Chokri Cherif
Editor

Textile Materials for Lightweight Constructions

Technologies - Methods - Materials - Properties

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Preface

The supply of natural resources for economic development is limited. In order to prevent the destruction of humanity's own livelihood, this limited supply requires a gentle and efficient handling of the available energy sources and materials by all the branches of industry, aimed at reducing emission of pollutants and the efficient use of materials. This has become particularly clear against the backdrop of globalization with the abrupt increase in global transportation and the steady growth of individual mobility. Particularly in branches of industry relying on the accelerated transportation of large masses, passenger and goods traffic, as well as mechanical and plant engineering, innovative lightweight construction technologies based on plastics are more important than ever before. These aspects of material and energy efficiency also apply for wooden and concrete reinforcements. In the construction industry, the number of applications increases for fiber-reinforced slender and filigree concrete components, for fiber-reinforced plastics, as well as for the reinforcement and restoration of existing structures. Furthermore, textile membranes are highly efficient and extremely lightweight construction materials with adjustable functionalities, making them relevant for a wide range of applications.

Textile materials and semifinished products have a versatile property potential and often act as carriers and driving forces behind innovative developments. They are distinguished by the use of high-performance fiber materials and advanced technologies. In the past decades, a unique interdisciplinary spectrum of knowledge has been evolved worldwide in the field of textile technology. The focus is placed on polymeric, mineral, and metallic fiber-based materials for use in high-tech applications. These textile materials will remain a crucial group of high-performance materials and will be established as a significant research priority in twenty-first-century material science. The fiber and textile technology research institutions will become the centers of an indispensable multidisciplinary research of innovative technologies and products.

The combination of material science, nanotechnology, microsystems technology, bionics, physics, and chemistry results in a new product range with properties adjustable to the individual demands in a wide range. The gamut and depth of the required processes and materials are immense and highly complex. Even products with unique characteristics and fundamental approaches toward intelligent and self-learning materials are realizable.

The aim of this first edition is to fully exploit the performance potential and the variety of textile materials and semifinished products. Experts of textile technology will share basic knowledge of textile and ready-made technology as well as future-oriented special knowledge for the manufacture and use of high-tech textiles. They show the possibilities for the application of textile structures in lightweight construction. Therefore, this book will concentrate on the detailed portrayal and description of the entire textile process chain from fiber material to the diverse yarn constructions and various textile semifinished products in two- and three-dimensional shapes, but will also touch upon preforming and interphase/interface design. Beyond those, tests according to valid norms and special, recently developed test methods for textile lightweight construction will be introduced. This reference book is rounded off by remarks concerning the modeling and simulation technology for the structure-mechanical calculations of highly anisotropic, flexible high-performance textiles, and exemplary applications from the fields of fiber-reinforced composites, textile concrete, and textile membranes. This aims to exemplify the potential of textile structures as innovative lightweight construction material by the specific selection and combination of textile processes for the realization of a nearly unlimited number of property profiles, and finding possibilities of functional integration as well as designing of near-net shape components. The aim is to create a conscious motivation for a wider use of textile high-performance materials in lightweight construction applications on a large scale, which will soon start their triumph in the field of fiber-reinforced composite materials.

The deliberations included in this book are based on long years of interdisciplinary research and development work, including special research areas and research clusters in the fields of fiber-reinforced composites, textile-reinforced concrete, and textile membranes. These research projects along the entire textile process chain are promoted at the Institute of Textile Machinery and High-Performance Material Technology of TU Dresden. Extensive teaching material could be gathered from engineering education and doctoral studies in textile and assembly technology as well as lightweight construction, all of which contributed to the successful creation of this textbook.

Dresden, Germany Chokri Cherif
June 2014

Acknowledgment

This textbook is the result of a combined effort of scientists of the Institute of Textile Machinery and High-Performance Material Technology (ITM) at Dresden University of Technology and external experts from research and teaching. The majority of them are experienced researchers with extensive knowledge in the areas of textile and assembly technology as well as of textile-reinforced lightweight construction gathered from working and teaching in these fields. Other contributions were provided from junior researchers, whose graduate studies yielded specialized insights into their respective fields. The intense cooperation of the editor with the individual authors and the resulting coherence of the content and interlinking of the chapters have created a consistent work on the subject of "Textile Materials for Lightweight Construction" from fiber materials and semifinished products to preforms, along the textile supply chain.

