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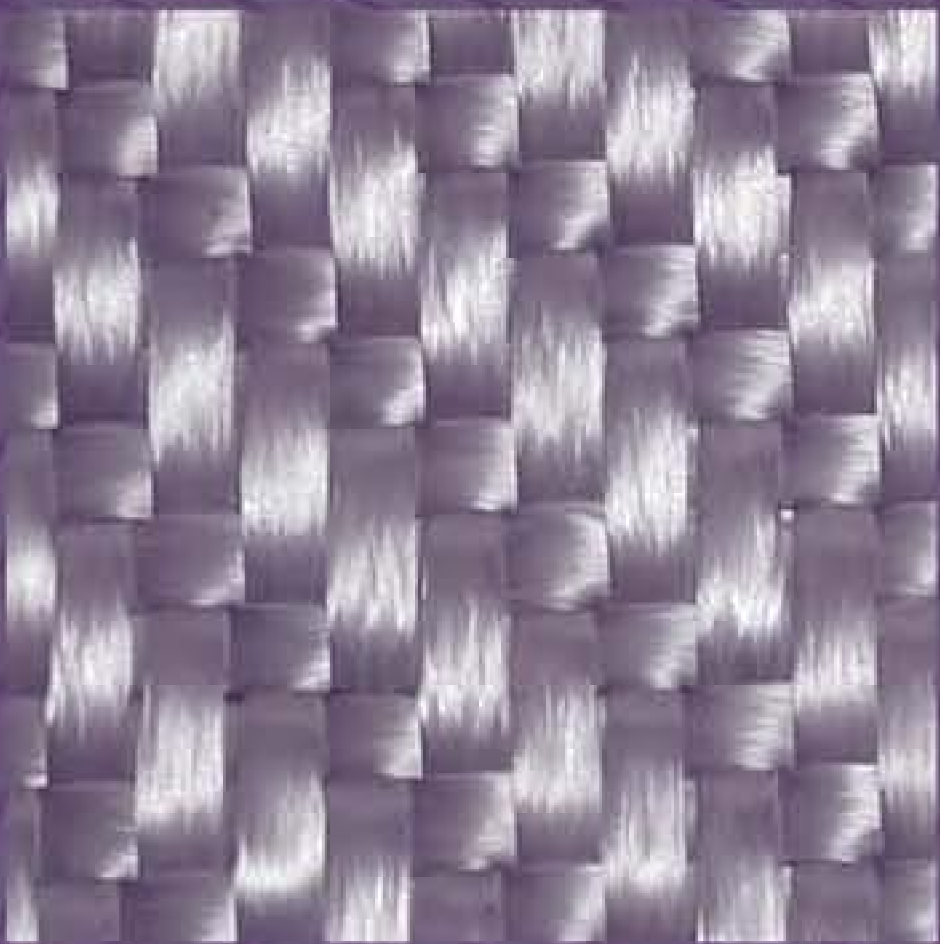

Design and manufacture of textile composites

Edited by A. C. Long

CRC

The Textile Institute

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Design and manufacture of textile composites

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Introduction

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Textile composites are composed of textile reinforcements combined with a binding matrix (usually polymeric). This describes a large family of materials used for load-bearing applications within a number of industrial sectors. The term textile is used here to describe an interlaced structure consisting of yarns, although it also applies to fibres, filaments and yarns, and most products derived from them. Textile manufacturing processes have been developed over hundreds or even thousands of years. Modern machinery for processes such as weaving, knitting and braiding operates under automated control, and is capable of delivering high-quality materials at production rates of up to several hundreds of kilograms per hour. Some of these processes (notably braiding) can produce reinforcements directly in the shape of the final component. Hence such materials can provide an extremely attractive reinforcement medium for polymer composites.

Textile composites are attracting growing interest from both the academic community and from industry. This family of materials, at the centre of the cost and performance spectra, offers significant opportunities for new applications of polymer composites. Although the reasons for adopting a particular material can be various and complex, the primary driver for the use of textile reinforcements is undoubtedly cost. Textiles can be produced in large quantities at reasonable cost using modern, automated manufacturing techniques. While direct use of fibres or yarns might be cheaper in terms of materials costs, such materials are difficult to handle and to form into complex component shapes. Textile-based materials offer a good balance in terms of the cost of raw materials and ease of manufacture.

