Core Installation

by Bruce Pfund

Cored construction has been with us since the start of composite boat building. Today's lightweight core materials are more advanced than the plywood cores of the 1950s, but they are also more sensitive to bonding, installation, and outfitting errors that can reduce their mechanical performance or shorten their service life. David Jones of D.E. Jones and Associates (St. Petersburg, Florida), Richard Downs-Honey of High Modulus (an advanced-composite design and consulting firm in Auckland, New Zealand), and I discussed core installation in detail at IBEX 2004 in Miami, and this article is loosely based on that presentation.

To be structurally effective, core materials must be successfully attached to their laminate facings. Sounds simple, doesn't it? As Downs-Honey pointed out, "Loads on the core-to-skin bondlines are rather small. The best failure mode we can get with foam cores is when the cells' structure tears uniformly, and the skin tears with the core attached to it. The failure loads for balsa may be higher in shear, but the preferred failure mode is the same—failure *within* the structure of the core, not failure of the core-to-skin bondline.

"Since all cores are so much weaker than laminates," he continued, "the adhesives that attach cores to skins don't really have to be all that strong, but the bondline must be effective in transferring loads between core and skins. Some really strong, cored-composite panels use *contact cement* to bond the skins and cores together. The panels fail in the preferred way. What more do you need from a bondline and adhesive?"

Downs-Honey is correct. Core-to-skin bondline loads are low, as illustrated in his chart of laminate, core, and core-adhesive properties on page **xx [refers to page in RDH presentation]**. His firm conducted finite element analysis on a type of core-to-skin defect I call a "neverbond"—that is, where core and skin fail to make a complete bond during construction. The results showed that loads become concentrated around defects and can trigger dynamic failures. That's why 100% contact between core and skins is critical.

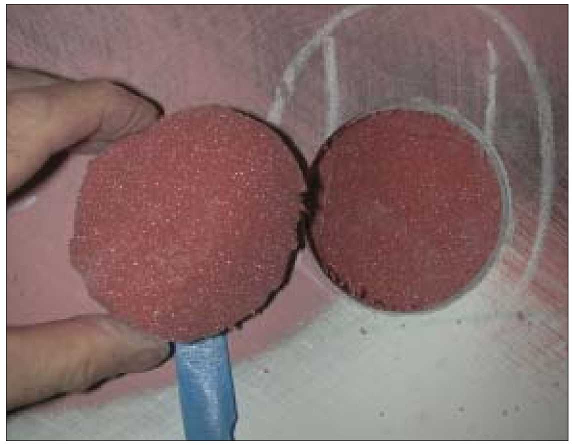
In this article, I'll take a close look at the various types of core-installation problems that boatbuilders face, whether with hand layup, vacuum-bagging, or infusion. I'll illustrate and analyze specific defect types, and suggest how to prevent each one.

Substrate Preparation: Peel Ply or Grinding

The substrate—the laminate surface to which the core is being bonded—is a frequent culprit in defective bondlines. The following conditions are "local" defects on the substrate:

- bumpiness and steep drop-offs at laminate panel edges;
- hairs and humps that are not ground off;
- ply drop-offs too close together or not taper-ground.

Above—This PVC sample shows the preferred failure mode for any core, whether plain or contour cut: failure within the core's structure, rather than failure of the core-to-skin bondline. Note the bleeder holes on 4" (25mm) intervals. These help vent bondline air when the core is not contour-cut.



Right—Here's a seat-of-the-pants field test to check the core-to-skin bondline: if a holesaw coupon resists removal, and then releases with a loud snap and fails the core when levered out, the bondline is probably adequate. Since levering puts the bondline in peel, weak bonds will sometimes fail—but not in the example pictured here.

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A "global" substrate factor to consider is the secondary-bonding window of the laminates' resin—especially if you're hand-fitting core panels to large parts, where days, weeks, or even months may elapse between the end of laminating and the start of core bonding. Try to minimize the amount of foot traffic and hand contact on the surfaces you expect the core to adhere to, so that the bonding surface stays clean.

