Low Cost Manufacturing Processes using UV Cure Resins

Presented at Composites ‘97 Manufacturing & Tooling Conference Advisory Committee
Liquid molding Session: Emerging Low Cost Manufacturing Processes for UV Cure Resins.
Tuesday Jan 21 1:30-4:30

Introduction

Light curing resins have been used since the start of fiberglass composite fabrication. Light curing was the original method for curing these initial composites. With the advent of peroxide catalysts, light curing methods were abandoned. Thick part curing was not achievable with the earlier photoinitiators. In 1986, BASF invented a new class of photoinitiators which worked very well in curing thicker (1/2"+) composite laminates using Ultra-Violet light. This newer class of photoinitiators has been refined to allow for a fast and complete cure. New development is ongoing and additional classes of photoinitiators and co-curing methods are currently under intense investigation. Additionally nontraditional methods of fabrication are being utilized with these resins, which were not able to be used with catalyst type curing systems. These new methods include Vacuum Assisted Resin Transfer Molding (VARTM), Cure on the Fly Fabrication, and Wet Edge. Most of us don’t realize how much money and effort we spend, and the amount of waste usually generated in the process, to achieve consistently good laminates using catalyst cure resin systems.

I. Light curing resins

Currently many composite parts are being made with light curing resins. These products range from large pipe couplings, electrical power line insulators, boats, tanks and hockey masks.

II. Advantages of light curing resins

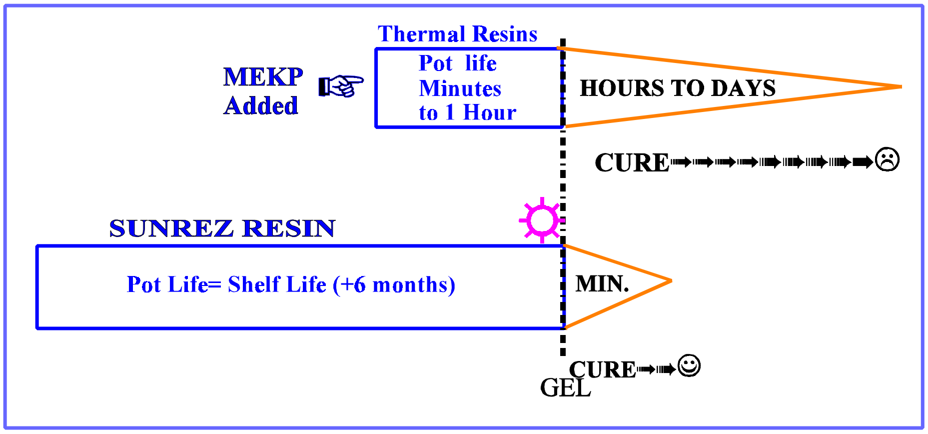

Figure 1 Comparison of MEKP cure to Light cure

True One Part System.
Cure On Demand.
The molds can be cycled at 2-8 times faster than MEKP parts.
No expensive mixing machines to buy or maintain.
Control of the cure is in the hands of the shop instead of the gods.
Fewer environmental controls are necessary for the shop floor.
Fewer molds.
Fewer rejected or unusable parts.
All unused resin is reusable.

III. Manufacturing techniques using light cure resins' Cure on Demand properties

Light curing resins are Cure on Demand systems. These resins do not begin to cure prior to the exposure to UV-A light. Standard indoor light will not cause them to cure. Sunlight and tanning type lamps will cause the resin to cure. Based on resins that are available today the properties of many epoxies can be duplicated with light curing vinyl ester resins. Speed of the cure for parts as large as 16 square feet, in product runs of 10,000 or more parts per year, are as economical as SMC or BMC systems. These light cured parts are processed on a 10-20 minute mold cycle time, using low-cost fiberglass molds. Expensive presses and steel molds are not required for this type of production.

