Composite Boat Repair: Part One, Damage Assessment

If it seems like this two-part series on boat repair is written for boat owners rather than manufacturers, it's my little effort to help us understand our customer base and the criteria they use to make choices in an increasingly competitive market. New buyers need to be educated about the ease of fiberglass repair when compared to the higher skill level required to work with other boatbuilding materials. Seasoned boat owners will look for a product with improved durability and life-cycle costs when compared to their current vessel. Boat surveying is a huge business in this country and as manufacturers we ought to listen to what they are saying because our customers certainly are.

A boat is typically surveyed for "damage" on three occasions. First, the manufacturer will perform, as a minimum, visual inspection for damage, which in this context covers manufacturing defects that can be corrected before the boat is sold. Next, a boat will receive a "Condition Assessment" by an independent surveyor when it's sold to another owner. From a boat builder's point of view these "Assessments" can seem like nitpicking, but a very detailed survey has true value to the perspective buyer and he relies on the integrity of the surveyor to support the validity of noted criticisms. And finally, the primary association we have with the term "Damage Assessment" is after an accidental collision or some obvious structural failure.

Damage Assessment for fiberglass boats involves knowing what to look for and how to use the tools used to quantify the extent of the damage. Before we review what type of damage to look for, it is instructive to understand the major cause of in-service failures. Greg Davis of the nationwide survey firm Davis and Company reported the following damage sources in 1996, as gleaned from their database of over 3000 surveys:

Struck Submerged Object	61%
Collision	17%
Poor Maintenance	14%
Grounding	5%
Manufacturing Problem	3%

Good to see Manufacturing Problems down around 3% and of course these are boats built by our competitors. The causes cited above lead to the following types of damage that we need to assess:

Puncture of hull or deck skin(s)
Delamination (between plies or skin to core bond)
Fracture or debonding of internal stiffeners, bulkheads and joinery
Deck joint failure
Water intrusion into core
Gel coat stress cracks

Non-Destructive Evaluation (NDE) Tools

Before we discuss damage assessment methods for these types of failures, let's take a look at what tools are available to determine the extent of the problem.

Visual Inspection
This is by far the most utilized method for discovering damage to a fiberglass boat. This works fine for the exterior of the hull and deck but can be problematic with heavily outfitted interiors. Features that make interior inspection difficult include foamed void spaces, liners & insulation, tanks, joinery, plumbing and wiring. Exterior visual inspection can be difficult if you're one of the 61% (cited above) who have struck a submerged object below the waterline and the boat is still in the water. Visual inspection can be tricky for the novice, as fiberglass damage can look worse than it is structurally and conversely, the extent of delamination can be greater than what meets the eye.

The U.S. Navy requires that glass reinforced laminates built for them not use colored gel coats to make visual inspection possible for detecting delaminations, voids, resin rich or starved areas, fiber misalignment, bridging and under cure. However, they recognize that visual inspection can be subjective and recommend that any potential problems be further investigated with more precise methods, such as ultrasonic testing.

Tap Testing
A common procedure for quantifying suspected delaminations not visually obvious is to tap on the laminate with a metal object or plastic hammer and listen for changes in the sound. Typically, areas of delamination will have a "lower pitched" response, corresponding to a lower natural frequency of the local structure. This technique can also reveal debonds between sandwich skins and cores, albeit only on the side being tapped.

Ultimately, tap testing is a subjective technique that relies on a trained surveyor's ear to differentiae between actual delaminations and inherent structural discontinuities. An instrumented sounding hammer system has been developed by Bruce Pfund to apply a more scientific approach to the ancient art of "sounding" a structure. A very sophisticated percussion NDE technique has been developed by Colin Ratcliffe of the US Naval Academy and Roger Crane of the Navy's research lab at Carderock, Maryland. They excite the composite structure of interest with a modally-tuned impact hammer over an established grid. According to Dr. Crane, structural "anomalies are determined by examining the frequency dependent curvature of the experimentally-determined vibrational motion of the structure." Dubbed SIDER (structural irregularity and damage evaluation routine), the patented technique has shown great promise with large marine structures but has yet to be formally adopted by the U.S. Navy.

Destructive Testing
This is my favorite method for evaluating potential damage in large composite structures not considered "high-tech." I say this because thin high-tech laminates with carbon reinforcements are difficult to repair. However, for most fiberglass solid or sandwich laminates, the information gained from a ¼″ drilled hole outweighs the damage done. Suspected delaminations and water intrusion can be confirmed with a small hole. In some cases it may be necessary to take hole-saw samples for resin content tests or even larger samples to test mechanical properties.

Thermography
A relatively new technique for evaluating the integrity of composite laminates over large areas uses a high-precision infrared camera to measure small temperature differences over the area of interest. Typically, the area of concern is heated locally and voids or trapped moisture show up as temperature differences as the subject area cools down. It's very easy to mark suspected areas on the laminate surface based on the image seen on the camera. What's more difficult is interpreting the images and understanding what a perfectly sound composite boat structure looks like in the infrared spectrum.