Laying down peel ply on wet laminates and ply drop-offs to reduce the amount of grinding needed is attractive but carries a few risks, particularly if you're laminating with "low-profile" resins or resins containing DCPD. These resins cure very rapidly—even more so when covered with peel ply, because the peel ply reduces the air-inhibition effects that retard resin surface cure and enhance secondary-bonding performance. For epoxies, which may have more-extended cure times, peel ply is a great way to remove amine blush and expose fresh, uncontaminated resin when the peel ply layer is stripped. Leaving the peel ply on the laminate until the very last minute before core bonding begins is most effective.

Ply edges, drop-offs, and tailoring overlaps (except on infused products) represent the largest surface disruptions on a laminate's surface. As laminates get heavier and thicker, ply drop-offs will require even greater attention from the grinders, especially when it comes to core tailoring, and much thicker bondlines of mat/resin or putty. Remember, thicker plies create bigger bumps. Knocking off a hard laminate edge won't prevent poor core-block fits unless a thick bondline layer is applied locally.

A good way to check the fairness of your parts is to get a thin, flexible batten and a flashlight. Lay the batten across a few ply drop-offs, darts, or overlaps, and shine the light on one side of the batten. The gaps may surprise you. Next, slit two or three rows of core blocks on scrim from a full sheet. Make the piece a foot or two long, and take it back to the part for another fit check. You will notice that individual blocks will offset nicely to accommodate a ply drop-off edge, but it's less likely that full sheets will register as accurately against an edge that probably is not as razor-straight as the lines of core blocks. Center a block on the drop-off edge and check how it teeter-totters back and forth, with the laminate edge acting as a fulcrum. Next, think about how much adhesive will be required to fill the gap, and which way the application trowel should be oriented. See the photo on page **xx [#7801]** for an example of how to do it wrong.

Kerf-Fill

All resin-infused core panels will have some type of filled-kerf system,

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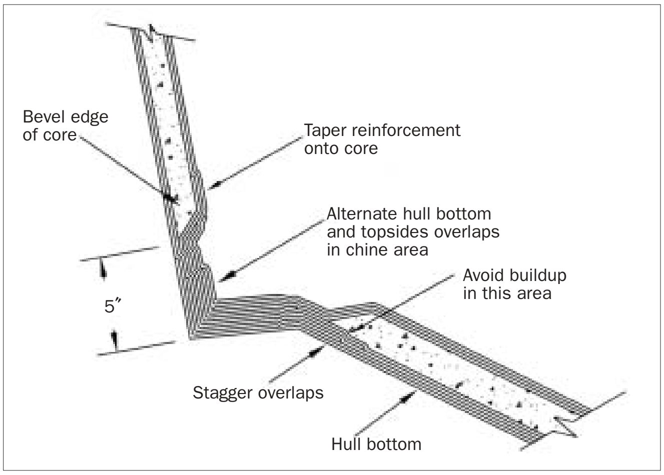
Clockwise from upper left: *•The builder forgot to remove the peel ply before tabbing this joint—a not uncommon mistake, given that the peel ply shown here is nearly transparent. That may be why some MILSPEC peel ply is bright orange. • Although both core sections are well bonded, dropping off three laminate plies within less than an inch—even after taper-grinding—is not recommended. Strength and stiffness of the skin and core change too rapidly across such a small span. • Razor-sharp inside corners in tooling gradually become gently radiused corners as laminate layers build up. Core bridging—here about 1⁄16" (1mm)—is likely unless the lower leading edge of the core is relieved, or the core is stopped well away from the corner transition, as shown in the illustration on the next page. • In this sample, three plies of laminate failed to overlap, or even meet, creating a trough approximately ¼" (6mm) deep and 4" (102mm) wide. Note that the trowel path tracked across and down into the trough. Had it run perpendicular to the drag marks shown, it would at least have filled the depression, preventing oilcanning when stepped on.*



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Above—*Diagram of a cross-section through a chine, showing fillet strips along core edges, tapered transitions, laminates overlapping onto core edges, and plenty of room to work. Stopping the core well away from the chine prevents core bridging, and also produces a thick solid laminate in way of an area that often gets point-loaded by support stands and blocking.* ***Upper right—****The void between the core and the back of the outer skin on this powerboat was approximately $\frac{3}{16}$" (5mm), and a 36" (.9m)-long straightened coathanger could be run in the void from hole to hole. The wavy yellow line roughly parallel to the chine indicates the vertical extent of the void as determined by hammer-sounding, and confirmed with the coathanger.* ***Lower right—****Closeup of a section taken through the chine area of a motoryacht. The lack of fillet strips along the edge of the core, plus not enough room to properly consolidate the laminates, led to the chine failing catastropically under lifting-sling loads.*

whether the resin flows across the surface of the core or through the kerfs. But, what about contour-cut cores that are bonded by hand layup or vacuum-bagging? Is complete kerf-fill possible, and why be concerned?

