COMPOSITE MATERIAL ADVANCES IN THE GOLF INDUSTRY

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SUMMARY: The popularity of carbon fiber composites as a primary structure for components in sporting goods appeared to gain momentum in the late 1980s and early 1990s. Particularly in the golf industry, these materials offered lighter weight, a variety of design options not possible with steel, and a high tech image to a rather affluent market. The sporting goods consumer desires equipment which represents the latest technology and is more expensive than his competitor's. Sporting goods companies are searching for the next advanced material that will allow them to gain another niche in the marketplace which will command a higher price and margin.

Successfully implementing these new technologies with the associated research and development requires partnerships among the sporting goods industries, the material vendors, and the academic community. Several product development efforts including metal matrix materials, robust resin systems, and high modulus carbon fibers are discussed.

KEYWORDS: sporting goods, golf, metal matrix, composites

INTRODUCTION

Background and Historical Perspective

Advanced materials and new processing technology has created the phenomenon of high-end sporting and recreational equipment for which sports enthusiasts are willing to pay a premium. It is not uncommon to find someone who is willing to pay $2500 for a cutting-edge bicycle made from advanced materials or $500 for a golf club driver. In fact, many of the dilemmas in introducing expensive composite materials faced by the aerospace markets are actually opportunities in the sports market, where a higher material price and material prestige is often a marketing advantage.

It is also important to note that over the past few years the prices of advanced material sporting goods have dropped tremendously because carbon fiber composites are now viewed as commodity items. The standard carbon/epoxy golf shaft or bicycle tube selling price has dropped approximately 300 percent since, due to increased capacity and the relative commodity status of 34 Msi carbon/epoxy materials. The sporting goods market is looking for the next wave of materials to further consumer enjoyment and performance standards, and, importantly to the component suppliers, increase the profit margin. If successful, research and development efforts and product launches can be continued at the pace of recent years.

Industry Size

The golf equipment industry represents $3.9 billion (US dollars) annually and is growing at an estimated five to seven percent annually. Golf shaft manufacturing is approximately a $400 million (US dollar) industry, with annual production of 63 million shafts per year (240,000 shafts/day). Figure 1 provides a breakdown of golf shaft materials used industry-wide as well as by geographical market segmentation. Approximately eighty percent of the shaft units are commodity-based products (those selling for $1-2). The remaining products are the high-end grades of graphite, titanium, or specialty grade steel shafts. Further growth of the industry depends on the introduction of new materials to offer improved performance and higher market entry points.