When you think about using standard, thermal cure thermoset resins, the first thing that one has to addressed is the necessary working life and cure times. How much catalyst and promoter are required to achieve these cure rates? Will the ambient temperature remain constant through the working life? How soon can the part be taken out of the mold? Is this a summer or winter resin? The use of light curing thermoset resins changes all of those perceptions. Sunrez light curing Vinyl ester, Polyester, Urethanes and Acrylic resins act and cure differently than a catalyst cured composites. These resins can be heated for lowering the viscosity with no ill effects on the resin or the finished product. This allows a faster mold filling time and better wet out.

A. Background

1. Catalyst curing systems

In any system involving the catalyzed curing of polyester or vinyl ester resins the minute the catalyst is added, (MEKP or BPO) the curing process begins. Once started the peroxide systems cannot be stopped from going through their curing cycle. These types of catalyst curing systems must complete an exothermic cycle in order to build the proper chemical structures to attain the desired properties. They must reach a prescribed temperature in order to achieve complete crosslinking.

In a normal laminate involving either a hand layup or wetout gun of one sort or another, the catalyst is added on a batch or continuous basis and the laminate is usually gelling and moving to cure within 1/2 hour after the catalyst has been added. This approach promotes enough exotherm for the product to cure properly, but must not involve a laminate thickness so great that a cube exotherm occurs. ("Cube exotherm" occurs in a laminate when the temperature of exotherm raised to the point that the catalyst becomes a Super Catalyst and feeds on its own exotherm heat instead of the promoters in the system.) Also, in a "normal laminate" the demolding time is controlled by the ability of the resin to build strength through the chemical reaction. The faster and closer to the ideal temperature reached, the faster the part reaches a "Barcol" hardness high enough to demold the part. Controlling the reaction of the resin to not be too hot and not be too cold is what proper catalization is all about, and the reason for the equipment manufactures to build their equipment with adjustable ratio catalyst injectors. This adjustable mechanism is what allows the fabricator to control the level of catalyst ratios throughout the day based on changing shop temperatures. Shop temperature can change as much as 40-70 degrees F in a single day, depending on location and as much as 70-100 degrees F seasonally. An important fact is that chemical reactions double their speed with every 17^0 F rise in temperature.

The other consequence of this is that molds must be kept stabilized at constant temperature. If the process is cooled or heated (plus or minus a few degrees) at any point after the proper amount of catalyst is mixed into the resin for a given temperature, all estimates of cure time are off. If the part has different thicknesses, than temperature profiles of curing will change in different areas, with possibilities of undercure or overcure in different parts of the structure.

Although all of these problems can be overcome in a climate controlled setting, the problem of cycle times still remains. With a room temperature cure-catalyzed resins the time from gelation to cure can run 1- 3 hours for a catalyst cured VARTM process because of the additional time needed for a safety factor. The part will cure to sufficient demolding strength after two times the amount of time that it took to gel the resin. Therefore a part that took one hour for the laminate to gel will require at least an additional two hours in the mold before it is ready to be demolded.

2. The Solution is CURE ON DEMAND

Light curing resins solve many of these problems. Light curing resins are not affected by temperature, except for viscosity, in any part of the cycle. Since light cure resins are one part systems, the resins are used right out of the drum, with no mixing needed. Light curing resins when cured properly will reach full heat distortion temperatures upon cure. Climate control is not necessary. The same resin will cure as well at 0^0 as at 180^0 F. Full cures can be easily achieved in as little as two minutes in 1/4 inch+ part. Cure speeds are dominated by light intensity and not temperature.

IV. New Processes Available with Light Cure Resins

A. UV-Vacuum Assisted Resin Transfer Molding

There are a number of very similar processes called by a variety of different names which include: The Marco Method, Vacuum Assisted Resin Transfer Molding (VARTM), Seemann Composites Resin Infusion Manufacturing Process (SCRIMP™), Resin Infusion under Flexible Tooling(RIFT), Vacuum Assisted Resin Infusion(VARI), Resin Injection Recycling Method (RIRM), LS Process and a variety of others. All of these processes are very similar in actual processing, with only minor variations.

A chief advantage of UV-VARTM is the ability to cure on demand. This ability to cure on demand allows the parts to be fully ready prior to curing. If any problems arise, the curing process can be delayed until the part is ready to be cured. Due to the rapid curing the part is under less risk of failure during the cure time of a few minutes instead of hours.