This textbook was first published in a German-language edition in 2011, which laid the groundwork for this translated version.

First of all, all staff members of the ITM involved in the creation of this book have to be acknowledged. Apart from conducting their activities in research and teaching, their personal dedication and commitment were crucial for the success of this project. This book is based on years of experience of the scientists of the ITM designated as authors. My special thanks are due to all authors of individual chapters for their contributions and understanding collaboration in ensuring the success of this book.

I would like to express my personal gratitude to the other experts: Dr. Beata Lehmann (former research fellow at ITM, currently research fellow at the Institute of Surface and Manufacturing Engineering at TU Dresden), Dr. Georg Haaseman (Institute of Solid Mechanics at TU Dresden), and Dr. Silvio Weiland (TUDALIT Markenverband e.V., Dresden), who contributed to some of the special fields. Prof. Dr.-Ing. Hilmar Fuchs of the Sächsisches Textilforschungsinstitut e.V. Chemnitz, honorary professor for technical textiles at TU Dresden, has kindly contributed to this textbook.

My gratitude is also due to all authors for their support in the translation of this book and for their invaluable advice. Many of them have left the ITM or the respective institutions since the original publication of the book to take over highly responsible managerial positions in the industry or in public institutions.

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Chapter 1
Introduction

Chokri Cherif

The recent concepts and trends in lightweight construction applications and the development of suitable fiber-based materials and matrix systems, as well as thoroughly automated manufacturing concepts contribute to an increased use of high-performance fibers and make fiber-reinforced composites (FRCs) the defining material class of the twentyfirst century. Textile materials and semi-finished products act as carriers and drivers of these innovative developments and are an important basis of quantum leaps in resource efficiency, CO_2 emission reduction and development of products able to meet consumer demands with wholly new ideas. In the future, energy consumption coverage in all civil and economic sectors will require wider use of renewable and CO_2 neutral energy sources and concepts, leading to innovations and changes within the energy sector. As a result, a paradigm shift in the use of materials driven by energy and resource scarcity will put fiber-based high-performance materials and the products based on them in high demand by a variety of industries [1].

Continuous fiber-reinforced composites, as a relatively new material class, consist of a tensile load-absorbing textile reinforcement structure and a shaping, compressive-load-absorbing matrix material. Composite materials also include textile membranes consisting of a coated or foil-laminated textile surface as reinforcement.

The excellent properties of fiber-reinforced composites, such as their high specific strength and stiffness, good damping properties, chemical resistance and low thermal expansion lead to the increased use of fiber-based lightweight construction products frequently classified as high-grade construction materials. In comparison to conventional materials, particularly based on metals, they are distinguished by outstanding corrosion resistance, ductility and weight reduction. In

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order to fully exploit the potential of the fiber reinforcement in the composite, the fibers have to be arranged stretched along the main load directions and suitably embedded into the matrix. The textile materials and semi-finished products providing reinforcement are often transferred into near-net shape component geometries by means of a large range of different manufacturing technologies.

Continuous fiber-reinforced composite components based on different matrix systems also display flexible adaptability of their structure and thus adjustability of material properties and property anisotropy to the individual requirements of processing and construction. Therefore, they possess high potential for a cost-efficient production of tailor-made composite components with broad use in lightweight construction for conventional and new application areas. In this regard, the setup of efficient, non-stop process chains for the development of textile-based lightweight construction structures is crucial. A requirement-suited designing of FRC components based on carbon fibers can attain weight reductions of 30 % compared to aluminum or even 70 % compared to steel. In construction, weight reductions of up to 80 % over the conventional ferroconcrete structures are feasible.