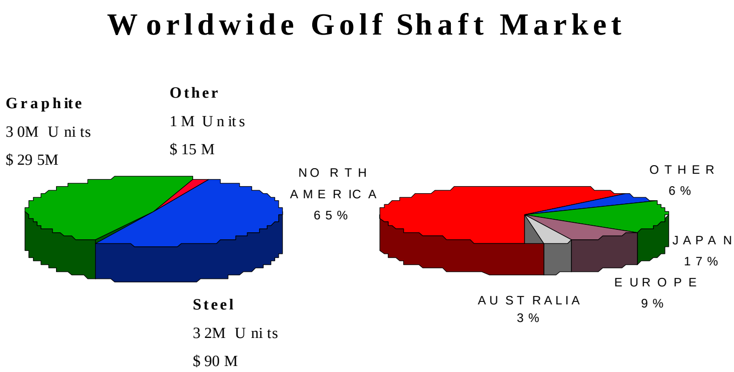

Figure 1: Market Share Assessment

History of Shaft Design

Golf shafts were first made from hickory wood in the 1400s. High modulus graphite, titanium, and high tensile strength steels predominate today. Figure 2 illustrates the material trends for golf shaft materials. An interesting point is that it took almost forty years for steel to displace wood as the primary shaft material. Specific strength and specific stiffness of the shaft material influence golf shaft design and club performance. Specific values are defined by the principle modulus or tensile strength divided by the material density. Figure 3 illustrates the specific stiffness and strength of several shaft materials as a comparison. Of the four materials listed, only the MMC material (far right) is in the research and development stage. The others are or were common shaft materials. A significant increase in the specific property is needed to make a breakthrough in the shaft design and to offer enough of a performance increase to warrant development and possible success in the marketplace. Aluminum, fiberglass, and stainless steel did not offer significant increases in performance to sustain acceptance and therefore were abandoned within a few years of introduction. Fiberglass and aluminum have reputations as being ineffective and present a cheap image for golf shafts. Titanium is an exceptional material for golf heads. The lower density of titanium allows a larger head and consequently a more forgiving sweet spot. On the other hand, the use of titanium as a shaft material has not met with success. The specific strength and modulus of titanium results in a shaft mass comparable to steel. This combined with a cost which is approximately four to five times more than carbon fiber shafts has resulted in a low acceptance level.

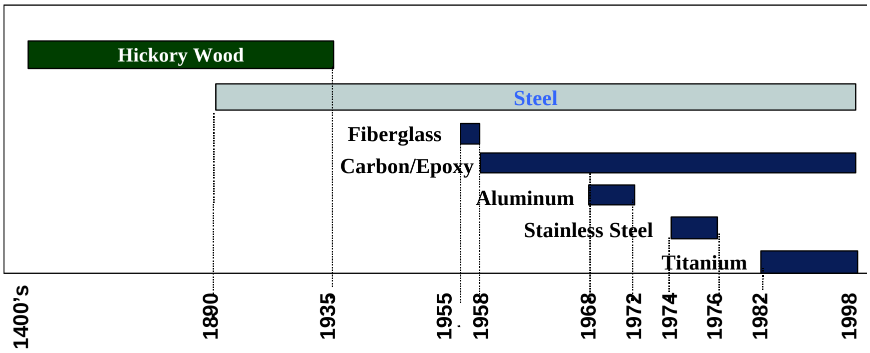

Figure 2: Evolution of Golf Shaft Materials

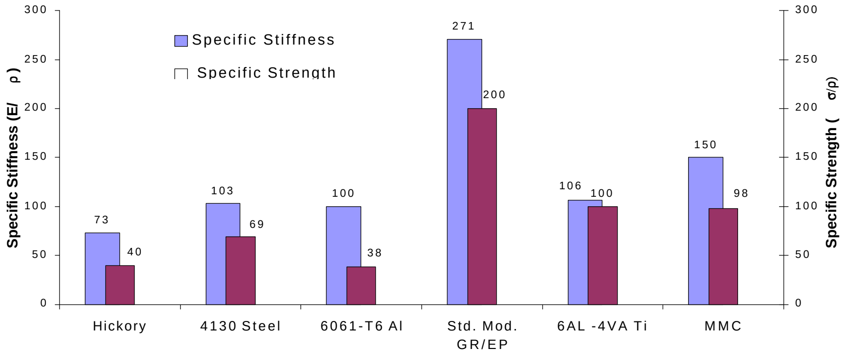

Figure 3: Specific Stiffness & Strength

As indicated, golf shaft design is driven by the specific properties of the material. Figure 4 summarizes the performance factors for shaft design as a function of the material properties over time. Improvements in performance stem from decreasing the shaft mass while maintaining stiffness. In general, over the past 200 years, the axial shaft stiffness (denoted by "*Deflection*" in Figure 4) of golf shafts for a particular club has remained relatively constant. In contrast, the shaft mass has dropped from about 160 gr. in the 1800s to about 65 gr. today. Decreasing the shaft mass allows the club designer to increase the head mass while still maintaining a low overall club mass. Providing a heavier club head while keeping a lower overall club mass helps the golfer to swing the club faster and results in increased carry distance. Recent innovations in golf including lightweight shafts, oversized heads, and larger sweet spots have opened the game to wider group of players at various ability levels.

