Fabricating the Spiral and Hemi-Spiral Orthosis Using a Composite Lay-Up Technique

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Introduction

Conventional thermoplastic materials previously utilized in the fabrication of spiral and hemi-spiral orthoses, have in many cases proved themselves to be ineffective. Some materials were found to be too brittle, leading to material fatigue and eventual failure. Other materials were found to be less brittle, yet too flexible to function as required by the design of the orthosis.

The application of composite materials in a semi-flexible acrylic lamination has made it possible to achieve the results required while eliminating the material fatigue and the breakage associated with previously applied materials. By incorporating the present materials technology in the spiral and hemi-spiral design, positive results have been achieved. There is an added advantage in that the orthosis can be custom tailored to achieve the desired balance between rigidity and flexibility, as required by a patient's specific needs. This can be easily accomplished by varying the lay-up of materials, an option not available in previously applied thermoplastics.

The only areas of concern addressed in this article are materials application and fabrication. For casting, modification, design and orthotic applications refer to the previously published materials available on the spiral and hemi-spiral orthosis (see references).

Design

Because of the unique characteristics each yields, a combination of three composite materials was chosen. The best results were achieved when the three materials were wrapped together into a "strut" design. This allowed the unique qualities of the materials to be balanced and to function together more favorably than they would alone.

The strut begins with an "inner core" of carbon. The carbon was utilized to control the compressive loading, due, in part, to the coiling action of the orthosis. It is necessary to maintain some compressive resistance during coiling to keep the spiral from collapsing under loading.

A layer of five ounce Kevlar-49(1) is used as an outer sheath. The Kevlar-49(1) has the unique property of being extremely flexible under a compressive load, yet highly resistant to tensile strain. This helps to keep the orthosis from stretching out during recoil.

In between the inner core and outer sheath is a middle layer of 6-ounce S-2 glass (2). This layer acts as the transition layer for the stress changes which are inherent to this design. The S-2 glass functions in both the compressive loading and tensile strain phases. Since carbon graphite is relatively weak under tensile strain and Kevlar-49 is relatively weak under compressive loading, the S-2 glass becomes the balance between the two layers aiding in the transfer of stresses between them.

The stresses on this particular design of orthosis are quite unique, contributing to failure of many previously applied materials. There are not only the typical surface strains associated with the changing stresses applied through the gait cycle (i.e., heel strike to foot flat, to toe off) which must be considered, but the coil and recoil action of the orthosis as well as the constant rotational torque applied must be considered as well.

Fabrication

After modification of the cast is complete, it is extremely important to define the trimlines. Because of the lay-up technique, and because of the difficulty in finishing any composite materials which might become exposed, it is important to predetermine all trimlines. When applying the materials to the model, keep them one-eighth inch to one-quarter inch within the final trimlines.

The orthosis is laid up in three separate sections; the cuff, the soleplate and the strut.

1. Cut four pieces of Kevlar-49, four pieces of S-2 glass and two pieces of carbon to the shape of the cuff.

2. Cut six pieces of S-2 glass and two pieces of carbon to the shape of the soleplate.

3. Cut the material for the strut (Figure 1) . To do so, measure the length required from about mid-cuff around the model to just superior to the plantar surface of the soleplate. The strut should extend as distally as possible without creating a wedging of the heel. Cut a piece of carbon four and one-half inches wide by the length required. Since the Kevlar is more difficult to cut than most composite materials, very sharp scissors will be required. (Also, the use of 3M double sided tape to mark out all cut lines will be helpful. Leave half the width of the double sided tape on the cut pieces. This will help in the application of materials to the model as well as the folding of the strut.)

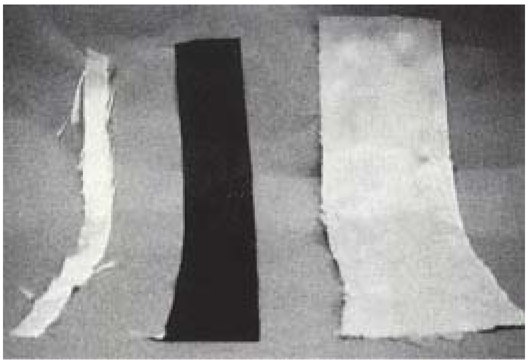


Figure 1. Cut materials for the strut.

Take the length of carbon for the strut and fold it so that a flat length of carbon, one and one-half inches wide by the desired length, three layers thick, is achieved.

Lay out the fiberglass. Place the folded length of carbon on the edge of the glass, matching length for length, and fold the glass around the carbon four times. This will result in a length of material with an inner core of carbon, an outer "wrapping" of S-2 glass totaling seven layers. (Two layers of glass on either side of the carbon.)

Lay out the Kevlar, placing the previously wrapped material on the edge of the Kevlar, matching length for length, and fold the Kevlar around the material approximately six times. The results should be a strut with an inner core of carbon (three layers thick), a transitional layer of glass (three layers thick) and an outer sheath of Kevlar six layers thick (three on either side of the inner layers).