Due to their structural variety, textile-based lightweight construction structures resulting from the combination of textile reinforcement components with plastic and mineral-based matrix systems have already been established as an innovative, economically viable and suitably designable material indispensable to lightweight construction applications. The potential of FRCs in fields of application requiring a great lightweight construction advantage is widely recognized. The market for fiber-reinforced plastic composites (FRPCs) has registered above-average growth rates in recent years [2]. Particularly, FRPCs based on short-fiber reinforcements, as manufactured in *sheet molding compound* (SMC) or the various long-fiber-reinforced thermoplastic (*LFT*) methods, have been used in the serial production of secondary components in passenger and utility vehicles [3]. A similar situation can be observed in construction, regarding market-proven short fiber concrete components such as facade elements and carbon-fiber-reinforced plastic composite lamellas for the strengthening of buildings. Numerous recent lightweight construction developments are aimed at a dedicated enhancement and acceleration of the use of continuous fiber-reinforced composite components. Apart from the expensive *Pre-preg technology* (pre-impregnated textile structures with a resin system), science and industry are closely tracking alternative production methods based on dry (i.e. non-pre-impregnated) reinforcement structures in combination with thermosetting matrix systems or through the use of thermoplastic-based hybrid constructions, aspiring to establish possibilities of a highly productive processing into complex, function-integrated composite components.

FRPCs are preferentially produced from a basis of thermosetting matrix systems. The broad use of such FRPC solutions, especially in aeronautics, wind power and sports equipment technology, has contributed to this technology's special potential concerning material, ecological and energy efficiency under economical aspects. They are increasingly being used in structural components and applications with challenging requirements. Despite the excellent properties and the considerable increase in the use of FRPCs particularly in aeronautics, the currently realizable cycle times are a limiting factor for application in large series. So far, their industrial applications have been largely limited to “prestige object” in the form of spoilers, side panels, tailgates, doors or roofs for vehicles [4]. The consistent automation of steps for the reproducible FRPC component manufacture and the development of cost-efficient textile semi-finished products, highly reactive resin systems and fast impregnation and consolidation technologies, which are at the center of attention of recent research are laying the groundwork for a promising industrial implementation in large-scale production areas.

The high potential of continuous fiber-reinforced thermoplastic composite materials for serial use in complex, highly loaded and recyclable vehicle and machine engineering parts have put them in the center of intensive developments in science and industry aspiring to realize dry structures. The possible specific strengths and stiffnesses that can be achieved are considerably higher and can be ten times as high as that of metallic materials, while requiring equal amounts of material. Load cases caused by alterations in component geometry due to thermal expansion can be avoided or generally defined by purposefully combining carbon fibers and matrix materials.

The various existing applications in the field of textile-reinforced concrete demonstrate the effectiveness of textile reinforcements as well as their practicality. A large number of applications of textile concrete have already been implemented. Most of them are related to the free shaping properties and low material consumption leading to the reduction of CO_2 emissions by conserving energy and material, in particular cement. Especially for the strengthening of old ferroconcrete constructions or the maintenance of existing structures, the use of textile reinforcements is becoming a technology with good prospects [5, 6]. The small geometrical changes and the great capabilities of the high-performance fibers, the correlating low own-weight loads and relatively easy applicability of the textile-reinforced fine-grained concrete layers lead to completely innovative usage and structural design possibilities. The almost unlimited formability and load-adapted arrangement of rovings in textile structures, their free designing and dimensioning, often inspired by nature, result in complex, aesthetically pleasing, and delicate architecture with economic market relevance.

Apart from FRPCs and textile concrete, textile membranes, usually thin ones mainly stressed by tensile forces, are another innovative class of technical materials adaptable to material choice and construction to fulfill a variety of different functions: for example, separating, delineating, encasing, filtering, load bearing and distribution; or protecting against weather, sound or heat. This results in a wide application spectrum ranging from membranes for textile construction to sails in high-performance yachting. Furthermore, it also includes sun protection textiles, advertising surfaces, tents, geotextiles and truck tarpaulins. Developments so far have been aimed at achieving high tensile strengths and Young’s moduli at small membrane mass. Thus, textile membranes are the basis of unlimited innovative technical lightweight construction solutions in the high-performance field.

