THE FABRICATION AND PERFORMANCE OF RING-STIFFENED CYLINDERS MANUFACTURED BY A COMBINED IN SITU AUTOMATED THERMOPLASTIC FILAMENT WINDING AND TAPE LAYING PROCESS

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SUMMARY

In situ filament winding for hoop (90°) and off-axis (±θ°) plies, and automated tape-laying for axial (0°) plies have been combined on the same machine center to fabricate carbon fiber/polyetherketone thermoplastic cylinders. The process produces well-consolidated microstructure with almost no layer waviness and thus superior compression properties compared to thermoset filament winding. Ring-stiffened [0°/90°] cylinders have been commercialized for submersible applications. Monocoque [0°/90°/±θ°] cylinders have been fabricated with superior surface toughness. Finally, [0°/90°/±θ°] cylinders up to 244cm in diameter have been fabricated for ballistic applications.

1. INTRODUCTION

Traditional thermoplastic filament wound cylinders suffer low axial stiffness and strength because only [90°/±θ°] plies can be fabricated, and low θ angles are unachievable with a heated in situ filament winding head. Therefore, to extend the process capability, the process reported upon herein integrates two heads on the same machine. A heated filament winding head is used to continuously wind hoop (90°) and off-axis (±θ°) plies from tow or slit tape. A second heated tape placement head sequentially places tapes in axial (0°) courses until the ply is completed.

2. THERMOPLASTIC IN SITU PROCESS AND EQUIPMENT

Fibers and thermoplastic matrix resin are combined off-line into impregnated tows for filament winding and impregnated tape for tape-laying[1]. The filament winding

[1] All tows and tapes referred to in this paper were fabricated by Cytec Engineered Materials (CEM) using either the APC or the TIFF process. APC-2 is the name for CEM's proprietary PEEK-based unitapes.

head in Figure 2.1 (90° ply) and Figure 2.2 (45° ply) preheats the underlying bare tool or previously laid composite laminate with a heated gas. The tow, stored on a creel, is also preheated to melt while passing through the head. The molten tow and molten base laminate are brought together under a heated shoe in the process spot. The shoe generates intimate contact between the inside surface of the incoming tow and the substrate outer surface, promoting reptation healing wherever intimate contact has been achieved. Healing, squeeze flow, and consolidation evolve as the longest polymer chains weld the interface, increasing interlayer bond strength. A following chilled roller provides a large compaction pressure to compress the void volume as an integral step in refreezing the laminate.

Figure 2.1 Heated filament winding head for hoop (90°) plies

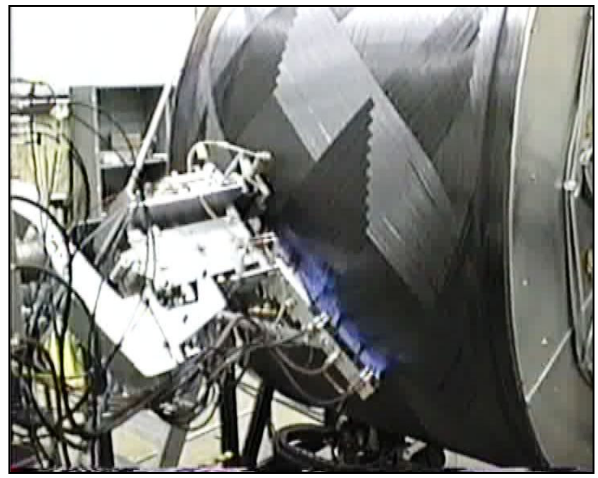

Figure 2.2 Heated filament winding head for off-axis (±θ°) plies

The tape is creeled on-head for the 0° tape layer, as shown in Figure 2.3. An infrared preheater melts the incoming tape. As with the filament winding head, one of the three main gas torches is aimed directly into the process nip. The compaction roller is shaped like an apple-core to assure uniform contact in the circumferential direction.