The following diagrams represent the basic layout for VARTM type processes.

Figure 1 shows a simple layout using a flexible vacuum bag and "tacky" tape as the seal.

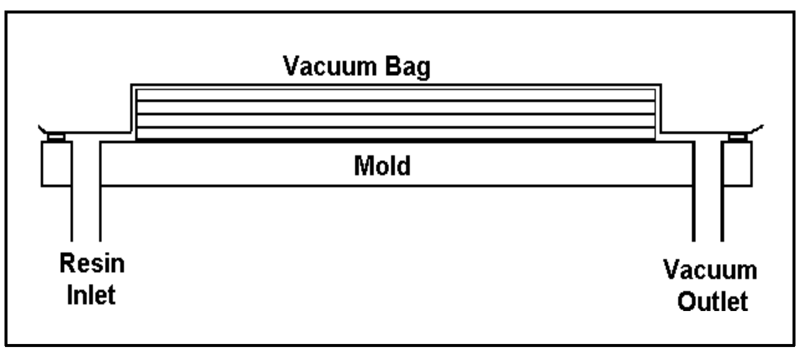

Figure 2 Basic VARTM Setup

Figure 2 shows a semi rigid top mold with the resin acting as the vacuum seal. It was important to keep the trough filled with the resin at all times during the process. This system was originally used to build US Coast Guard boats in 1950.

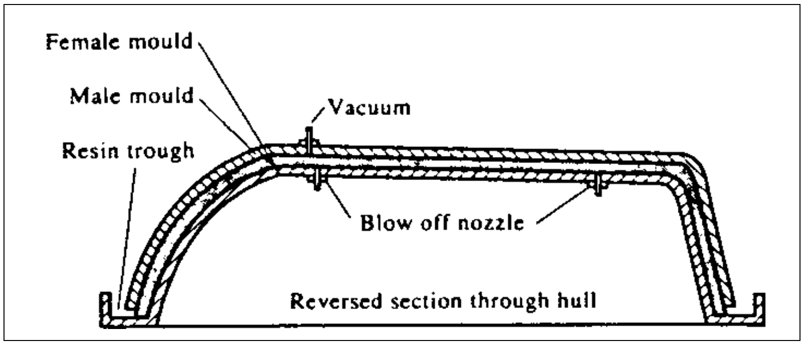

Figure 3 Marco Method

A vacuum is applied to the part and resin is drawn thru the laminate toward the vacuum port(s). When the resin has fully saturated the materials, the resin and/or the vacuum valves are closed and the process is complete except for curing. With a two-part resin system timing is critical. Gel must not begin prior to completion of the saturation process.

As you can well imagine, this process is very sensitive to temperature and cure times. Using Light curing resin and clear vacuum bags or molds, allows the fabricator to fill the laminate without fear of premature gelation. When the laminate is fully wet out, the UV -A lamps are turned on and the product is cured in 5-20 minutes.

B. Light curing Prepregs

Because of the cure on demand properties of the light cure resins and because they are a one part system, prepregs can now be made using styrene monomer resins which can be stored at room temperature for up to one year. One swipe with a squeegee and the thixotropes break down and allow the resin to spread, then return to a thickened state within a couple of minutes. These thixotropes can be adjusted to control the final viscosity of the resin up to the consistency of a thick peanut butter. Prepregs are currently being used in the U.S. Army and Navy for Battle damage repair and commercially in truck repair, pipe joining and sports equipment repairs.

C. **Wet edge Concept** (partial part curing)

Since light curing resins cure only under the influence of UV-A light. Portions of a laminate or prepreg can be totally cured and other portions of the same laminate can be totally uncured. This allows the fabricator to accomplish what we call wet edge laminations. In its simplest form a laminate is laid down and the final 6 inches of material is covered with an opaque film. The majority of the laminate is cured. The opaque film is removed and a new laminate is overlapped onto the 6 inches of uncured laminate. This laminate is cured and a primary bond is formed instead of a secondary bond. This method allows the corners of a box to be cured and sealed after being made from a flat sheet. The laminate sees no secondary bonding or joints. This process also works at any portion of a laminate.