The load-adapted alignment of textile reinforcement structures in complex-shape components adds high engineering-technological requirements on both the calculation and simulation software used as well as on the realization of appropriate machinery concepts and production methods. Compared to metallic materials, fiber-reinforced composites, at purposeful choice of reinforcement structures and low-fiber-damage production, can allow a more cost-efficient component designing. This requires the selection of suitable technology and the coordination of the chosen material with the geometry, regarding design and construction aspects. If this is taken into account, composite materials help realize complex component geometries that would be costly to realize with metallic materials.

However, innovative and efficient lightweight construction means designing each individual part with the global concept of the application in mind. In product development, economical and ecological aspects (e.g. end-of-life vehicle laws, emission and fuel consumption regulations) are understood not as antagonism but as supplement and symbiosis [7]. Efficient use of available and the development of new fiber materials, construction methods, and technologies for lightweight construction products can contribute to sustainable climate protection. The lower the weight of cars, airplanes or machines, the smaller the amount of energy required to operate them and the fewer greenhouse gasses and air pollutants are emitted. While load-adapted and recyclable designing and near-net shape manufacturing methods can help attain high material efficiency in production, energy efficiency in the daily use of the products or parts is a decisive competitive criterion.

The technologies currently used for the production of textile fiber materials, structures and *preforms* (near-net shape and dry fiber structure) and their subsequent exact positioning within the impregnation tool are usually suitable for a number of different application areas, regardless of the component manufacturing methods and the matrix material used. A sustainable breakthrough for the wider use of textile-based lightweight constructions in large series can only be achieved by thoroughly exploiting the different textile constructions' potential for the respective applications [8]. The extremely wide range of textile materials, production technologies, and their combinations complicate the user's efficient design of manufacturing processes and component-related choice of suitable materials. The following complexes and challenges are relevant to ensure an efficient and reproducible manufacture of processable and load-adapted textile semi-finished products and preforms from a multitude of textile constructions with near-net shape geometries, suitable for the economical processing into complex and high-loaded fiber composite parts for automotive and machine engineering, construction, membrane technology as well as the elastomer and timber industries [9]:

- reduction of fiber and semi finished product cost by correct selection of textile fiber materials and manufacturing technologies, waste minimization, e.g. by employing near-net shape production methods and damage free processing of high-performance fiber materials aimed at attaining highest possible material efficiency,
- development and selection of cost-effective technologies and machine types for the realization of dry structures or their hybridization/(partial) impregnation, temporary fixing of textile semi-finished products for the production of complex,

suitable and easy-to-handle preforms with component-adjusted reinforcement as well as near-net shape/thickness-adjusted dimensions for medium and large series,

- selection of reproducible and automated preforming processes and concepts, with subsequent impregnation and consolidation at short cycle times,
- cutting of production costs and process times of components by correctly selecting textile reinforcement structures and related technologies dependent on the matrix systems, impregnating and consolidating quickly and flawlessly, as well as choosing adjusted machine concepts and impregnation strategies accordingly,
- tailor-made *interface design* by means of surface modification and realization of adapted interfaces for the application-related adjustment of composite properties between reinforcement and matrix component,
- development of intelligent concepts for a function-integrated lightweight construction in multi-material design,
- development of powerful, non-destructive and fast testing methods and quality control systems for textile materials, semi-finished products and preforms, as well as
- development and implementation of effective and reliable simulation software for the design of flexible reinforcement structures to produce complex components

This textbook emphasizes the detailed introduction and interpretation of definitions as well as the distinct delineation of textile production methods. These will help avoid misinterpretations and enable the most efficient use of the near-unlimited possibilities of textile and ready-made technology for energy efficient fiber-reinforced plastic composites in the areas of lightweight construction. Specialized know-how is conveyed, taking into account exact textile terminology and interconnections and contexts of the multifaceted textile process steps. Furthermore, special methods that are currently being developed are presented and research trends are illustrated. The potential, properties and versatility of textile materials and semi-finished products as well as their combinations into completely new possibilities and product geometries are to be extracted in particular in the course of this book.