Jack Allinson is a marine surveyor located in Jacksonville, FL who makes extensive use of infrared imaging to diagnose fiberglass boat structural problems and gives seminars on the use of infrared imaging equipment in marine surveying. Mr. Allinson notes "Infrared imaging clearly is a valuable tool for a marine surveyor. Like other investigative tools, it should not be used as the sole source for identifying a problem. A surveyor's experience, knowledge of how the boat's systems function, the construction methods used, and use of other supporting investigative tools are key to the accurate interpretation of what the infrared images show."

Moisture Meters
Moisture meters are perhaps the most debatable diagnostic tools used by marine surveyors. Yacht brokers hate them as many deals have fallen through because a survey concluded that moisture was trapped in a boat's skin laminate or core. Perspective buyers rely on moisture meter surveys to alert them to potential water in the laminate, especially with sandwich construction. James G. Merritt, a marine surveyor in Austin Texas tells us, "After using a moisture meter on over 1,000 surveys, I have yet to see a recently-hauled boat that indicated anything less than 'high' (7+ on a scale of 1 - 10) on surfaces below the waterline. These readings have been taken with a variety of meters……. The end result is that I ignore meter readings below the waterline while still paying close attention to exterior surfaces above the waterline, particularly around through-hull fittings and any deck hardware." With fiberglass, meter readings will always be on a "relative" scale and destructive testing (i.e. cutting open the laminate) is required to get an absolute reading.

Ultrasonic
According to Olympus NDT, a supplier of ultrasonic field measurement equipment, "Ultrasonic nondestructive testing (NDT) - characterizing material thickness, integrity, or other physical properties by means of high-frequency sound waves - has become a widely used technique for quality control. Ultrasonic testing uses high frequency, highly directional sound waves to measure material thickness, find hidden internal flaws, or analyze material properties. Nearly 30 years ago, Panametrics was the first company to develop a thickness gage and transducer that were specifically designed to make digital thickness measurements from one side of the fiberglass. Modern hand held gauges are simple to use and highly reliable."

Bruce Bandos, a U.S. Navy NDE expert, uses sophisticated ultrasonic equipment to evaluate the ever-increasing volume of composite structures appearing in the fleet. Laminates investigated include both solid and sandwich construction made with E-glass

and carbon fiber. According to Mr. Bandos, "Ultrasonic testing is used to detect and quantify the extent of discontinuities throughout the volume of composite material, measurement of laminate thickness and evaluation of bondline characteristics. Discontinuities identifiable with ultrasonics include resin starved laminate, resin rich laminate, delaminations, porosity or voids, and inclusions, as well as the quality of laminate skin-to-core bonds." The reliability of ultrasonic evaluation is higher for uniform laminates. Presently, testing is done manually, which can be very time consuming for large marine structures.

Damage Types

Now that we've established our "toolkit," let's take a look at the types of fiberglass damage we might see in fiberglass boats caused by accidents, inadequate design or manufacturing deficiencies.

Puncture of Hull or Deck Skin(s)

Punctures are the least mysterious types of damage we see in fiberglass boats. Collisions with other boats, foreign objects or docks are difficult to go unnoticed by the operator, although it is not unheard of for larger motoryachts (sometimes operating on autopilot) to strike submerged objects, buoys, and even other boats without recognition. For the most part, a collision or grounding will usually prompt at least a visual inspection of suspected damage. The next question is how much the delamination extends beyond what is visible on the exterior or to the interior that may not be accessible for inspection? This is a good time to use the laminate tapping technique, marking suspected damaged areas as you go. The boundary of the damaged area should be confirmed by drilling a small hole since this area is going to be repaired anyway.

Delamination (between plies or skin to core bond)

Delaminations within the laminate typically can't be diagnosed visually, although sometimes the panel will be "softer" when loaded. Tap testing or ultrasonic evaluation is required to quantify suspected delamination damage. Knowledge of laminate construction and interior structure enhances the value of NDE for laminate delamination detection. Before investigating the extent of delaminations or voids in a laminate, it is necessary to establish what we consider to be an "allowable" delamination or void size. For instance, a one-inch diameter defect may not adversely affect the performance of a properly designed laminate.

Fracture or Debonding of Internal Stiffeners, Bulkheads and Joinery

Internal stiffeners "attract" loads and therefore are a location for stress concentrations. This can be a good thing as compared to failures in hull panels that could lead to sinking. The bad news is that these stiffeners are not always accessible for visual inspection as interiors are finished with furniture and liners that increase a boat's appeal. Often stiffener failure is revealed by stress cracks seen on the opposite side of the supported panel.

Deck Joint Failure

Deck joints are subjected to global hull loads and also must resist hard dockings. This area is also a key Quality Assurance check point during construction, as it's critical that

mechanical fasteners and adhesive are assembled as designed. Damage to deck joints is usually visually apparent on the exterior but traces of water intrusion on the interior can also be helpful. Due to the complex geometry of deck joints, more sophisticated NDE techniques are not suitable to investigating deck joint failures.