It's probably not possible to totally fill the kerfs with hand layup. But, *you can get very close* if you use a putty-adhesive system. The core sheets may become sloppy messes, but through diligent squeegeeing during priming-resin and core-adhesive application, the kerfs can be filled. A variety of bending fixtures, with curves matching the contoured sections of the part, will be needed to open the kerfs to the correct extent. It may also be necessary to transport the prefilled core sheets to the part on curved carriers, so that the sheet can't be straightened, squeezing out the adhesive.

It's more difficult to get complete kerf-fill with hand layup of core sheets into chop. The low-viscosity laminating resin typically drains out of the kerfs, whether it's introduced into the kerf system by priming the core sheet before placement, or when the core is pressed down into a resin-rich layer of chop.

Why worry about kerf-fill at all? Unfilled kerfs have been common in cored construction for decades, and by and large these cores have worked quite well. Problems arise, however, when water gets into the kerf system and flows around the part. As plants and animals in the water expire and decompose, the water in the kerfs can become remarkably stinky in a short period of time. Water in the kerf system also creates longevity issues. Some wood cores are vulnerable to accelerated deterioration if water from the kerf system reaches face-grain surfaces of the core blocks at neverbonds or porous bondlines. That's why establishing a good core-to-skin bondline is always the first priority. Partial or complete kerf-fill is second—except in infusion, where kerf-filling is usually an integral part of the process.

Core Styles: Plain or Contour-Cut

The main advantage of contour-cut core is its ability to conform to curved surfaces. Unfortunately, the drawback to the kerf system—which makes this flexibility possible—is that it either ends up unfilled, with the potential for water migration; or filled, with the consequences of added weight and the potential for bulk exotherm print-through. What's the solution to this contradiction?

Try plain foam. It should cost less than contour-cut stock because it's simpler to manufacture. Plain foam is usually perforated by punching or drilling to enhance its air-bleed characteristics. Contour-cut cores, by contrast, are produced by complex and expensive machines such as scrim applicators, computer-controlled gang-saws, sheet snappers, and vacuum tables. Filling the kerfs can raise the core's true density by 50% or more, particularly when the core is applied to heavily curved surfaces. For weight-critical projects, thermoformed plain foam cores are a cost-effective alternative to contour-cut cores. (Plain foam can have resin flow grooves cut into it for core-surface infusion. In such a setup, precisely determined inter-sheet gaps act as flow manifolds. This type of system is quite complicated, and a full explanation is beyond the scope of this article.)

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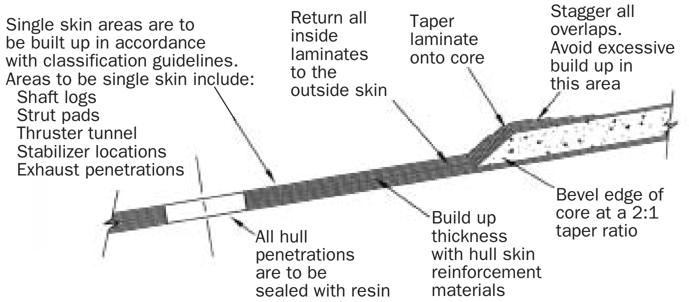

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__1.__ Cross-section showing a good way to finish an area of penetration such as a through-hull. Note the beveled core edge and additional plies of tapered and overlapping reinforcements. __2.__ A leaking rod-holder fitting and poor core closeout allowed water into the balsa-core deck of this sportfisherman. __3.__ Leaky through-hull fittings and improper core closeouts led to water ingress into the unfilled kerfs of cross-linked PVC-foam core. __4.__ With the outer laminate skin removed, it's evident that water migrated through the rudder port of the motoryacht pictured here into the unfilled kerf system. Large blackened area is where the linear-foam core was not attached to the outer skin. __5.__ With its outer topside laminate removed, a 40' (12m) sportfisherman reveals the effects of water ingress through poorly sealed portlight cutouts.