Another iteration of this practice was used for the US Navy in building a all UV-Prepreg Hull Section. Most of the longitudinal stiffeners were built on a mold away from the hull and stored prior to bonding them into the hull. The upper portions of the hat section stiffener were UV cured. The feet of the stiffener were shaded and were not allowed to cure. These stiffeners were then stored until they were required in the building sequence. As they were needed they were brought to the hull and the opaque cover on the foot portion of the stiffener was removed and the wet prepreg was laminated to the hull. No additional resin was necessary to wet out the part. When the prepreg was correctly positioned and rolled out, the UV-A lamps were turned on and the Stiffener was bonded in place.

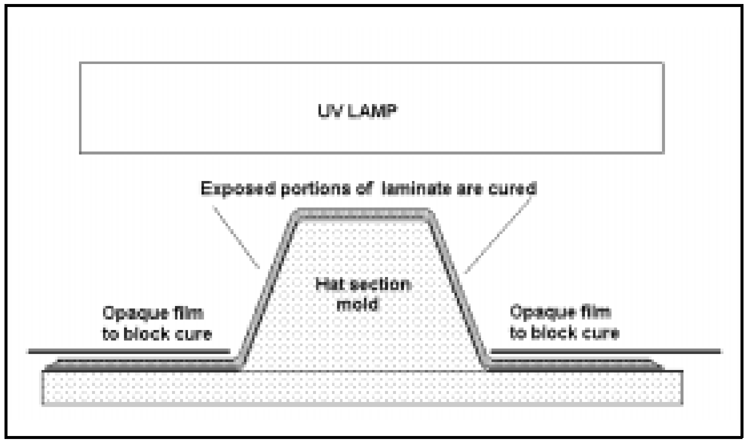

Figure 4 Sectionally cured part for later bonding

D. Filament winding and cure on the fly fabricating

Light cures are used in filament winding operations as either prepreged roving or bath wetout systems. These filament wound parts can be cured as they are wound. This allows the operator to remove a completed part as soon as he is finished winding the material onto the mold. Also the quick curing of light cure resins and prepregs allows a direct fiber lay down and cure directly from tape or fiber dispensing machines.

E. Preforms for RTM

Light curing resins are now being used in fiberglass preforms to hold multiple layers of mixed style fabrics together for use in RTM operations using RTM tooling or VARTM tooling. Precision cutting and proper placement of these fabrics, allows the fabricator to build net size parts. Light curing allows these preforms to be bonded together within 20 seconds. Light cure preforms and UV-VARTM when combined, allow medium size parts (10-30 sq ft, 1-3 M sq) to be built economically at 10,000 + parts per year. A total cycle is less than 20 minutes per part.

V. Tables and Figures

The following are tables and pictures of Sunrez's project using UV-VARTM on a U.S. Navy Test section. A test section exactly the same was built using UV curing prepregs.

The comparative results and pounds per man hour are given on Table 1 and 2.

These laminates were U.S. Navy type laminates. UV-VARTM laminates had an average of 66% fiber by weight and UV-Prepregs had an average of 58% fiber by weight. The UV cured hull sections had far better Productivity and Cost benefits over other processes.