Target application areas for textile composites are primarily within the aerospace, marine, defence, land transportation, construction and power generation sectors. As an example, thermoset composites based on 2D braided preforms have been used by Dowty Propellers in the UK since 1987[1]. Here a polyurethane foam core is combined with glass and carbon fibre fabrics, with the whole assembly over-braided with carbon and glass tows. The resulting preform is then impregnated with a liquid thermosetting polymer via resin transfer moulding (RTM). Compared with conventional materials, the use of textile composites in this application results in reduced weight, cost savings (both initial cost and cost of ownership), damage tolerance and improved performance via the ability to optimise component shape. A number of structures for the Airbus A380 passenger aircraft rely on textile composites, including the six metre diameter dome-shaped pressure bulkhead and wing trailing edge panels, both manufactured by resin film infusion (RFI) with carbon non-crimp fabrics, wing stiffeners and spars made by RTM, the vertical tail plane spar by vacuum infusion (VI), and thermoplastic composite (glass/poly (phenylene sulphide)) wing leading edges. Probably the largest components produced are for off-shore wind power generation, with turbine blades of up to 60 metres in length being produced using (typically) non-crimp glass or carbon fabric reinforcements impregnated via vacuum infusion. Other application areas include construction, for example in composite bridges which offer significant cost savings for installation due to their low weight. Membrane structures, such as that used for the critically acclaimed (in architectural terms) Millennium Dome at Greenwich, UK, are also a form of textile composite. Numerous automotive applications exist, primarily for niche or high-performance vehicles but also in impact structures such as woven glass/polypropylene bumper beams.

This book is intended for manufacturers of polymer composite components, end-users and designers, researchers in the fields of structural materials and technical textiles, and textile manufacturers. Indeed the latter group should provide an important audience for this book. It is intended that manufacturers of traditional textiles could use this book to investigate new areas and potential markets. While some attention is given to modelling of textile structures, composites manufacturing methods and subsequent component performance, this is intended to be substantially a practical book. So, chapters on modelling include material models and data of use to both researchers and manufacturers, along with case studies for real components. Chapters on manufacturing describe both current processing technologies and emerging areas, and give practical processing guidelines. Finally, applications from a broad range of areas are described, illustrating typical components in each area, associated design methodologies and interactions between processing and performance.

The term ‘textile composites’ is used often to describe a rather narrow range of materials, based on three-dimensional reinforcements produced using specialist equipment. Such materials are extremely interesting to researchers and manufacturers of very high performance components (e.g. space transportation); an excellent overview is provided by Miravette[2]. In this book the intention is to describe a broader range of polymer composite materials with textile reinforcements, from woven and non-crimp commodity fabrics to 3D textiles. However random fibre-based materials, such as short fibre mats and moulding compounds, are considered outside the scope of this book. Similarly nano-scale reinforcements are not covered, primarily because the majority of these are in short fibre or platelet forms, which are not at present processed using textile technologies.

The first chapter provides a comprehensive introduction to the range of textile structures available as reinforcements, and describes their manufacturing processes. Inevitably this requires the introduction of terminology related to textiles; a comprehensive description is given in the Glossary. Also described are modelling techniques to represent textile structures, which are becoming increasingly important for prediction of textile and composite properties for design purposes. Chapter 2 describes the mechanical properties of textiles, primarily in the context of formability for manufacture of 3D components. The primary deformation mechanisms, in-plane shear, in-plane extension and through-thickness compaction, are described in detail, along with modelling techniques to represent or predict material behaviour. Chapter 3 describes similar behaviour for pre-impregnated composites (often termed prepregs), focusing on their rheology to describe their behaviour during forming. Chapter 4 demonstrates how the behaviour described in the previous two chapters can be used to model forming of textile composite components. This includes a thorough description of the theory behind both commercial models and research tools, and a discussion of their validity for a number of materials and processes. Chapters 5 and 6 concentrate on manufacturing technologies for thermoset and thermoplastic composites respectively. Manufacturing processes are described in detail and their application to a range of components is discussed.