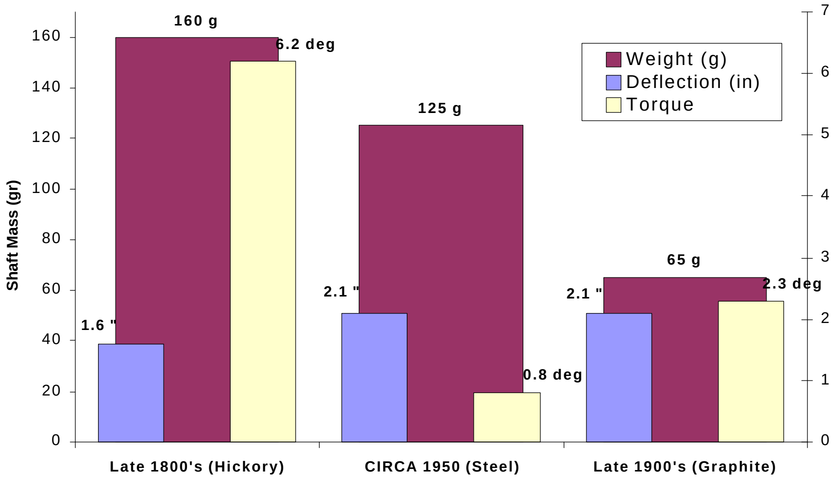

Figure 4: Shaft Performance Factor Trends

Material Advances: Carbon Fiber/Epoxy

Initial sporting goods applications of carbon fiber/epoxy sometimes met with disappointment and unfortunately in some cases tarnished the value of these materials for future consumer expectations. Resin systems were not user friendly, as high pressures and temperatures were needed to cure the material. In addition, very short out-times and complicated handling and curing requirements were not applicable to smaller shops. Not many of the sporting goods component suppliers could afford autoclaves.

Early attempts at manufacturing golf shafts ended up with poor consolidation, fiber misalignment, and generally insufficient strength to withstand the stress exerted during the golf swing. In addition, early golf shafts were made of glass/epoxy. Although a good engineering material, glass/epoxy met with disapproval from the market place due the to perception that fiberglass is a cheap material. Besides detracting from the structure strength of the laminate, voids can create extensive cosmetic problems and rework costs. Indeed, many sporting goods components have higher manufacturing costs in the finishing and cosmetic process than in the raw materials. Figure 5 is a cross-section of an early golf shaft laminate that exhibits a high degree of porosity.

Today, many material advances have allowed tremendous breakthroughs in sporting goods composites. The material community, by working with the sporting goods manufacturers, have developed new markets with materials specifically designed for consumer applications. Cost and ease of processing were the critical requirements. The rigorous test protocols required in the aerospace community were not worth the extra cost in the sporting goods industry. Probably most important was the development of robust room and low temperature cure resin systems with translation properties similar to aerospace systems. Another breakthrough has been the continued development and refinement of the pre-preg process. Fiber areal weights below 150 gr/m^2 and resin contents below 32 percent were uncommon five years ago. Today areal weights are as low as 50 gr/m^2 and resin contents are in the 25-26 percent range. Lower areal weights and hence a lower ply thickness has allowed shaft designers to develop stronger laminates and shafts at a lower overall mass. In addition, many designs incorporate alternate materials to enhance the feel, fatigue strength, tip strength, and surface cosmetic qualities. One such enhancement is the use of very lightweight glass scrim materials to improve the transverse strength of the shaft laminate in very lightweight shafts (below 60 gr.). Scrims are cowrapped with high modulus graphite to improve the hoop strength of the shafts. Very lightweight shafts generally fail from geometric instability rather than from material limits being exceeded. As the shaft deforms during loading, the cross-section ovalizes and can initiate longitudinal cracks (Figure 6). The glass scrim helps improve the transverse strength of the laminate while minimizing weight and playability issues. Processing and material improvements today result in exceptional laminate quality (Figure 7).