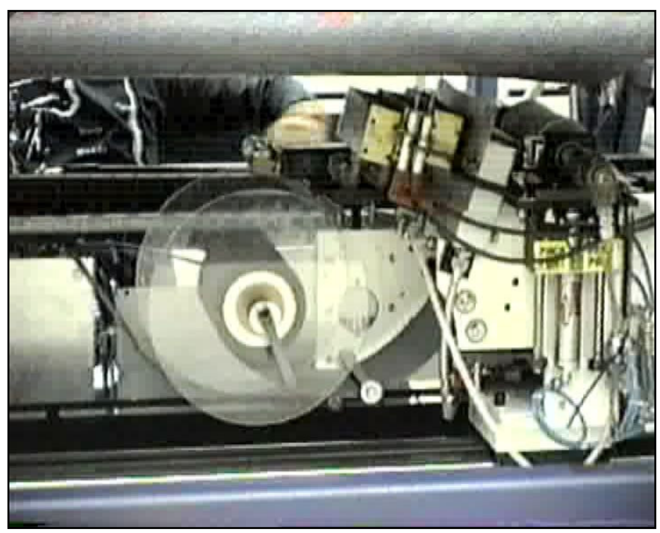

Figure 2.3 Heated tape laying head for 0° plies lies underneath the cylinder on axial ways.

3. THERMOPLASTIC FILAMENT WOUND/TAPE LAID PARTS - STIFFENED

Thermoplastic filament winding/tape laying has achieved autoclave level properties in thin and thick right circular cylinders for submersible applications. The cylinders are strength and buckling critical and feature integrally wound 90° rings fabricated on innovative collapsible tooling, as shown in Figure 3.1. The APC-2/AS-4 61cm (24-in) OD, 16mm (0.629-in) wall thickness ring-stiffened $[90°_{2.27}/0°]_n$ cylinder shown in Figure 3.2 achieved 1.4% axial strain in all gauges away from the ends, and a collapse pressure of 37.9MPa (5500psi), one of the highest performing composite pressure hull scale models ever [1].

Figure 3.1 Innovative collapsible tooling is used to wind ring-stiffened cylinders

Figure 3.2 61cm diameter 16mm thick ring-stiffened APC-2/AS-4 cylinder

Figure 3.3 shows the laminate microstructure of the process indicating an absence of unwanted waviness. Table 3.1 shows a property comparison with autoclaved flat laminates; the high strengths are a testament to the high level of consolidation and low layer waviness.

Table 3.1 APC-2/AS-4 Cylinder End Ring Results

Property	Replicates	Strength, MPa (ksi)	Flat Panel
S13	30	44 ± 9 (6.4 ± 0.7)	46 (6.6)
X33c	46	584 ± 94 (84.7 ± 13.7)	565 (81.9)

