Chapter 4

3D Fabrics for Technical Textile Applications

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Additional information is available at the end of the chapter

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Abstract

Two dimensional (2D) woven, braided, knitted and nonwoven fabrics have been used for the fabrication of soft and rigid structural composite parts in various industrial areas. However, composite structure from biaxial layered fabrics is subject to delamination between layers due to the lack of through-the-thickness fibers. It also suffers from crimp which reduces the mechanical properties. Triaxial fabrics have an open structure and low fiber volume fraction. However, in-plane properties of triaxial fabrics are more homogeneous due to bias yarns. A 3D woven fabric has multiple layers and is free of delamination due to the z-fibers. However, 3D woven fabric has low in-plane properties. Three dimensional braided fabrics have multiple layers and they are without delamination due to intertwine type out-of-plane interlacement. However, they have low transverse properties. A 3D knitted fabric has low fiber volume fraction due to its looped structure. A 3D nonwoven fabric is composed of short fibers and is reinforced by stitching. However, it shows low mechanical properties due to lack of fiber continuity. Various unit cell based models on 3D woven, braided, knitted and nonwoven structures were developed to define the geometrical and mechanical properties of these structures. Most of the unit cell based models include micromechanics and numerical techniques.

Keywords: Fabric architecture, woven fabric, braided fabric, knitted fabric, 3D nonwoven fabric

1. Introduction

The objective of this chapter is to provide up-to-date information on the development of 2D and 3D fabric formation and formation techniques particularly on 2D and 3D nonwoven fabrics, methods, and properties of nonwoven web, including possible emerging application areas. Three-dimensional (3D) fiber structures produced by textile processes are used in various industrial applications since they have distinct properties when compared to conventional materials. The most important application area of 3D textiles, by far, is composite industry, where they are used as reinforcement materials in combination with several matrices to make textile structural composites. These composites are used extensively in various fields such as civil engineering and military industry [1, 2], thanks to their exceptional mechanical properties and lower density in comparison with common engineering materials like metals and ceramics [3, 4]. Textile structural composites are also superior to conventional unidirectional composites when the delamination resistance and damage tolerance are taken into account [5]. Textile preforms are readily available, low-cost, and not labor intensive [1]. They can be manufactured by weaving, braiding, knitting, stitching, and by using nonwoven techniques. Each manufacturing technique has its own advantages and disadvantages in terms of specific composite properties and the selection can be made based on the end-use. The simplest form of 3D woven preforms is made up of two dimensional (2D) woven fabrics that are stacked one on top of another and stitched together in the thickness direction to impart through-the-thickness reinforcement. Three-dimensional weaving is another preform production technique that can be employed to manufacture 3D woven preforms by using specially designed automated looms. Near-net shape parts can be produced with this technique which substantially reduces the amount of scrap [6, 7]. In-plane properties of 3D woven composites are generally low due to through-the-thickness fiber reinforcement, despite of its positive effect on out-of-plane properties [8]. Simple 3D braided preform consists of 2D biaxial fabrics that are stitched together in the thickness direction depending on a chosen stacking sequence. Three-dimensional braiding is a preform technique used in the multidirectional near-net shape manufacturing of high damage tolerant structural composites [9, 10]. Three-dimensional braiding is highly automated and readily available. Three-dimensional braided preforms are fabricated by various techniques such as traditional maypole braiding (slotted horn gear matrix), novel 4-step and 2-step braiding (track and column) or more recently 3D rotary braiding and multi-step braiding [11, 12]. The fabrication of small sectional 3D braided preforms is low-cost, and not labor intensive [1]. However, the fabrication of large 3D braided preforms may not be feasible due to position displacement of the yarn carriers. Three-dimensional knitted preforms are fabricated by the 3D spatial formation of 2D warp or weft knitted fabrics in order to make near-net shape structures like spheres, cones, ellipsoids and T-pipe junctions. Three-dimensional knitted composites generally have low mechanical properties as a result of their characteristic looped architecture and low fiber volume fraction. A 3D nonwoven preform is a web or felt structure consisting of randomly positioned short fibers. There is no particular textile-type interlacing or intertwining between the fibers other than random entanglements. Through-the-thickness stitching of layered nonwoven webs is also possible. The most common methods for nonwoven production are needle-punching, stitch-bonding, high-frequency welding, chemical bonding, ultrasound and laminating. Recently, electrospinning method is utilized to make nonwoven nano web structure [13]. The entanglement type defines the fabric properties such as strength and modulus, flexibility, porosity and density [14]. Nonwoven fabrics and their composites display low mechanical properties due to fiber discontinuity. Multiaxis knitted preform comprises four fiber sets such as +bias, -bias, warp (0˚) and weft (90˚) along with stitching fibers which enhance in-plane properties [15]. Multiaxis knitted preform suffer from limitation in fiber architecture, through-

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thickness reinforcement due to the thermoplastic stitching thread and three dimensional shaping during molding [3]. Multiaxis 3D woven preforms and their composites exhibit improved in-plane properties due to off-axis fiber positioning [16, 17].

