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Composite Development in the Consumer Products Industry
Opportunities and Challenges of the 21st Century

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INTRODUCTION

The popularity of carbon fiber composites as a primary structural component is well established in the sporting goods and recreational products industries. Over the past decade, several companies offering full service design, engineering, and production services have evolved to meet the rapidly changing demands of consumer products. The consumer marketplace is characterized by short product life cycles, high production volume, and low cost expectations. These factors underscore the importance of robust materials and operator friendly processing methods in order to remain competitive. Several challenges remain, however, in the implementation of new material process technologies to meet the expectations of the changing marketplace.

This paper gives an overview of composite material processes and discusses recent advances in the field and lessons learned, from the consumer products market perspective. Examples are drawn from technology development and experiences at HST, Inc. HST is one of the largest consumers of pre-impregnated carbon fiber material and manufacturers of structural components in the consumer products marketplace.

OVERVIEW

The use of carbon fiber composites within the consumer and recreational goods market appeared to gain momentum in the late 1980s and early 1990s. Particularly in the golf industry, which is perhaps the largest single volume user of carbon fiber pre-preg, these materials offer lighter weight, a variety of design options not possible with steel, wood, or aluminum, and a high-tech image for a rather affluent market. Advances in materials and new processing technology have created the phenomenon of high-end sporting and recreation equipment for which enthusiasts are willing to pay a premium. It is not uncommon to find someone who is willing to pay $2500 for a bicycle made from advance materials for $500 or a golf club driver.

Several manufacturing technologies exist for processing composite materials. These processes include but are not limited to:

- **Table or Mandrel Rolling**
- **Bladder Molding**
- **Filament Winding**
- Autoclave Molding

- Resin Transfer Molding (RTM)
- Compressing Molding
- Thermoforming
- Pultrusion
- Wet/Hand Lay-Up

The first three processes; table rolling, bladder molding, and filament winding are by far the most common processes for high volume recreation products. Products produced with these processes include golf shafts, fishing rods, hockey sticks, arrows, and bicycle tubes. This paper will present an overview of these three processes with advantages and disadvantages of each and some of the processing and material challenges the facing the industry.

TABLE ROLLING

Table rolling is the most common process for manufacturing round tubes. Sheets of pre-impregnated composite material are wrapped around the mandrel that in turn defines the inner shape of the part. A compacting tape is spirally wrapped around the uncured material to debulk the structure and to provide consolidation during the curing process. Since the mandrel is left in the part during curing, the mandrel profile cannot exhibit any concave surfaces. Once cured, the mandrel is extracted, the consolidation tape is removed, and the outer surface is sanded and subsequently painted.

Fig. 1 Pattern cutting operation illustrating pre-preg tip inserts for golf shafts.

Fig. 2 Lay-up mandrels for golf shaft products. Each rack holds approximately 100 mandrels.

Fig. 3 Table rolling presses. The upper platen is in the down position.

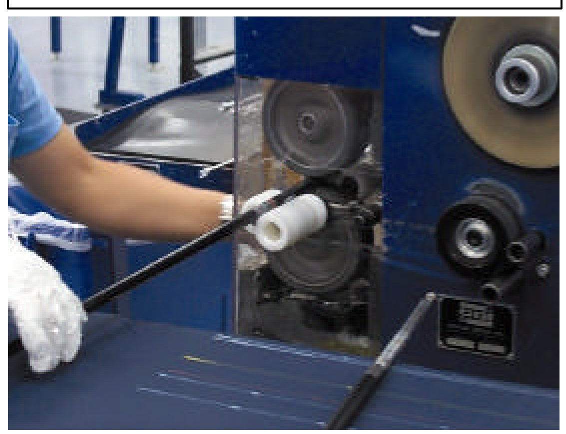

Fig. 4 Consolidation tape wrap operation. The tape is discarded after cure.

Advantages-Table Rolling	*Disadvantages-Table Rolling*
Inner diameter control +/- 0.0025mm, (+/- 0.001")	Outer diameter is not controlled
Low tooling costs	Mandrel design must allow extraction
Low cost process and low barrier to entry	Compaction tape requires sanding operation
Lends to some automation	Variation issues of hand lay-up
High volume manufacturing possible	Not effective for large diameters > 75 mm (3")
Process retains fiber alignment	Not effective for long tubes > 3m (10 feet)
Results in uniform wall thickness	

Table rolling is the most common manufacturing process for very high volume tubular recreation products such as golf shafts, arrows, and bicycle tubing. Daily output for some manufactures can exceed 20,000 units a day. Customers are now demanding very rapid product development cycles, on the fly design changes, and dock-to-stock shipping requirements. The industry trend is towards very low work in process (WIP) and build-to-order practices (no inventory). Table rolling is currently moving away from the batch type process in which different departments are responsible for rolling, curing, grinding, and painting to a cellular process in which a team takes responsibility for the entire process.

Challenges in Table Rolling

- Continued development of automation technologies to lower labor content.
- Pre-preg resin systems that allow conveyor cure processing (UV, IR, quick cure systems).
- High flow, long out time, and operator friendly resin systems.
- Continued development of pre-forms to reduce lay-up labor costs.

