7 Composite Structure – Property Guidelines

7.1 Introduction

The objective of this chapter is to document the effect of constituent properties on composite properties. Detailed micro-mechanics formulae will not be discussed. However, the functional relationships will be analyzed to provide guidelines concerning which constituent property should be modified to effect a change in a particular composite property. The constituent properties of interest for fibers appear in Table 1, Chap. 3. Matrix properties of interest appear in Tables 4 and 9, Chap. 2. Interfacial effects discussed in Chapter 5 will be amplified as they relate to composite properties.

Discussions which focus on the selection of matrix resins to improve composite properties have been presented by Serafini [1] and McCullough [2]. Trends in composite performance in the presence of aqueous or solvent environments at room or elevated temperature are discussed by Chamis [3, 4] and Collings [5]. Additional composite structure property functional relationships can be found in [6] and [7]. Analyses of composite moduli, composite strength and the influence of variables that relate to these characteristics such as matrix resin, fiber/fiber volume, interface/interphase, and method of testing are described. Tests such as edge delamination strength and $\pm 45^\circ$ tension provide a measure of balance of composite system performance, i.e., toughness and in-service environmental performance.

7.2 Composite Moduli

Micro-mechanical relationships [6] to predict composite moduli are the most highly developed and most reliable in the generation of data. Axial composite moduli depend directly (in a linear relationship) on the fiber modulus and the volume of fiber in the composite. Transverse composite modulus is inversely dependent on the fiber modulus and directly dependent on the matrix modulus. Composite shear modulus and Poisson’s ratio depend directly on the matrix modulus. All the above properties are dependent on the fiber volume fraction and the geometry of reinforcement. A complete discussion of micro-mechanical equations and structure property relationships is presented in [7].

In general, the highest composite axial modulus will result when the highest modulus fiber is employed at the highest fiber volume fraction. The highest
transverse composite modulus and composite shear modulus will result from the highest modulus matrix resin. Implicit in these discussions on composite structure property guidelines is the assumption that the laminates being characterized are of high quality. Specifically, the fiber and matrix resin are uniformly distributed, void level is low (generally less than 1 volume%), and that residual thermal strains and microcracking induced by the cure/consolidation cycle are minimal. Nondestructive evaluation of cured laminates is essential to ensure quality (Chapter 4). Furthermore, test coupons must be machined to minimize edge damage and ensure alignment of the fibers in the desired direction. Test technique is also very important and requires accurately calibrated testing machines, correctly installed extensometers and/or strain gauges, and proper alignment of the test coupons in the testing machine grips. Detailed discussion of proper test techniques and the effect of improper testing in measured composite properties are described in [8–15].

7.3 Composite Strength

Table 1 lists basic composite strengths, the constituent property which strongly effects each strength, and the ASTM test techniques most often used to characterize strength.

Axial tension is directly dependent on the ultimate strength of the fiber, the fiber volume fraction, the matrix modulus, and ultimate strain or matrix ductility. For a given matrix ultimate strain, the composite tensile strength will increase linearly with the matrix modulus. However, the interfacial bond between the fiber and the matrix must be optimal. Too low an interfacial shear strength leads to premature debonding while too high an interfacial strength can result in a brittle longitudinal or axial splitting failure mode. Axial tensile strength is also extremely sensitive to fiber alignment. Fiber misalignment as little as 1/4 to 1/2 a degree off-axis can reduce apparent composite tensile strength by 25 to 50%. In general, to achieve high composite axial tensile strength with a fixed interfacial shear strength, it is desirable to have the highest strength fiber and a ductile, high ultimate strain matrix resin.

Axial compressive strength is highly dependent on the failure mode, which is correspondingly dependent on the constituent properties. The highest strengths will result from composites based on fibers with high inherent compressive strength, with excellent alignment in a matrix resin with a high tensile (and hence shear) modulus. This combination forces a compressive failure of the fibers. Other dominate failure modes which result in less than optimal composite compressive strength are symmetric or nonsymmetric buckling predominately caused by a low matrix modulus and debonding or interfacial shear failure caused by a weak interfacial bond.

1 Axial compressive strength is discussed more thoroughly in Chap. 8.