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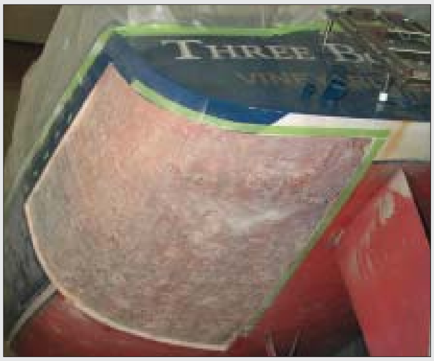

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The author visited Brewer's Pilots Point Marina (Westbrook, Connecticut) to look at an unusual cored boat—unusual, in that the port and starboard topsides were built differently. According to the shop's carpentry and composites foreman Brian Lenihan, "My first work on this boat was to correct rotten balsa core in the transom. The central drain tubes exited through solid laminate, but the generator and engine exhaust tubes went right through the core, and were just puttied in place, not taped with laminate. Although those locations might have been cored when the boat was built, by the time I saw it the core was completely gone. [__left photo__] When I de-skinned the entire transom I discovered that on the starboard side, the transom core ended with a gradually tapered edge, and was not connected to the balsa core in the topsides. To port, however, the transom and topsides cores butted together, and their kerf networks were connected. That explained the extremely high moisture readings we got on the port side almost to the bow. We started de-skinning and de-coring from aft, which was where we noted the most core deterioration. The outer skin was easiest to remove well aft, but we found discoloration and the start of rot just about everywhere that was wet. We'll re-core and re-laminate the sections opened up so far, jog the positions of the support stands to the repaired sections, and then continue to de-skin, de-core, and re-skin until the port side is fully repaired." The complexity of the relaminating was increased by other factors: an extra ply of outer skin from the keel sump to the waterline; extra layers added in way of the keel floors; and the need to skin the outer face of the inside skin with a layer of mat to establish vacuum integrity, so that the new core could be bagged in place. __Right—__Local regions of accelerated core deterioration were found in way of inner skin fastener penetrations, presumably where fresh air contacted the core. Here, a self-tapping screw has been ground flush with the inner skin as part of the core-removal process.

Typical shear strengths		
E-glass / polyester @ 55% FWF (ILSS)	22 MPa	3190 psi
E-glass / epoxy (biaxial laminate)	29 MPa	4205 psi
Divilette (core-bonding adhesive)	10 MPa	1450 psi
Plexus (adhesive) (MASSO)	8.9-12.4 MPa	1290–1800 psi
9 lb end-grain balsa (145kg/m)	2.8 MPa	411 psi
6 lb PVC foam (96 kg/m)	1.6 MPa	230 psi
4 lb PVC foam (64 kg/m)	0.8 MPa	120 psi
4 lb Nomex (64 kg/m)	250 psi(L), 125 psi(W)	

Above*—It's a common mistake to misidentify core-shear failures (and their consequences) as core-to-skin bondline problems. Note in the sample here how the shear failure in the core, initiated by a heavy impact, starts at the end of the resin filling the kerfs, goes to the core-to-skin bondline, and then runs along it.* ***Right****—As High Modulus' Richard Downs-Honey's data shows, core-to-skin-bondline loads are relatively low.*

Core Priming

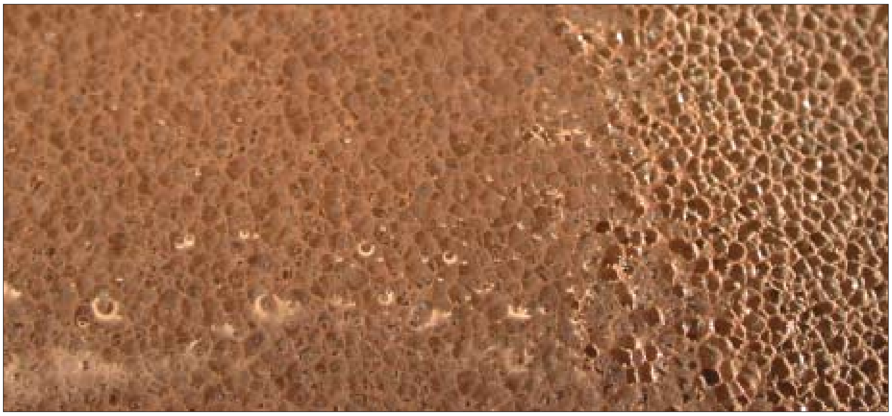
A core-bedding adhesive must wet the core's face and kerf surfaces to produce an effective bond. Because the range of core properties and adhesive specifications is huge, we didn't address individual systems at IBEX. But we did touch upon the importance of following the core and adhesives manufacturer's specifications to the letter.

