CHAPTER 1

Filament Winding—Introduction and Overview

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Introduction

The objective of this book is the facilitation of fabrication of useful composite shapes by the most efficient and least costly method: filament winding. A previous book on filament winding, Filament Winding; Composite Structure Fabrication (Ref 1.1), was published in 1994 by the Society for the Advancement of Material and Process Engineering. It was aimed at the large audience of filament winders who were using two- and three-axis machines with either mechanical or computer controls. The audience has changed. Now, most winders have computer controls and at least three axes. Winding with four axes is common because the shapes of the products have evolved to include more complexity. However, the automation used on the winding machine and ancillary components does not eliminate the need for proper fiber handling. This book is a primer on how to use the new machines, starting with an overview of what is available for automation, a look at what has been done, and a primer on handling the fibers with minimum damage prior to laydown.

Computer and Computer Controls

There has been great progress in machine automation during the last 16 years. Much of the progress can be attributed to the impact of computers, although much of this work has been accomplished outside of the United States. For example, most publications in the realm of reinforced piping have originated in Canada, and a significant number of papers on rocket motors/pressure vessels have had South Korea as their source.

The advances in machine control give the winders an opportunity to wind noncylindrical and nonsymmetric objects and allow for a much more precise laydown of fiber. The higher capacities of computer memory that is now available allow the control of up to six axes of motion: mandrel rotation, cross feed, horizontal carriage movement, vertical carriage movement, wind eye rotation, and wind eye yaw (Fig. 1.1).

Control of ancillary components is now common so that there can be automated mandrel placement, automatic tie-on and cut-off, automated loading of wet fiber-covered mandrels into the curing oven, and finally, automated extraction. The new machine systems have allowed pipe manufacturers the ability to wind rather than hand lay-up, spray-up, resin transfer mold, or compression mold their elbows, reducers, and tees. Filament winding these components results in better mechanical properties through the use of continuous fibers, with the accompanying lowering of manufacturing costs (Ref 1.2).

Composite Analysis

Increasingly better methods for composite analysis have given designers a quicker, more reliable answer for closed-form analysis. There are “B”-basis allowable data for fiber/resin combinations for 121 °C (250 °F)-curing prepreg for the aircraft composite component industry (e.g., AGATE) (Ref 1.3), but there is no comparable
database for filament-wound composites that use prepreg tow and wet resin-impregnated tow or roving. The principles of composite analysis and “B”-basis allowables are discussed more extensively in Chapters 8 and 7, respectively.

Structural Analysis

Structural analysis has also progressed so that structures can be modeled and the model transferred into any of several finite-element analysis programs, which can also incorporate laminate analysis routines and libraries of composite micromechanical properties for fiber/resin combinations. These tools can accomplish in one day what normally took several months in 1994, when Ref 1.1 was published.

Pressure Vessels

Pressure vessel designers can benefit from the analysis from netting, closed-form, and finite-element analysis routines incorporated in the Composite Design and Analysis Code. There are several case dome configurations shown in Chapter 8. Design has also benefited from the wider use of the Standard Test and Evaluation Bottle, enabling dome and skirt testing and optimization as well as providing information on the pressure vessel. These subjects are more fully elaborated on in Chapter 8.

Two new designs for small pressure vessels have gained wider use. Isotensoid vessels (Fig. 1.2) are essentially composite pressure vessels with Isotensoid domes but without a cylindrical section. They are proposed for use as liquid propane gas containers and would be placed in the automobile spare wheel well. For automotive use, rigorous tests must be imposed. Additional information is presented in Chapter 8.

Toroidal pressure vessels (Fig. 1.3) are in commercial use to contain air for breathing. Advantages quoted for the QinetiQ, United-Kingdom-manufactured doughnut-shaped composites, are lighter weight, better use of volume, and greater protection for the pressure regulator (Ref 1.4, 1.5).

Pipes

Pipe manufacturers have seen that multiangle filament-wound pipe can confer some desirable properties, such as addition of higher bending strength for a pipe simply supported at the ends, hoop layers to improve buckling strength for
buried pipe, or more axial strength with low-angle helicals for a vertical pipe (Ref 1.6).

**Grid Structures**

The commercialization of grid structures has been realized on the Proton-M launch vehicle, which uses a composite Anisogrid structure for interstage (first to second stage is open, and second to third stage is overwound with aramid/epoxy), payload attachment fittings, and composite fairing (Fig. 1.4). A 15% weight savings is reported for the lattice adapter compared to other adapters (Ref 1.7, 1.8).

The Isotruss, developed at Brigham Young University, is a three-dimensional configuration that can be filament wound but, in the more complicated designs, is more aptly fabricated with a technology that looks more like weaving.

One of the initial Isotruss applications was a composite bicycle frame weighing less than 3 lb (1.36 kg) (Fig. 1.5) (Ref 1.9).
Deep Sea Oil Platform Drill Risers

Composite drill and production riser development began almost 30 years ago, based on perceptions that they would reduce deck loads and provide several other benefits. The National Institute of Standards and Technology was the funding agent to initiate these programs. The principal composite contractors are Spencer Composites Corp. (Lincoln, CA), which is working with Kvaerner (Oslo, Norway), and Northrop Grumman (Sunnyvale, CA), which is working with ABB Vetco Gray (Houston, TX). The key technologies are the metal-to-composite interface (MCI) and the liner. The Spencer MCI uses a proprietary traplock design, a 0.12 in. (3 mm) titanium liner, and titanium flanges, which make it interchangeable with the standard titanium drilling riser currently used on the Heidrun tension leg platform in Norway. The riser has been in service since 2001. The Northrop Grumman MCI is the convex version of the wound-in-place hyperboloid joint invented at Westinghouse for the lower joint of the Tomahawk Missile Launcher. The Northrop Grumman riser has been slated for sea trial by Petrobras, Brazil since 2003 but has not seen service yet. Some problems remain; for example, the composite drill riser is reported to be approximately 30% to 3 times the cost of the steel riser, and the composite wall is thicker, which may negatively influence hydraulics (Ref 1.10–1.16).

High-Speed Rotors

The design of high-speed rotors now benefits from the use of very high-strength carbon fibers such as Toray T 800 and T 1000 (Toray Composites America, Tacoma WA). The research into high-speed rotor design started with filament-wound monolithic rings made with conventional epoxies, then liquid polyurethane elastomers were introduced; continuous curing was effected, and finally, multiring composite rotors have been selected for further study. Each iteration had a positive effect on the upper limit of rotational speed (Ref 1.17–1.19).

Filament-Wound Preforms

The filament-winding process is a low-cost method of manufacturing composite preforms, which have a high fiber volume with a virtually unlimited number of repeatable and accurate fiber angles. As an alternate to woven fabric and braiding, Storage Tek Composites (Louisville, CO; now part of Oracle, Inc.) used dry high-strength carbon fiber, a prepreg delivery head, and a polyester scrim cloth that is melted at the ends of the mandrel to hold the fibers in place for resin transfer molding (Ref 1.20).

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