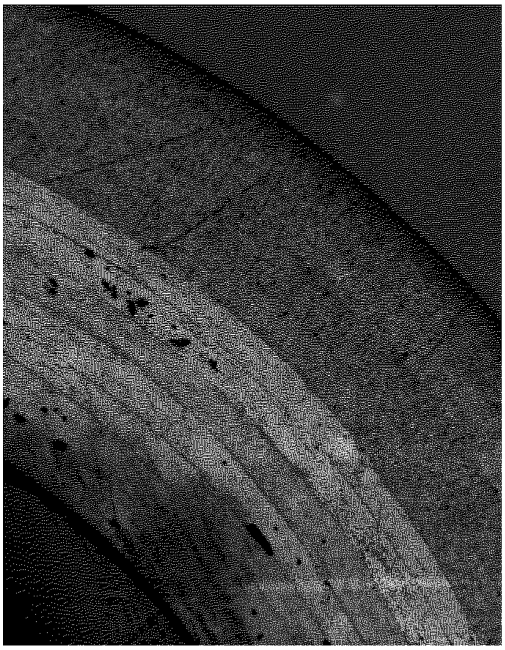

Figure 5: Poor Lamination due to Low Flow Systems and Poor Consolidation Methods.
Magnification: 50X

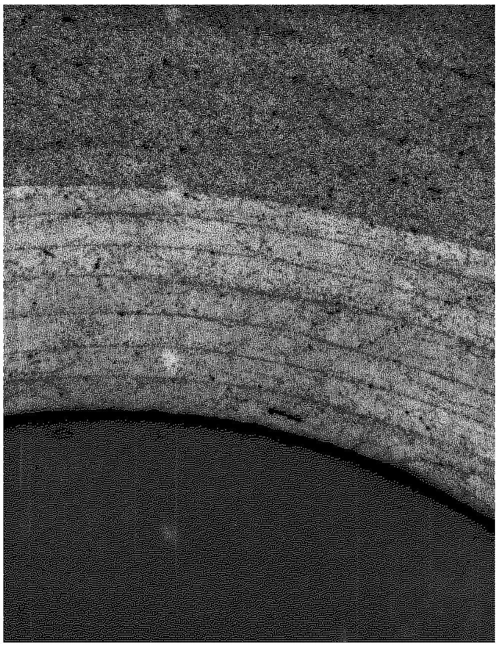

Figure 7: Higher Flow Systems and Improved Compaction.
Magnification: 50X

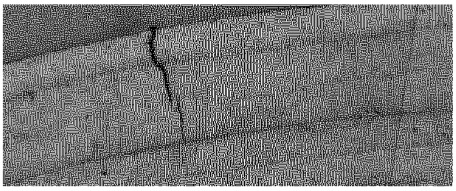

Figure 6: Surface Crack Due to Geometric Instability. In many cases utilizing glass scrim materials can reduces this.
Magnification: 50X

Material Advances: Metal Matrix Composites (MMC)

The metal matrix material in use in the sporting goods industry generally consists of an aluminum matrix with a reinforcement particulate of silicone carbide or boron carbide. Metal matrix composites are very attractive as engineering materials for sporting goods applications. The specific strength and modulus of these materials can offer design advantages not possible with steel or carbon/epoxy composites (refer back to Figure 3). In addition, metal matrix has a tremendous marketing appeal for the high-end sporting goods consumer because it's new. Early attempts at using MMC for bicycle tubes met with limited success. Many of the tubes exhibited fatigue failures at the weld zones. During the welding process, the reinforcing particulate in the weld zone floated to the surface, making the tube connection areas brittle. Golf shafts and in particular iron shafts also can benefit from the MMCs. Metal matrix composites offer the consistency of an isotropic material with the material property tailoring of composites. Research efforts into boron carbide/aluminum MMC yielded materials modulus ranging from 10 Msi to 14 Msi with strengths in the neighborhood of 85 ksi.

Figure 7 illustrates hairline cracks due to excessive cold working of the material from the shaft tapering process. The taper process, also referred to as swedging, basically hammers the material in a set of rotating and compressing steel dies machined to outer shape of the shaft. A two-step forming process was developed: partially tapering the shaft followed by an anneal, then on to the final swedging operation.