I visit lots of shops where core priming consists of a fast choppergun pass with the chopper turned off. There's lots of overspray and very little squeegeeing—not a very effective method. All it would take to improve it would be a bit of back-and-forth with a stiff squeegee or short-bristle brush. Spray application can stop just shy of the sheet edge, reducing overspray's mess and material waste, and squeegeeing can work the resin out to the sheet's perimeter.

The key to successful surface priming, especially with foam cores, is to wet *every open cell* on the core's surface with resin. This will dramatically increase the surface area of the contact patch between resin and core. Try this experiment: After resin is sprayed, poured, or rolled onto the surface of a foam core, set up some good lighting and inspect the core's surface through a low-power magnifying glass. See all those little shiny spots? They are air bubbles trapped in open cells at the core's surface, reflecting back at you.

Next, scrub the core's surface with a squeegee, north to south, then east to west. Notice how there is less resin on the surface? Get out the magnifying glass again, and check for reflections. There should be many fewer.

Now, try this simple bondline-failure test. Make three cored panels, one with each of the following types of core-to-skin bondline: dry, partially primed, and correctly primed. After the panels cure, pry the bondlines apart. The test is quite unrepresentative of real-world loads on the core-to-skin bondline, because the failure mode is peel, which Downs-Honey noted should never occur in a well-designed structure. Nevertheless, this test gives a good sense of how core-face wetting affects all failure modes. Properly wet-out core should leave big chunks of itself attached to the skin; incompletely primed core less;



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Top*—Note the reflective bubbles trapped in the core cells on the left, which have been rolled with lots of resin. On the right side is dry, unprimed core.* ***Above****—Two criss-cross passes with a stiff plastic squeegee spread the resin and busted plenty of air bubbles on the core's surface. Unless air is released while the core is oriented bondline-up, it will bleed to the nearest kerf or perforation when the core sheet is inverted and placed on the skin.*

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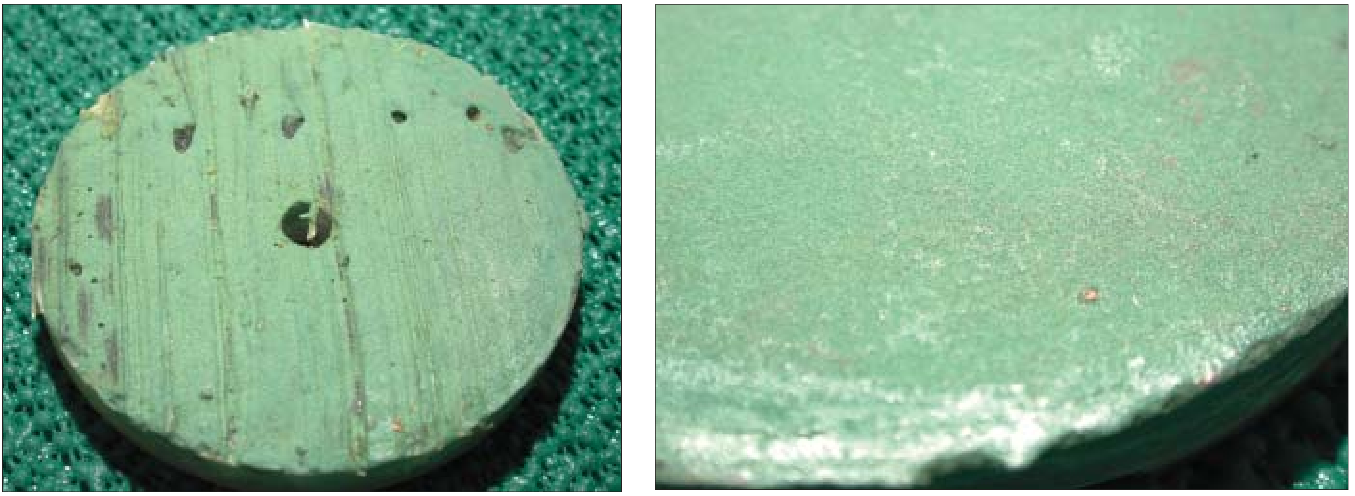
***Left—**In this sample, the core was not primed before being placed on an adhesive layer that was too thin. Incomplete bondline contact produced large air pockets that printed through the thin, dark-colored exterior skin. **Right—**Coarse aggregates belong in concrete, not core-bonding putty. In other coupons from the same boat, aggregate prevented the core from registering against the skin.*