Water Intrusion into Core

Water intrusion into the core of a sandwich laminate is difficult to casually observe. However, I have examined boats with severe enough water intrusion to affect performance and how the boat floats. A lot of times water intrusion is discovered when holes are drilled to install new hardware. Indeed, poorly bedded hardware installation is very often the cause of water intrusion. Saturated decks may be "spongy" to walk on and hull panels may flex more than usual but I am unaware of any total structural failures attributed to water intrusion. If properly used, moisture meters can provide a relative indication of moisture variation within a laminate. Thermographic imaging with an infrared camera is very useful for determining the exact location of water trapped in a sandwich laminate.

Gel Coat Stress Cracks

Beautiful gel coat finishes help sell boats. Stress or "spider" cracks cause potential buyers to be apprehensive. I often council people that unlike metal, these cracks rarely propagate through the thickness of the laminate causing structural failure. Gel coats fail at strain levels lower than the structural portion of the laminate, so the stress cracks serve as an indicator of potential future problems. Because gel coat stress cracks are by definition on the laminate surface, visual inspection is the most effective NDE technique. Sometimes, dye penetrant can be used to enhance visual inspection.

Manufacturing Defects

Most manufacturing defects can be uncovered through careful visual inspection. This is best done during key stages of construction before structural elements are hidden by outfitting. Conscientious builders understand that standardized, documented Q/A inspections can minimize future warranty claims and enhance brand identity. Jack Allinson has shown that an infrared inspection of newly molded hulls can highlight areas where there are voids under the gel coat, which is a potential warranty item once the boat leaves the factory.

Conclusion

Visual inspection remains the primary method for inspecting damage in fiberglass boats. Tap testing is also commonly done, but this requires a trained ear to interpret the results. NDE instruments, including moisture meters, infrared cameras and ultrasonic gauges are useful only when operated by a trained technician. Understanding how carefully our boats are scrutinized after they leave the factory allows us to avoid future warranty claims.

Figure 1. Visual Inspection of Hull Damage from Grounding Showing Temporary Repair [http://svmirador.net/February_8_2004.htm]

Figure 2. A Marine Surveyor Uses a Moisture Meter to Examine a Boat Bottom [http://www.powerandsailmarinesurveyors.com/serv01.htm]

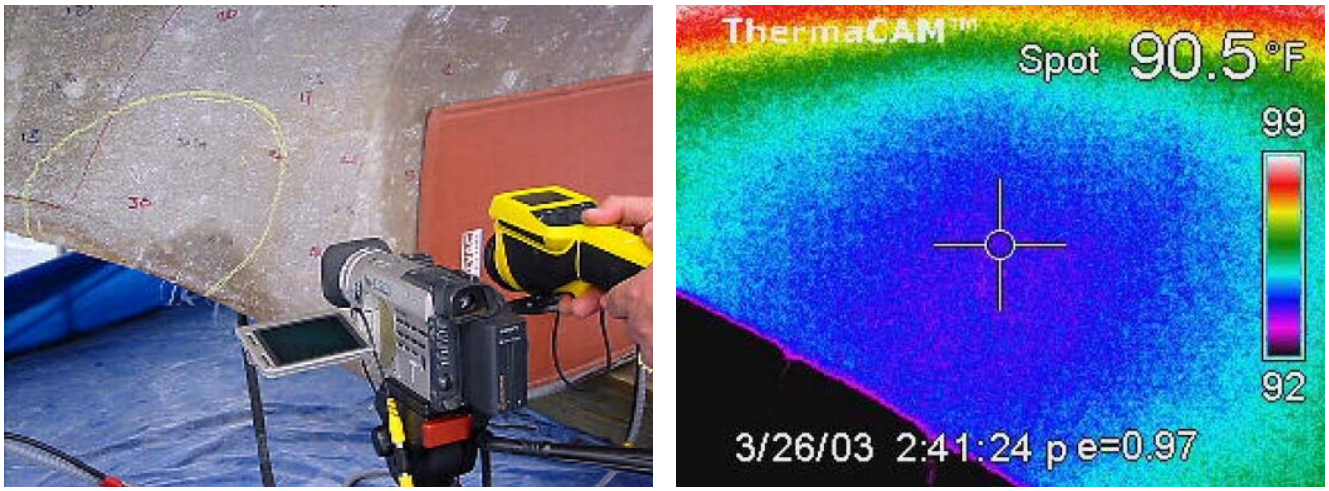

Figure 3. Water Intrusion Documented with Infrared Camera [http://allinson.com]

Figure 4. Ultrasonic Thickness Measurement Gage Used to Determine Thickness of a Sailboat Racing Hull [http://www.olympusndt.com/en/ndt-application/87-id.209715260.html]