Although the processing was successfully developed to convert MMC tube stock into a shaft, the final component strength and consistency did not allow a sufficient reliability factor for a shaft material. Initial prototypes at the targeted weight goals (below 85 gr.) were prone to tip bending. Increasing the wall thickness near the tip section to inhibit bending results in shaft weights slighter lower than premium steel shafts, which really doesn't offer the consumer advantage at a higher price-point. In addition, the boron carbide particle, which is a very abrasive material, created processing scratches and fatigue initiation sites during drawing and forming of the tubes. The boron carbide particles created small imperfections that turned into voids, crack initiation sites, and fine surface tears. Although boron carbide MMC appeared to offer specific properties desired in a shaft material, in practicality, including process and design variations resulted in shafts that exceeded weight goals at costs many times that of similar performing steel shafts.

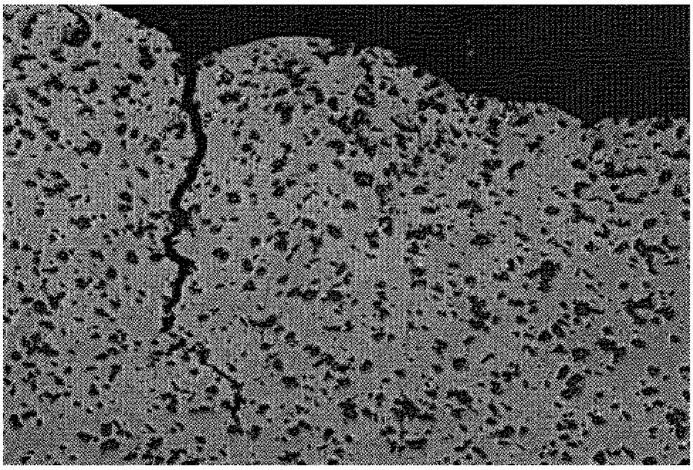

Figure 7: Boron Carbide/Aluminum Cross-Section of a Golf Shaft Tip Exhibiting Internal Radial Cracking from Excessive Cold Forming.
Magnification: 200X

What Are the Materials of the Future?

Many advances in the sporting goods industries and in particular the golf industry can be attributed to teaming between the materials suppliers and the sporting goods manufacturers. Material vendors -- sometimes out of necessity to meet market demands -- developed new streamlined processing techniques leading to lower cost and material systems well suited to smaller operations. The material vendors developed new product lines while the sporting goods suppliers were able to develop product extensions that complemented consumer demand.

The material of the future must offer the consumer awareness of a cutting edge product. Consumers are willing to pay for performance and prestige; however, the material must offer a true performance benefit or the image of the material will be tarnished. Figure 9 offers a prediction of the material properties needed for the next breakthrough in golf technology. Materials with these properties are under development. It will take continued collaboration, especially at the academic and materials community level, to move these materials into the marketplace.

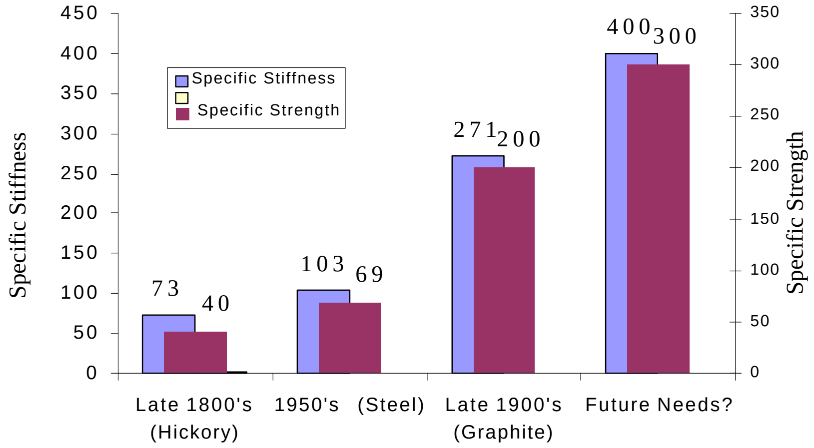

Figure 9: Future Material Trends

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