In Chapter 7, resin flow during liquid moulding processes (e.g. RTM) is discussed. This starts with a description of the process physics but rapidly progresses to an important area of current research, namely optimisation and control of resin flow during manufacturing. Chapter 8 describes the mechanical properties of textile composites, including elastic behaviour, initial failure and subsequent damage accumulation up to final failure. The first half of the chapter provides an excellent primer on the mechanics of composites in general, and shows how well-established theories can be adapted to represent textile composites. The second half on failure and impact builds upon this and concludes with a number of applications to demonstrate the state of the art. In Chapter 9 flammability is discussed – an important topic given the typical applications of textile composites and the flammability associated with most polymers. Chapter 10 introduces concepts associated with technical cost modelling, which is used to demonstrate interactions between the manufacturing process, production volume and component cost. Finally the last four chapters describe a number of applications from the aerospace, construction, sports and medical sectors.

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1
Manufacturing and internal geometry of textiles

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1.1 Hierarchy of textile materials

Textiles technologies have evolved over millennia and the term 'textile' now has a very broad meaning. Originally reserved for woven fabrics, the term now applies to fibres, filaments and yarns, natural or synthetic, and most products derived from them. This includes threads, cords, ropes and braids; woven, knitted and non-woven fabrics; hosiery, knitwear and garments; household textiles, textile furnishing and upholstery; carpets and other fibre-based floor coverings; industrial textiles, geotextiles and medical textiles.

This definition introduces three important notions. First, it states that textiles are **fibrous** materials. A fibre is defined as textile raw material, generally characterised by flexibility, fineness and high ratio of length to thickness; this is usually greater than 100. The diameter of fibres used in textile reinforcements for composites (glass, carbon, aramid, polypropylene, flax, etc.) varies from 5 μm to 50 μm. Continuous fibres are called *filaments*. Fibres of finite length are called *short*, *discontinuous*, *staple* or *chopped* with lengths from a few millimetres to a few centimetres.

Fibres are assembled into *yarns* and fibrous plies, and then into textiles. The second important feature of textiles is their **hierarchical** nature. One can distinguish three hierarchical levels and associated scales: (1) fibres at the *microscopic* scale; (2) yarns, repeating unit cells and plies at the *mesoscopic* scale; and (3) fabrics at the *macroscopic* scale. Each scale is characterised by a characteristic length, say 0.01 mm for fibre diameters, 0.5–10 mm for yarn diameters and repeating unit cells, and 1–10 m and above for textiles and textile structures. Each level is also characterised by dimensionality where fibres and yarns are mostly one-dimensional while fabrics are two- or three-dimensional, and by structural organisation where fibres are twisted into yarns, yarns are woven into textiles, etc.

Textiles are **structured** materials. On a given hierarchical level one can think of a textile object as an entity and make abstraction of its internal structure: a yarn may be represented as a flexible rod, or a woven fabric as a membrane. This approach is useful but the internal structure must be considered if one wishes to assess basic features and behaviour of textile objects such as the transverse compression of yarns or shear behaviour of fabrics. The diversity of textile technologies results in a large variety of available textile structures. Figure 1.1 depicts textile structures that are widely used as reinforcements for composites; these are discussed in this chapter.

The properties of a fabric are the properties of fibres transformed by the textile structure. The latter is introduced deliberately during manufacturing. Modern fibres turn millennium-old textile technologies into powerful tools for creating materials designed for specific purposes, where fibre positions are optimised for each application. Textile manufacturing methods and internal structure are two important topics that are addressed in this chapter.