Though this may seem like a lot of material, using 25 inches to 30 inches of mercury vacuum and stringing any excessive resin from the lay-up will produce a strut about three-sixteenths inch to one-fourth of an inch thick.

By utilizing this technique of folding the material around itself, we have found four major benefits.

First, moving from the core outward in either direction, we have created a smooth transition of material from rigid, to semirigid, to flexible (under compressive loading).

Second, the uni-directional knit or a bi-directional (0 degrees - 90 degrees) weave of the material allows the axis of the fiber to be applied in the direction of the spiral's configuration without interrupting the length of the fiber by cutting. This allows the stress to be transferred along the long axis of the fiber, increasing the fiber's function and strength.

Third, if the strut becomes exposed along an edge during trimming, only one layer of material is exposed, the outer layer. With the typical sandwich lay-up, if the strut were to be exposed in trimming, all 12 layers would become exposed.

This leads to the fourth advantage. With a bi-directional weave (0 degrees - 90 degrees) the folding of the material will eliminate the delamination which would occur between layers. The wrapping eliminates the edges where delamination would begin typically in the sandwich lay-ups.

This "strut" design has also been utilized with great success in the fabrication of the rigid frames for the flexible socket systems in prosthetics.)

Once the materials are cut and ready, prepare the model for lamination. It is important that the materials be applied in the sequence noted to ensure best results.

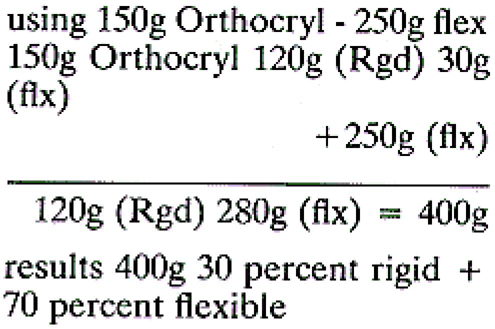
Lay-Up of Model

1. Inner layer of elastic stockinette over entire model (Figure 2) .
2. Two of the Kevlar cuff pieces, followed by two of the S-2 glass cuff pieces, and three of the S-2 glass soleplate pieces. The various pieces of material are held in place by the double-faced adhesive film (Figure 3) .
3. Wick layer of elastic stockinette over entire model (to facilitate resin flow).
4. One layer of carbon in both the calf and soleplate.
5. Apply strut to model-run from carbon layer at mid-cuff to carbon layer just superior to plantar surface of soleplate (Figure 4) .
6. One layer of carbon in each the cuff and soleplate positioned so that they cover the ends of the strut.
7. Wick layer of elastic stockinette over entire model (to facilitate resin flow).
8. Two layers of S-2 glass followed by 2 layers of Kevlar in the cuff and 3 layers of S-2 glass in the

soleplate.

9. Outer cosmetic layer of elastic stockinette (Figure 5) .

Laminate the model using an acrylic resin mix of 70 percent flexible, 30 percent rigid resin. It is important to remember that most resins, if premixed, are already 20 percent flexible.Example:



using 150g Orthocryl - 250g flex
150g Orthocryl 120g (Rgd) 30g (flx)
+250g (flx)

120g (Rgd) 280g (flx) = 400g
results 400g 30 percent rigid + 70 percent flexible

A 30 percent rigid, 70 percent flexible resin mixture will result in an orthosis which is relatively compressible and best utilized in light-to-medium duty applications. If a more rigid orthosis is desired, the best results will be achieved by increasing both the layers of carbon and fiberglass and the resin rigidity slightly.

It should be noted that as the resin mixture is increased, the possibility of resin crazing also increases. This is why the materials and resin should both be increased together.

Summary

After extensive research into materials and their applications, more than half a dozen prototype designs were fabricated. These were used to test the materials in spiral and hemi-spiral configurations and to see how they reacted under stress. It was not until satisfactory results were achieved here that the first orthosis was fabricated for a patient.

Over a period of three years, more than six orthoses have been prescribed. This includes bilateral spiral orthoses. Some of the spiral and hemi-spiral orthoses fabricated from composites have been applied to patients who had broken conventional thermoplastic orthoses. To date, none of the composite orthoses have undergone material fatigue or functional failure and all of the patients are in the original orthoses fabricated for them.

Though the time involved in fabrication is increased, so are the results. The application of composite materials to the fabrication of the spiral (Figure 6) and hemi-spiral orthosis may allow a more thorough look at its application and effectiveness in patient management.

Figure 6. Completed spiral orthosis laminated of composite material.

Manufacturers

1. Kevlar-49 is an E.L. duPont De Nemours & Co. fabric used for its extremely high tensile strength. It was developed for aerospace and military applications and is widely used in outdoor sports equipment.
2. S-2 glass is an Owens Corning fabric developed for military and aerospace applications. It has superior laminate properties to standard fiberglass and is categorized by structural engineers as an advanced composite.

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