Productivity exceeded 40 lbs. per man hour on single skin panels

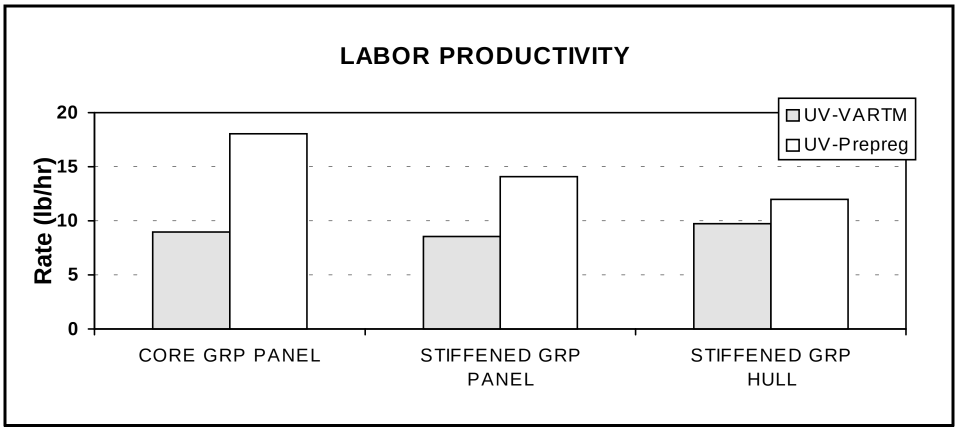

Table 1

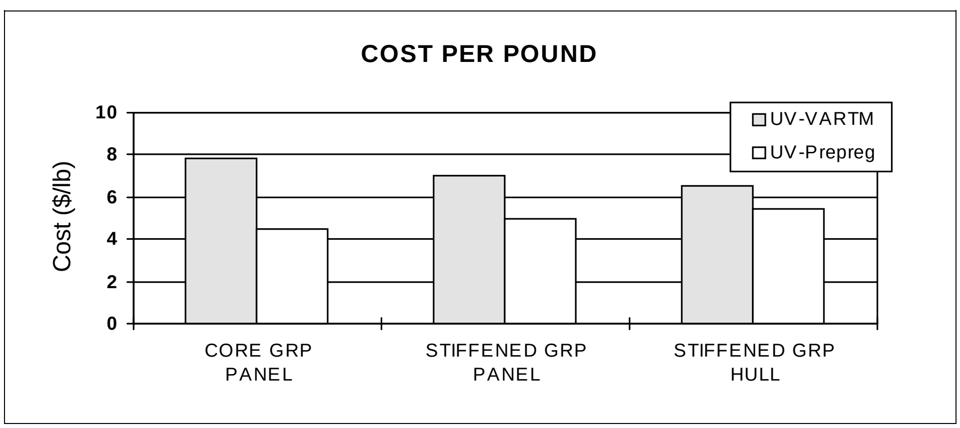

Table 2

Figure 1 Start of Infusion

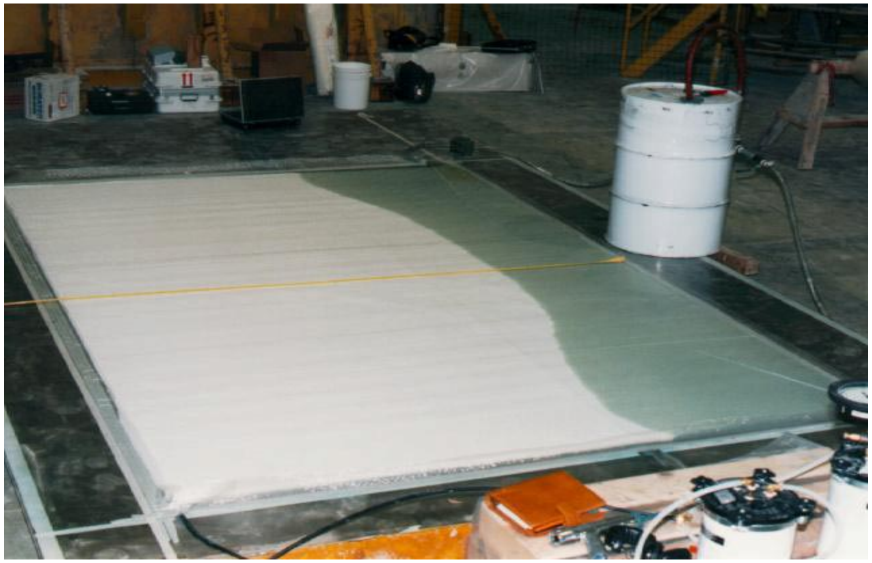