The focus of this book will be on an illustration of the importance of textile constructions based on fiber-based high-performance materials for function-integrated lightweight construction applications. This includes applications of fiber-reinforced plastic composites on thermoplastic and thermosetting bases, of textile membranes and of lightweight constructions with concrete. Furthermore, reinforcements for wooden and elastomer materials are other target groups. For the first time, manufacturers of composite materials will obtain a comprehensive overview of the possibilities and the potential of fiber and textile technologies and the corresponding machine technologies for an economical production of suitable 2D and 3D textile structures for lightweight construction in complex architectures, as previous relevant textbooks only touch upon selected fields.

The book is to be a “classic” as a modern teaching and learning package and is targeted at students, engineers, designers and developers as well as research institutions in the areas of textile and ready-made technology, plastics, elastomer and wood engineering, lightweight construction, fiber-reinforced plastic composites, materials science, civil engineering and architecture. The book concentrates mainly on textile materials and semi-finished products. The selected application examples in the textbook (FRPCs, textile concrete and textile membranes) are limited to a short introduction of the requirements for the components and are followed by explanations of the required textile process chains and the component production technologies necessary to fulfill them. For purposes of additional information on the subject areas of fiber-reinforced plastic composites, textile concrete and textile membrane technology, relevant textbooks and publications are listed.

References

1. SGL Group: Textilbewehrter Beton - ein neuer Verbundwerkstoff für die Bauindustrie (Fachpresse-Information). Meitingen, Deutschland, 28. November 2008
2. ANONYM: Composite Materials Price Trends, Forecast and Analysis, Marktanalyse. Dallas, USA, 2007
3. NASSAUER, J.: Automobil + Innovation - Internationale Märkte, technische Entwicklung. Nürnberg, 2007
4. NEITZEL, M.; MITSCHANG, P.: Handbuch Verbundwerkstoffe. München, Wien : Carl Hanser Verlag, 2004
5. CURBACH, M.; MICHLER, H.; WEILAND, S.; JESSE, D.: Textilbewehrter Beton - Innovativ! Leicht! Formbar! In: BetonWerk International 11 (2008), Nr. 5, S. 62–72
6. DUBEY, A. (Hrsg.): Textile-reinforced concrete. Farmington Hills, USA : American Concrete Institute, 2008
7. HUFENBACH, W.: Materialeffizienz durch Systemleichtbau. In: Proceedings. 11. Dresdner Leichtbausymposium. Dresden, Deutschland, 2007
8. CHERIF, Ch.; DIESTEL, O.; GRIES, Th.: Textile Verstärkungen, Halbzeuge und deren textiltechnische Fertigung. In: HUFENBACH, W. (Hrsg.): Textile Verbundbauweisen und Fertigungstechnologien für Leichtbaustrukturen des Maschinen- und Fahrzeugbaus. Dresden: SDV - Die Medien AG, 2007
9. CHERIF, Ch.: Trends bei textilbasiertem Leichtbau / Trends in textile based lightweight design. In: Technische Textilien/Technical Textiles 51 (2008), S. 22–23, E22–E23

Additional Literature

LÄSSIG, R.; EISENHUT, M.; MATHIAS, A.; SCHULTE, R.T.; PETERS, F.; KÜHMANN, T.; WALDMANN, T.; BEGEMANN, W.: Series production of high-strength composites: perspectives for the German engineering industry. VDMA study, 2012

BAI, J.: Advanced fibre-reinforced polymer (FRP) composites for structural applications. Woodhead Publishing, 2013, ISBN: 978-0-85709-418-6

VEIT, D.: Simulation in textile technology: theory and application. Woodhead Publishing, 2012, ISBN 0857097083