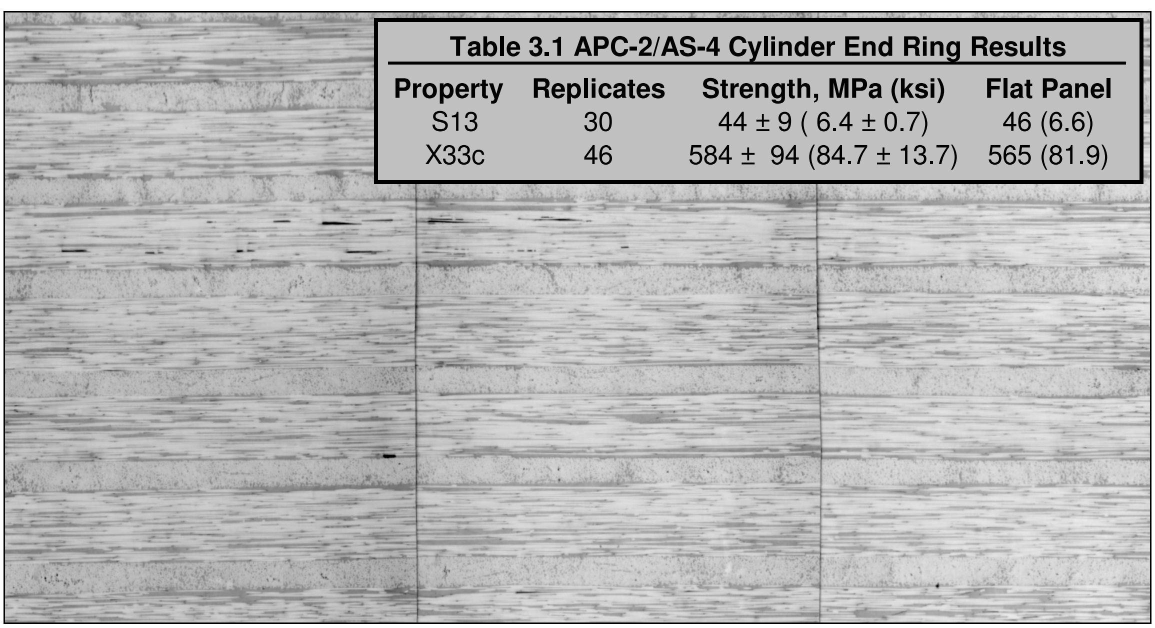

Figure 3.3 Photomicrograph of the $[90°_{2.27}/0°]_n$ APC-2/AS-4 ring-stiffened cylinder

The success of this cylinder led to more opportunities for fabricating underwater vehicles. The cylinders shown in Figures 3.4 and 3.5 have thick walls with $[90°/0°]_n$ and $[90°_2/0°]_n$ laminate stacking sequences. These pressure hulls were built to a high laminate quality from APC-2/IM-7, with excellent consolidation and low circumferential and axial layer waviness. Compression properties exceeded those available from cylinders fabricated by thermoset autoclave processing. Figure 3.6 shows the assembled underwater vehicle after completing pressure and thermal fatigue cycling.

Figure 3.4 Filament wound/tape laid APC-2/IM-7 $[90°/0°]_n$ and $[90°_2/0°]_n$ ring-stiffened underwater vehicle hull sections

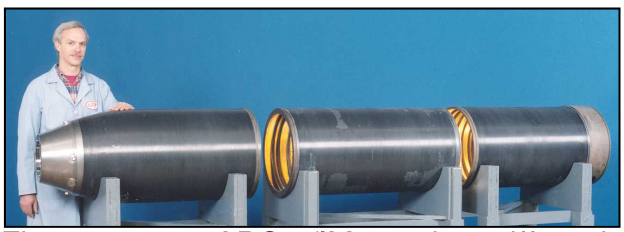

Figure 3.5 APC-2/IM-7 ring-stiffened submersible cylinders join together to form a complete underwater vehicle

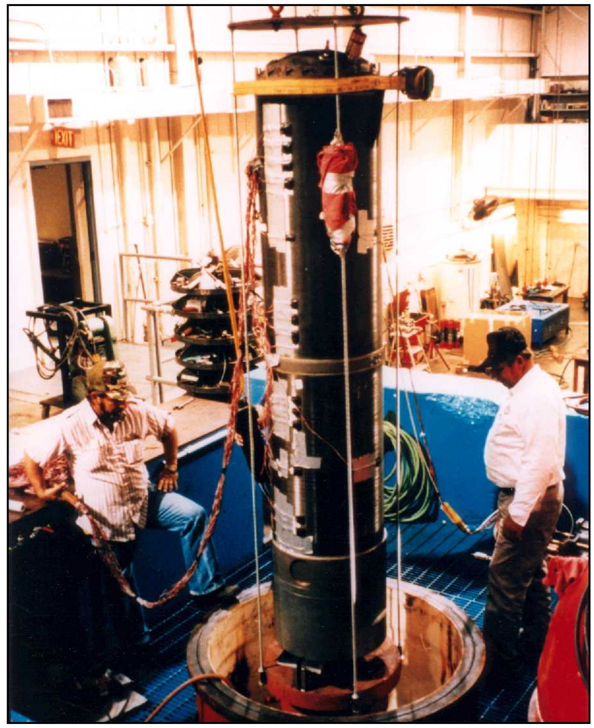

Figure 3.6 APC-2/IM-7 assembled underwater vehicle after completing pressure and thermal fatigue cycling