1.2 Textile yarns

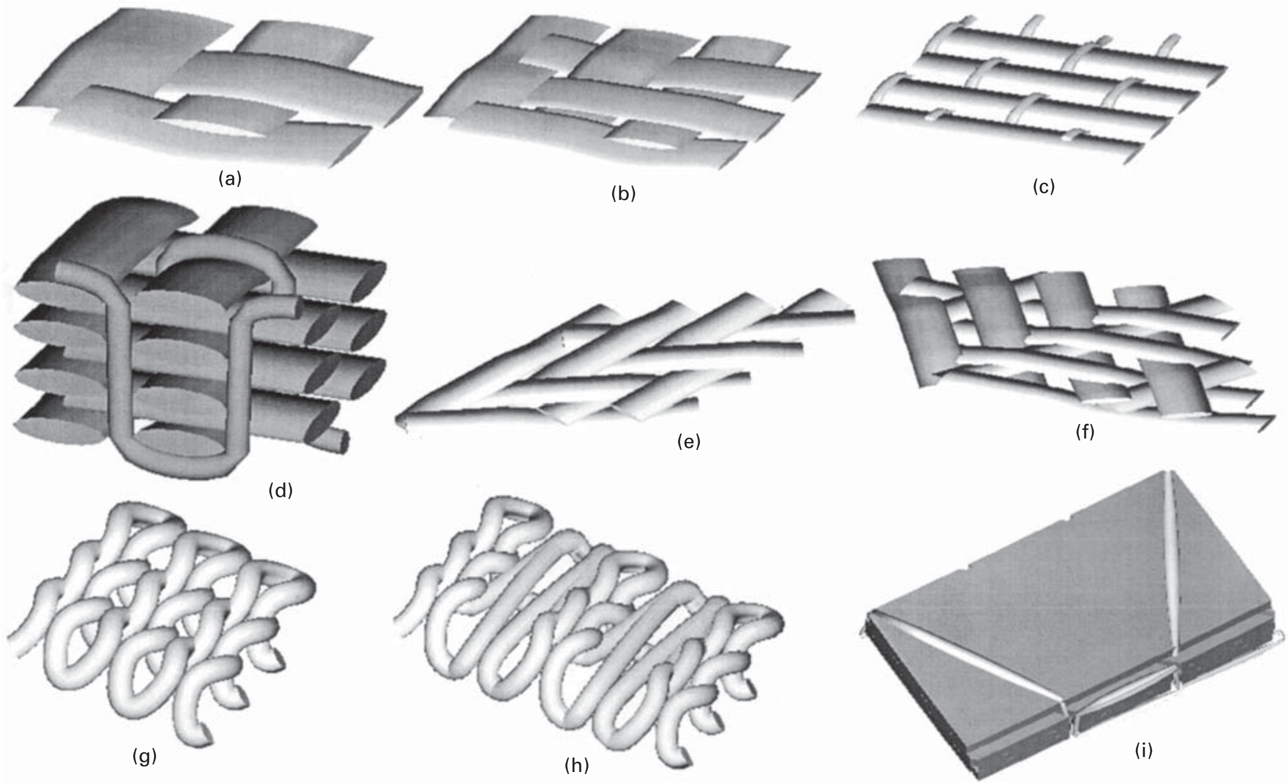
1.2.1 Classification

The term yarn embraces a wide range of 1D fibrous objects. A yarn has substantial length and relatively small cross-section and is made of fibres and/or filaments, with or without twist. Yarns containing only one fibre are *monofilaments*. Untwisted, thick yarns are termed *tows*. Flat tows are called *rovings* in composite parlance; in textile technology this word designates an intermediate product in spinning. *Sizing* holds the fibres together and facilitates the processing of tows; it also promotes adhesion of fibres to resin in composites. In *twisted yarns*, fibres are consolidated by the friction resulting from twist. A twist is introduced to a *continuous filament* yarn by *twisting*. For a *twisted yarn made of staple fibres* the process is called *spinning* and involves a long chain of preparatory operations. There are different *yarn spinning* processes (*ring spinning, open-end spinning, friction spinning*) leading to yarns with different internal distributions of fibres. Note that these are distinct from fibre spinning processes such as wet spinning, melt spinning or gel spinning, which are used to make individual fibres, most often from various polymers.

Fibres of different types are easily mixed when yarn spun, producing a *blend*; thermoplastic matrix fibres can be introduced among load-carrying fibres in this way. Finally, several strand yarns can be twisted together, forming a *ply* yarn.

1.2.2 Linear density, twist, dimensions and fibrous structure of yarns

The *linear density* is the mass of a yarn per unit length; the inverse quantity is called *yarn count* or *number*. Common units for linear density are given in Table 1.1. Linear density, the most important parameter of a yarn, is normalised



1.1 Textile structures: (a–c) 2D woven fabrics; (d) 3D woven fabrics; (e, f) 2D braided fabrics; (g, h) weft-knitted fabrics; (i) multiaxial multiply warp-knitted fabric.