CHERIF, Ch.; KRZYWINSKI, S.; LIN, H.; SCHULZ, Ch.; HAASEMANN, G.: New Process Chain for Realisation of Complex 2D/3D Weft Knitted Fabrics for Thermoplastic Composite Applications. In: Procedia Materials Science 2 (2013), pp. 111–129

GAND, A. K.; CHAN, T.-M.; MOTTRAM, J. T.: Civil and structural engineering applications, recent trends, research and developments on pultruded fiber reinforced polymer closed sections: a review. In: Frontiers of Structural and Civil Engineering 7 (2013), No. 3, pp. 227-244

Chapter 2
The Textile Process Chain and Classification of Textile Semi-finished Products

Chokri Cherif

This chapter gives a general overview of the most important steps of the textile process chain and will thus facilitate a deeper understanding of the material group of functional textiles. The introductory material- and process-related definitions concerning fibers, yarns, fabrics and their further processing are explained in depth in the following chapters. The scope of technical textiles has been extended far beyond the original technical application areas. The steady and intense use of micro system and nanotechnology, measurement and sensor technology, plasma technology and modern finishing techniques are suitable to equip textiles with specific, adjustable properties and functions. One main characteristic of functional textiles is their orientation toward functionality, performance and an added value in comparison with conventional textiles.

2.1 Introduction

For decades, the European textile industry has been experiencing a structural change focused on the development of innovative high-quality products. Current trends and the know-how transferred into practice reveal the great potential of textile innovation. This does not only affect the textile industries, but also other branches of industry and products. Apart from the classical uses in garment and home textiles, technical applications are present in nearly all areas of everyday life. The production of technical textiles is a new, innovative, and promising field. Technical textiles are often distinguished by their functional diversity, and specific know-how is required for their design and production.

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The use of these technical textiles is multi-faceted and not limited to clothing or home textiles, but extends to a variety of disciplines like automobile construction, aeronautics, construction engineering, and architecture, as well as healthcare, and security services.

Technical textiles feature the use of high-performance fibers, highly developed technologies and the incorporation of other, often non-textile materials. Their properties display an extremely versatile potential and turn both textile materials and the related production methods into mainstays and driving forces for the development of innovative products. The fiber materials and textiles with their unique properties are the best precursors for new products and technologies, e.g. in the fields of materials science and microsystems engineering, and for intelligent and adaptive materials.

Technical textiles are characterized by diversity, compatibility, functionality, flexibility and interactivity. These properties have broadened the range of applications and allow the development and opening of entirely new product groups. The range of variation and functionality of technical textiles is extremely large because of the near-unlimited multitude of property profiles resulting from fiber type and mixture, yarn formation, fabric production, as well as surface modifications and functionalizations on various production levels. These possibilities create perfect conditions for compatibility and connection with other, non-textile materials like plastics, metals and concretes. The combination of technical textiles with micro systems technology creates interactive data and information media [1] and integrated sensor and actuator networks, used for instance for structural monitoring and oscillation dampening in composite components. This allows the flexible use and customization of textile materials and semi-finished products with their adjustable properties.

The use of technical textiles as an independent product group is by now well-established in nearly all disciplines, beyond applications in technical areas. This requires an intense analysis of terminology and distinction of technical and functional products from conventional garment, home and household textiles. With the steady and intense use in micro systems technology, nanotechnology, metrological and sensor technology, modern finishing technology and bionics sees textiles being fitted with specific adjustable properties and functions are going far beyond the requirements of technical applications. Therefore, the term functional textiles will be favored within the framework of this textbook. This product class is distinguished by its focus on functionality, performance and the obvious additional usefulness in comparison with conventional textiles.

Textile technology and its variety of production methods offer outstanding possibilities for the development of bionics-based solutions. The most popular bionic product in garment production is probably the hook-and-loop fastener, fashioned after the natural seed distribution mechanism of the burdock plants [2]. Other inspirations in plants include bamboo, horsetail or arundo characterized by extreme stability with long stems and thin-walled culms. These construction principles are exploited in the development of structurally optimized fiber composite materials with a similar combination of stability and small mass [3–5]. Leaf