4. THERMOPLASTIC CYLINDERS – RANGE OF SIZES

Thermoplastic filament winding/tape laying has achieved autoclave level properties in thin and thick right circular cylinders as shown in Figure 4.1. The largest cylinders in the figure are 152cm (60-in) in diameter. Unusual shapes have been fabricated, including oval-shaped flex-tensional transducer shells for surface ship towed arrays and triangular-shaped rotors (in Figure 4.1 wound from Kevlar®)

Figure 4.1 Carbon and glass thermoplastic filament-wound cylinders up to 152cm (60-in).

The largest cylinder fabricated using the combined filament winding/tape laying process was the APC-2/IM-7 fan containment case shown in Figures 4.2 and 4.3. The 244-cm (8-ft) cylinder was fabricated to a 12mm (0.5-in) thickness in 96 hours.

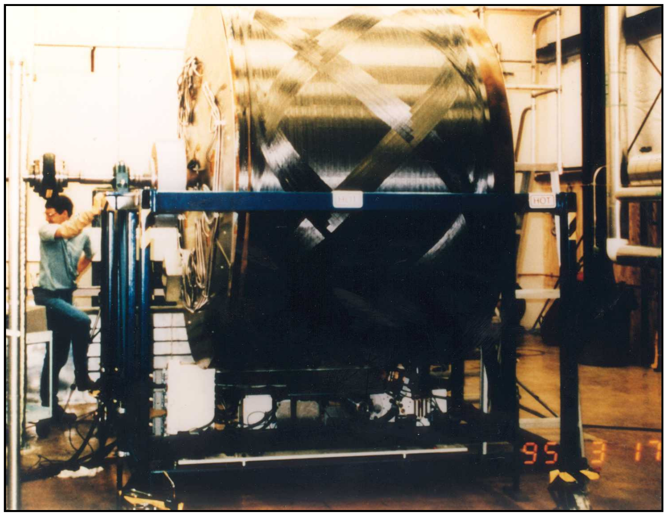

Figure 4.2 The fan containment case 90º and ±45º plies were filament wound and the 0º plies were tape-laid from APC-2/IM-7 in 96 hours

Figure 4.3 The 244-cm APC-2/IM-7 fan containment case weighed 363 Kg (800 lb) when complete.

5. THERMOPLASTIC CYLINDERS – TAKING ADAVANTAGE OF RESIN PROPERTIES

Thermoplastic matrix resins have excellent solvent resistance in addition to their high mechanical properties when wound to high quality. As a result, APC-2/AS-4 was wound into down-hope drill shafts, as shown in Figure 5.1. The shafts have a high fraction of ±45º plies for torque transmission.

Figure 5.1 Down-hole drill shafts

The excellent environmental resistant properties make the filament winding process a candidate for producing thick cylinders for industrial washer and bushing applications in challenging chemical processes, as shown in Figure 5.2.

Finally, AS-4/PEKK was used to fabricate launch barrels for a military weapon system shown in Figure 5.3, including variable diameter, embedded electrical connections, and thermoplastic connection lugs. The excellent surface toughness of the thermoplastic matrix resin allowed more rounds to be fired without damaging the barrel inner surface.

Figure 5.2 Thermoplastic industrial washers and bushings have excellent environmental resistance properties for challenging chemical processes

Figure 5.3 Thermoplastic barrels used in launcher

10. SUMMARY

A thermoplastic in situ fabrication filament winding/tape laying process has been demonstrated via the fabrication of many monocoque and ring-stiffened thermoplastic cylinders from a variety of resin systems. Cylindrical laminate properties rival or exceed those from thermoset autoclaved cylinders, especially for thick sections. The process is well-suited for cylinders loaded in external hydrostatic compression.

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