BLADDER MOLDING

Bladder molding is essentially the reverse of the table rolling process. Bladder molding is common for complex outside surface shapes such as a tennis racket. A female mold defines the outer shape of the part. The material is generally hand wrapped around a mandrel which helps define the inside shape of the part. However, once the material is wrapped into place, the mandrel is removed and an inflatable bladder is inserted in its place. Bladder materials include silicones, latex, and plastic films. The uncured composite material and bladder are then placed in the mold press, the bladder opening is attached to the pressure source and the mold is closed. Heat is applied to the mold to cure the material and pressure is applied within the expandable bladder to inflate the material against the inside mold surface for consolidation. Once the cure cycle is complete, the part is removed from the mold, the flash line is removed, and the part is finished and painted. Some products leave the bladder in place while other products may require bladder removal. Bladders are generally discarded after use and are considered a consumable part of the bladder molding process.

Advantages-Bladder Molding	*Disadvantages-Bladder Molding*
Tight outer diameter control	Bladder can rupture thus scrapping the part
Shorter cure cycles	Computer controlled design and tool path software is necessary to develop mold
Net shape surface	Molds can be very expensive
Reduced geometry constraints	Variation in inner diameter control
Possible to mold hybrid products	Potentially high consumables cost - *bladders*
	Fiber distortion common as material expands

Fig. 5 Composite bat with a co-molded aluminum barrel illustrating latex bladder and pressure attachment fittings.

Fig. 6 Removal of bladder molded product from press illustrating mold cavities.

Molding allows unique shapes and designs not possible with table rolling or filament winding. However, two major obstacles to overcome with this technology include improved surface finish and painting requirements of the final product and the high cost and long lead-time of prototyping products.

Painting and finishing require a clean and smooth surface in order to achieve the level of cosmetics expected by a discriminating consumer. Molding often results in a flash line where the mold sections meet, which must be removed. Also, mold releases are often used to prevent the composite from adhering to the mold surface. Unfortunately this mold release, if not removed properly from the part, creates a multitude of finishing and painting problems.

Prototyping molded composite parts often require a physical sample representative of the production process for customer approval. A great deal of time can be spent programming the surface model design and subsequently machining the prototype mold. Many times the development times of prototypes can exceed the product opportunity window. Typical development times for one revision of a tool and part design can range from three to six weeks.

Challenges in Bladder Molding

- Mold treatments that do not transfer to the part (non-stick mold coatings).
- High flow resin systems to enhance improvements in surface cosmetics.
- Mold design, mold materials, and machining technology for reduced mold flash.
- Prototyping methodologies to facilitate product development and to reduce prototype costs.
- Improvements in upstream (customer) surface model development and commonality of design codes and machine interfaces.
- Pre-form development to lower lay-up costs.

FILAMENT WINDING

Unlike table rolling or bladder molding, filament winding is somewhat of an automated process. Rather than hand-roll material around a mandrel or hand-place material in a mold, machine control defines and places the composite material on the tool. A mandrel defines the inside surface similar to table rolling. As the mandrel rotates in the filament winding machine, a carriage holding the fiber tow(s) transitions from left to right, depositing the composite material as the mandrel rotates. By varying the mandrel rotation speed and the carriage traverse speed, a variety of fiber angles are possible. Fiber is deposited as a single tow (for smaller diameters) or a combination of several tows, which increase the band size for larger objects. Fiber bands can be of similar materials or a mixture of materials for hybrid designs. Hockey sticks and bicycle products sometimes use a mixture of glass, aramid, and carbon tows to achieve a variety of performance and visual characteristics. Filament winding also allows the use of the materials at their lowest cost form. Although messy, dry forms of tow can be impregnated in-line by passing the tows through a resin bath, thus bypassing the pre-preg condition.

Fig. 7 Computer controlled filament winding machine. A composite bike tube is being wound with pre-preg 12k carbon tow.

Advantages-Filament Winding	***Disadvantages-Filament Winding***
Highly repeatable and automated process	Generally poorer surface condition
Allows continuous fiber placement	Low fiber angles are difficult < 5 degrees
Good for large diameter tubes	Higher scrap content due to turnaround ends
Low labor content	Design must allow mandrel extraction
Low costs for wet resin impregnation	Pre-preg tow cost is higher than pre-preg tape
Material is applied under tension	Higher void content
Unique surface appearance possible	High cost of computer controlled machines

Challenges in Filament Winding

- Difficulty in achieving fiber angles of less than five degrees can hinder product strength.
- Surface finish is usually rough and irregular which can require extensive finishing.
- Consolidation and curing techniques to improve surface quality.
- In process fiber impregnation and B-staging to lower material costs.

CONCLUSIONS

Table rolling, bladder molding, and filament winding are the most common manufacturing processes for recreational products. The bulk of composite material proceessed in the recreation market is consumed in the high volume manufacturing of golf shafts, hockey sticks, bicycles, and archery arrows. Pre-preg materials are generally chosen due the tight specifications and stringent customer requirements necessary in these products and for the ease of handling for high volume-labor intensive manufacturing.

The market place is characterized by stiff competition, rapid product development times, and low cost expectations. To improve competitiveness, areas of development emphasis should include pre-form development, resin and matrix systems that facilitate infrared conveyor curing, and materials and processes that enhance cosmetic quality.