Figure 2   Infusion after 10 minutes

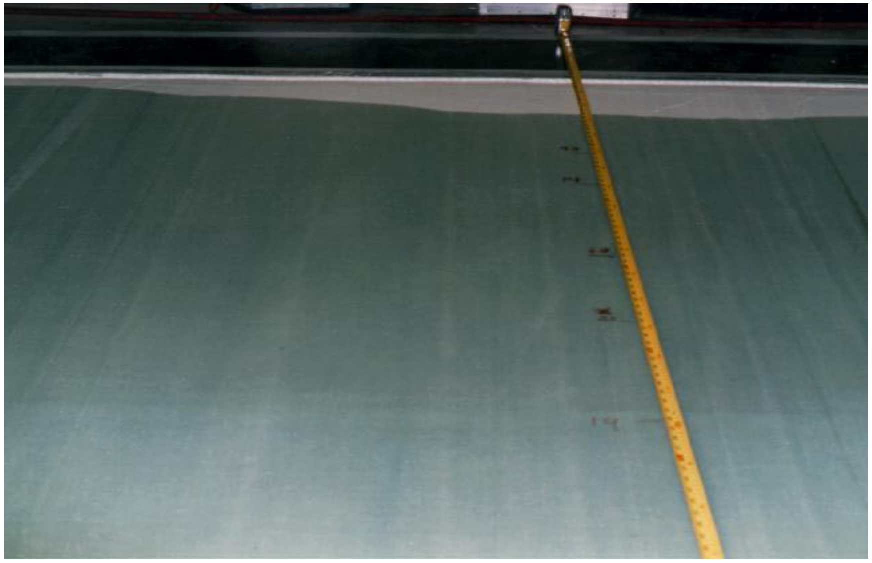

Figure 3   Infusion after 40 minutes

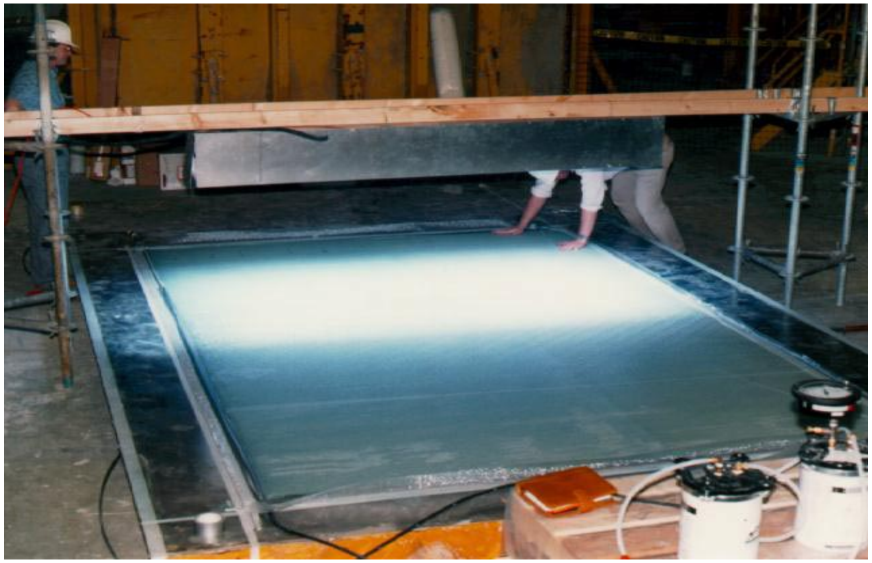

Figure 4   Start of cure cycle

Figure 5 Main deck Infusion 22' x 30'