In this chapter, 3D fabrics including 3D nonwoven for technical textile applications are reviewed in the light of the existing literature. First, the classification of textile fabric structures was introduced based on various classification schemes suggested by experts in the field. Types of textile fabric structures were explained under two main groups such as 2D and 3D fabrics. Various formation techniques including 2D and 3D nonwoven techniques were reviewed with regard to manufacturing processes and resulting fabric and composite properties. Applications of technical textiles in various industrial areas were covered with an emphasis on the future trends and technologies.

2. Classification of fabrics

Three-dimensional woven preforms are classified based on various parameters such as fiber type and formation, fiber orientation and interlacements and micro- and macro-unit cells. One of the general classification schemes has been proposed by Ko and Chou [3]. Another classification scheme regarding yarn interlacement and process type was proposed (Table 1) [18]. In this scheme, 3D woven preforms are subdivided into orthogonal and multiaxis fabrics, and their processes have been categorized as traditional or new weaving, and specially designed looms. Chen [19] categorized 3D woven preforms made by traditional weaving techniques based on their macro-geometry. According to this classification, 3D woven preforms are grouped as solid, hollow, shell, and nodal structures with varying architectures and shapes (Table 2). Bilisik [20] suggested a more precise classification of 3D woven preforms according to their interlacement types (fully interlaced woven/non-interlaced orthogonal), macro geometry (cartesian/polar) and reinforcement direction (2-15) (Table 3).

Non-interlacing Orthogonally Orientating and Binding	**Type Uniaxial**	Direct Binding	Modified 2D Weaving Machine	Thick Panel [21]
			Specially Designed Machine	Profiled Bar/Beam [22]
		Indirect Binding	Modified 2D Weaving Machine	Profiled Bar/Beam [23]
			Specially Designed Machines	Profiled Bar/Beam [24-26]
				Thick Tubular [27]
	Type Multiaxial	Direct Binding	Specially Designed Machine	Thick-Walled Tubular [28]
		Indirect Binding	Modified Warp Knitting Machine	Thin Panel [29]
			Specially Designed Machines	Thick Panel [30, 31]
				Thin Panel [32]

Table 1. Three-dimensional woven fabric classification based on non-interlace structuring [18].

Structure	Architecture	Shape
Solid	Multilayer; Orthogonal; Angle interlock	Compound structure with regular or tapered geometry
Hollow	Multilayer	Uneven surfaces, even surfaces, and tunnels on different levels in multi-directions
Shell	Single layer; Multilayer	Spherical shells and open box shells
Nodal	Multilayer; Orthogonal; Angle interlock	Tubular nodes and solid nodes

Table 2. Three-dimensional woven fabric classification based on macro-structure [19].

Direction	Three dimensional weaving			
	Woven		Orthogonal nonwoven	
	Cartesian	Polar	Cartesian	Polar
2 or 3	Angle interlock; Layer-to-layer; Through the thickness	Tubular	Weft-insertion	Weft-winding and sewing
	Core structure			
3	Plain and Plain laid-in	Plain and Plain laid-in		
	Twill and Twill laid-in	Twill and Twill laid-in	Open-lattice Solid	Tubular
	Satin and Satin laid-in	Satin and Satin laid-in		
4	Plain and Plain laid-in	Plain and Plain laid-in		
	Twill and Twill laid-in	Twill and Twill laid-in	Corner across Face across	Tubular
	Satin and Satin laid-in	Satin and Satin laid-in		
5	Plain and Plain laid-in	Plain and Plain laid-in		
	Twill and Twill laid-in	Twill and Twill laid-in	Solid	Tubular
	Satin and Satin laid-in	Satin and Satin laid-in		
6 to 15	Rectangular array	Rectangular array	Rectangular array	Rectangular array
	Hexagonal array	Hexagonal array	Hexagonal array	Hexagonal array

Table 3. The classification of three-dimensional weaving based on interlacement and fiber axis [20].

Three-dimensional braided preforms are classified based on various parameters, including manufacturing technique, fiber type and orientation, interlacement patterns, micro-meso unit

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