such as commercial reality, smart clothes and wearable technology, biomimetics and environmental issues.

In Chapter 5, Merianne Nebo has written about the functional design of sports footwear. Primary features of sports footwear are comfort, performance, protection, support and shock absorbance. A functional footwear design means understanding the shoe end-usage, sport/performance requirements, shoe construction and manufacturing techniques. Topics covered include: functional fit of sports footwear; biomechanics of the foot; fitting areas of the shoe such as flexing point, heel, toe and arch, heel-to-joint; shock absorbency; fastening system; and shoe size systems. Finally, functional materials and components in sports footwear are described.

In Chapter 6, Thomas Stegmaier, Joseph Mavelly and Petra Schneider describe the structure–property relationship of high-performance fibres and textiles and how fibres and textiles are treated to produce highly functional materials. High-performance fibres are made of special polymers using specific fibre-spinning techniques which result in fibres of high modulus, high strength, high shear stability, high thermal stability, high fire resistance and high resistance to chemicals. An overview of different textile formation processes and of finishing and coating is also given. The authors then describe the advances made in highly functional fibres and textiles for applications in sportswear and outline how these properties can be obtained from the constitutive materials and by means of adding properties using chemical, physical and mechanical methods.

In Chapter 7, Harriet Meinander writes on the topic of smart and intelligent fibres and fabrics with particular reference to sportswear. She describes some smart textile materials including phase-change materials, shape-memory materials and chromic materials. Some smart clothing solutions are also described, including clothing with adjustable thermal insulation, heating and cooling garments and wearable technology.

In Chapter 8, Walter Fung writes about coated and laminated materials and sports products made from these materials. He describes the basic fabric types used and the technology available for producing highly functional coated and laminated fabrics. Testing of coated and laminated fabrics and quality assurance are also described in brief. Some environmental, health and safety aspects are also discussed.

In Chapter 9, Volkmar Bartels describes the importance of physiological comfort of sportswear. The wear comfort affects not only the well-being of the wearer but also the wearer's performance and efficiency. Wear comfort has become a major marketing strategy. Bartels describes the methodology used to make objective measurements of wear comfort which incorporates both physiological and mechanical comfort parameters. The influence of fabric type and construction and the finishing treatment on comfort properties are described. Some sportswear applications are discussed, giving examples of elastic knitwear, biofunctional textiles, foul weather protective laminates and their combinations with functional underwear.

In Chapter 10, Jacqui Voyce, Petros Dafniotis and Simon Towlson write about the elastic textiles used in sportswear. Minimizing a garment's resistance to the body's demands in movement can be achieved through increased fabric fullness in the pattern or through fabric stretch. Increasing the fabric stretch means garments can be cut to achieve a more streamlined appearance and can conform better to the body, whilst maintaining comfort for the wearer in motion. The methods for creating fabrics with optimal stretch properties are described, as are important fabric properties in relation to maximizing comfort and performance for participants in active sports. Other aspects covered in this chapter include garment engineering, hydrodynamics in swimming, and aerodynamics for track, field and cycling. The subject of well-being through clothing is also discussed.

In Chapter 11, Raechel Laing and Debra Carr consider human protection against impact using clothing and personal equipment, or 'Is protection part of the game?' Impact is relevant in many sporting activities, therefore the prevention of injury during sporting activity is of great importance. By considering the injuries sustained during a selected group of sporting activities, this chapter examines the issue of impact protection provided by protective sportswear and equipment, and the effect of protective clothing and equipment on human performance. A description of guidelines, codes of practice and standards is also given.

In Chapter 12, Ingvar Holmér considers the protective requirements of thermal clothing for a wearer in a cold environment, such as that encountered in winter sports, endurance sports, cross-country skiing, skating, alpine skiing, sleeping outdoors and water sports. The issues discussed in this chapter are thermal stress factors in winter sports, metabolic heat production during the performance of winter sports, human heat balance, requirements for protective clothing, measurement methods, performance of winter sports clothing, and specific materials for cold protection in winter sports.

In Chapter 13, Ji-Young Ruckman writes about water resistance and moisture transfer properties of sportswear. The subjects described in this chapter include waterproof and breathable garments, performance and protection under steady-state conditions, performance and protection against windy conditions,

performance and protection against rainy conditions, performance and protection under wind-driven rainy conditions, and the condensation problem in waterproof breathable fabrics for sportswear.

In Chapter 14, Kathleen Van de Velde looks at the development of textile composites for use in sports products and equipment. The materials and technology used for manufacturing these composites are described, followed by several examples of combinations of materials, design features and production processes for different sports goods applications, including pole vault, fishing gear, bicycles, golf clubs, baseball bats, tennis rackets, kayaks, skis/snowboards and hockey gear.

In Chapter 15, Roy Buckley writes about textiles in sailing. Most consumption of textiles specific to sailing boats, yachts and ships, whether for competitive sport or for leisure, is in cloths for sails and spinnakers. These two products therefore receive most attention in this chapter, along with coverage of laminates and cover fabrics. Manufacture of polyester sailcloth is described in detail, including polyester sailcloth preparation, dyeing of polyester sailcloth, finishes and finishing of polyester sailcloth. The author also describes the production and processing of nylon spinnakers. Other items covered are: sail design and the sail making process, laminated sails and cover fabrics.

In Chapter 16, Edward Frederick and Craig Wojcieszak write about the use of textiles in sports shoes. It was in mid-1970 that the North American and, later, European general public's increased interest in jogging and fitness began to change the face of sports shoe making, where textiles played a major role. A broad array of uses of textiles in footwear can be identified. The authors describe the current use of textiles in sports shoes regionally within the shoe, starting with the shoe upper with its constituent layers and ending up with the components in the shoe sole. They have also presented a wish list for future textile developments to better meet the needs of the foot.

This book is intended for a broad spectrum of readers worldwide, ranging from scientists, designers and technical staff employed at academic institutions, to biomedical researchers, to material buyers, designers and product development staff working in companies that manufacture sportswear, sports footwear and sports equipment, to undergraduate students, to active sportspersons and consumers in general. The contents and layout are designed to provide information about a variety of important developments related to textiles in sport. The book should be of great interest to the general public since the developments in materials and design of sportswear and sports footwear often lead to new fashion trends in the leisurewear markets.

