OPPORTUNITIES AND CHALLENGES FOR TEXTILE REINFORCED COMPOSITES

Christopher M. Pastore

Keywords: textile reinforced composites, 3-D reinforcement, modeling, prediction of mechanical properties

For several decades researchers have been interested in textile processes for the production of composite reinforcement. These technologies have offered several promises: reduced fabrication costs, 3-D multiaxial reinforcement, and damage tolerance. Despite these advantages, textile composites have not reached the level of implementation of laminated composites. In this paper, the opportunities provided by textile reinforced composites and the challenges that limit their implementation will be discussed in detail. Textile composites refer to a family of processes: weaving, braiding, knitting, and hybrids thereof. The various families of textiles will be defined and the basics of fabric formation for each family will be detailed. In particular, the strengths and weaknesses of each manufacturing technique will be addressed to provide a view of the applicability of each technology. This will include some guidance on shape formation capability, property ranges, size limitations, and estimates of cost to produce. Potential applications for these materials will be presented. Among the limitations on the application of textile reinforced composites is the lack of adequate modeling capabilities for these materials. Textile composites have rather large unit cell structures and are highly inhomogeneous throughout their volumes. These features provide benefits in manufacturing, but require novel modeling techniques to correctly understand the mechanical behavior. A review of analytical techniques applied to textile composites will be presented along with a discussion of the benefits and weaknesses of each of these methods. The enabling technologies needed to further the implementation of textile composites in structural applications will be discussed.

Textile Reinforcements for Composites

Textile reinforced composites are fiber-reinforced composites whose unit reinforcement structures are characterized by more than one fiber orientation. The unit cells are formed through textile processes that manipulate either individual fibers or yarn bundles to create an integral structure. These materials are typically formed from hierarchical systems built from fibers, yarns, and fabric structures. Figure 1 shows a schematic illustration of the hierarchical nature of textile materials. As illustrated, the fiber is a basic unit from which textile materials are formed. Additionally, it is possible to join various sub-assemblies together to form even more complex structures.

Fibers can be converted into laminated tapes, yarns, or direct-formed fabrics. Laminated tapes can be cut into thin strips (called slit tape) and used as a type of yarn. Yarns can then be converted into a variety of fabric structures. Brief descriptions of each of these material forms are presented below. A glossary of textile terms applicable to composites can be found in Pastore (1993). A brief glossary is also included in the Composites volume of the ASM Engineered Materials Handbook (1987).

Textiles are typically considered to have significant cost savings compared to tape lay-up. The primary reason is that the individual layer of fabric is much thicker than tape. Thus, fewer lay-up steps are necessary to create the final structure. Further, textile composites are typically formed from dry fibers and infiltrated with resin in a secondary operation. This means that the handling

1 Submitted to the 11th International Conference on Mechanics of Composite Materials (Riga, June 11-15, 2000).

and storage requirements of the material are reduced compared with prepreg. Further, the fabric manufacturer can make a single product which is suitable for a variety of matrix materials, reducing inventory and manufacturing costs.

Traditionally textile materials are considered to belong to two general classes of fabric: 2-D and 3-D. Although clearly all fabrics are necessarily three-dimensional, the classification of 2-D to a fabric system implies that the fabric is fundamentally thin. This is further clarified to mean that the thickness of the fabric is formed by only two or three yarns in the thickness direction. A 3-D fabric can have substantially greater thickness, limited by the current state of the machine, not by any fundamental physical phenomenon.

2-D Fabrics

All fabrics are made using yarns or fibers as the basic manufacturing unit. Direct-formed fabrics are those made directly from fibers. Woven, knitted, and braided fabrics are made from yarns. These four classes represent the vast majority of fabrics used in composite materials. In the textile nomenclature, woven fabrics are formed by interlacing yarns, knitted by interlooping yarns, braided by intertwining yarns, and direct formed fabrics by interlocking fibers. A comparative discussion of fabrics for composites can be found in Clarke and Morales (1990) or Ko and Pastore (1987). Some detail is presented below. Because of the high width-to-thickness ratio of these fabrics and the fact that they are typically layered to form a thick structure, they are called “two-dimensional” or 2-D fabrics. This distinguishes them from “3-D” fabrics, which possess a much greater inherent thickness. Clearly these fabrics are not two-dimensional, as an examination of the unit cell readily reveals.

Direct Formed Fabrics. Direct-formed fabrics, as indicated above, are created directly from fibers without a yarn processing step involved. Furthermore, there is no interlacing, intertwining, or interlooping of fibers within the structure. Thus, these fabrics are called nonwovens in much of the literature, despite the obvious inadequacy of this term.

Generally, there are two steps in the direct forming process. First, a web is constructed of fibers. The web formation process dictates the distribution of in-plane fiber orientation. Next, the web is densified to create a handleable material. Densification typically involves some through-thickness entanglement or bonding. The interested reader is directed to texts such as Buresh (1962) or Krema (1971) for specifics on the manufacturing process.

The formation of a web starts with the opening of the fiber supply. The opening process mechanically separates the fibers from each other. The resulting mass is typically deposited onto a conveyor belt creating a continuous roll of low-density material with a width of roughly one meter and a thickness 10-20 cm called a picker lap. The fibers have a virtually uniform, random orientation in the plane, with substantial out-of-plane orientation. To reduce the density of the picker lap, the material may be passed through a card that performs a series of complex combing operations. Individual fibers within the picker lap are oriented in the direction of material flow through the machine. This orientation allows the fibers to pack closer than previously, resulting in a thickness reduction, increased density, and a preferred distribution of fiber orientations in the machine direction. The resulting material