Figure 6 Main deck stiffeners being Infused

Figure 7 Main deck being moved off mold

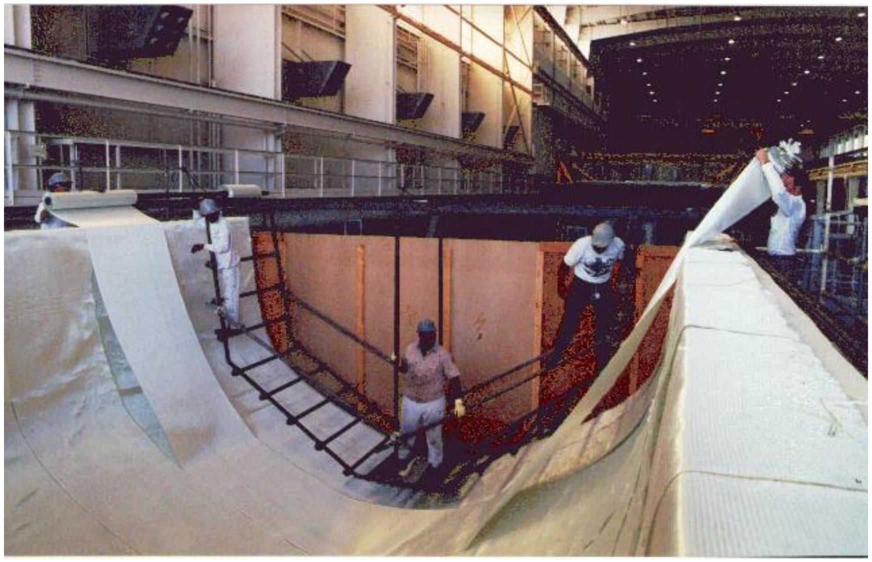

Figure 8 Hull being prepared for Infusion

Figure 9 Installation of stiffeners and deck plates

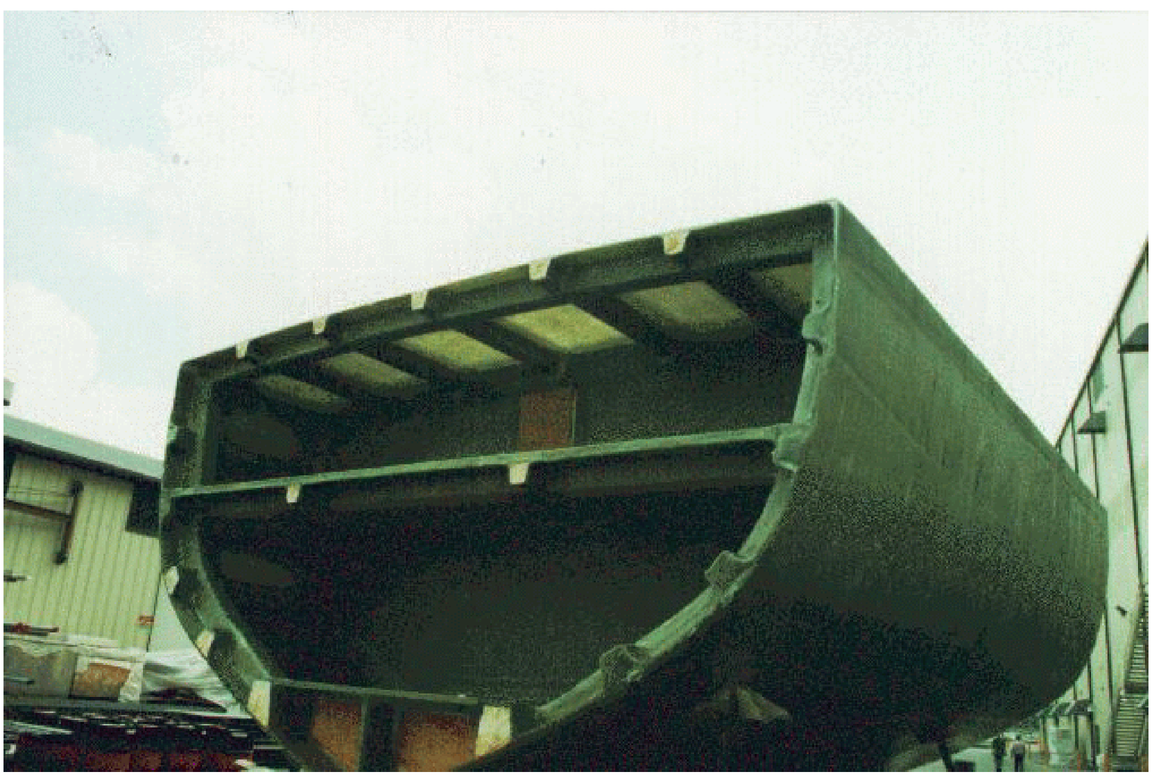

Figure 10 Completed Hull test Section