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***Left—**Uncompressed trowel grooves in the core-bedding putty characterize a classic neverbond. **Right—**This unusual example shows a "kissing" neverbond: the putty was still soft enough to pick up the cellular texture of the core, but was starting to gel, and unable to establish a bond. Note the pink priming resin on the lower part of the coupon. The absence of core material attached to the priming resin indicates that it had not gelled—when the putty already had.*

and dry core just a hint of the core's cellular structure.

Core-Surface Preparation

Procedures for priming and resin-wetting vary among core types and among core manufacturers. The core-bonding products chosen may also affect the laminate surface preparation recommendations. Regardless, a few commonsense considerations apply:

- Core faces must be clean and dust-free. I prefer vacuuming to brushing. I advocate compressed-air blow-downs only in shops that have convinced me that their compressed air is clean and dry. Even so, blowing off parts only moves the contaminants somewhere else in the shop, while vacuuming captures them once and for all.
- Core cells must be effectively wet with priming resins or adhesives.
- Core kerfs should be open or filled as per process expectations.
- Core is contour-cut, grid-scored, slotted, or perforated at the appropriate intervals relative to resin or adhesive gel time and viscosity.
- The up side of the core must be correctly filled, ground, vacuumed, and primed.

During another IBEX 2004 session I did on carbon fiber construction with Eric Goetz of Goetz Custom Boats (Bristol, Rhode Island), he mentioned that extra caution was required when handling honeycomb cores. “Foam-core materials,” he commented, “have huge bondline surface areas compared to honeycomb cores, where only the cell walls become incorporated into the bondline. With foams, the adhesive contacts not only the edges of the cut cell walls but also the interior walls of each cut cell. So, it’s much easier to compromise the cleanliness of honeycomb by simple handling during unpacking, cutting, and placement. We have our guys wear clean white cotton gloves every time they touch honeycomb, just to keep moisture and skin oils off the core.” Think about this the next time you take off a latex glove and grab a sheet of core with your sweaty hand.

Core Edges and Corners

Core-panel edges are a troublesome area, especially in complex parts such as sailboat decks. Butt edges on core panels can cause inner-skin laminate bridging, and may result in laminate voids after the core is bonded to the first skin. For hand-layup parts, such voids are both a weak spot and a potential water channel. In infusion, voids represent low-resistance paths for the resin front.

Hard corners and resulting laminate bridging are a common occurrence with thick cores and reinforcements, whether in hand layup, vacuum-bagging, or infusion. Even chopped-strand mat does not conform well to hard corners. Three solutions are available, each with benefits and drawbacks.

The first is to cut sheet-edge bevels, once the sheet perimeters have been established. It’s no problem on straight edges, but it’s more complex on curved ones. The second option is to apply tapered edge-strips. They’re very effective, but once the edge strips and the butt faces of the core sheets are resin primed and puttied, conditions can become a bit sloppy, especially in vacuum-bagging.

How closely must tapered edge-strips be fitted? Minimal gaps and mitered inside and outside corners are preferred, but puttying that fills in all gaps can compensate for crude tailoring. Left unfilled, these gaps would produce either resin puddles or voids underneath the next laminates. Infusion processing, however, demands tight fits to prevent the resin racetracking through large perimeter passages, where resistance is lower than in the core’s kerf system. If that happens, the laminate will be insufficiently wet out, and the kerfs won’t be filled.

Taping-off the open laminate surface and core adjacent to where the


With infusion bonding of cores, all assembly is done dry, rather than into wet chop or putty. The multiple winch foundation pictured here features a dual-density core stack with well-aligned edge-tapering that produces void-free infused laminates.

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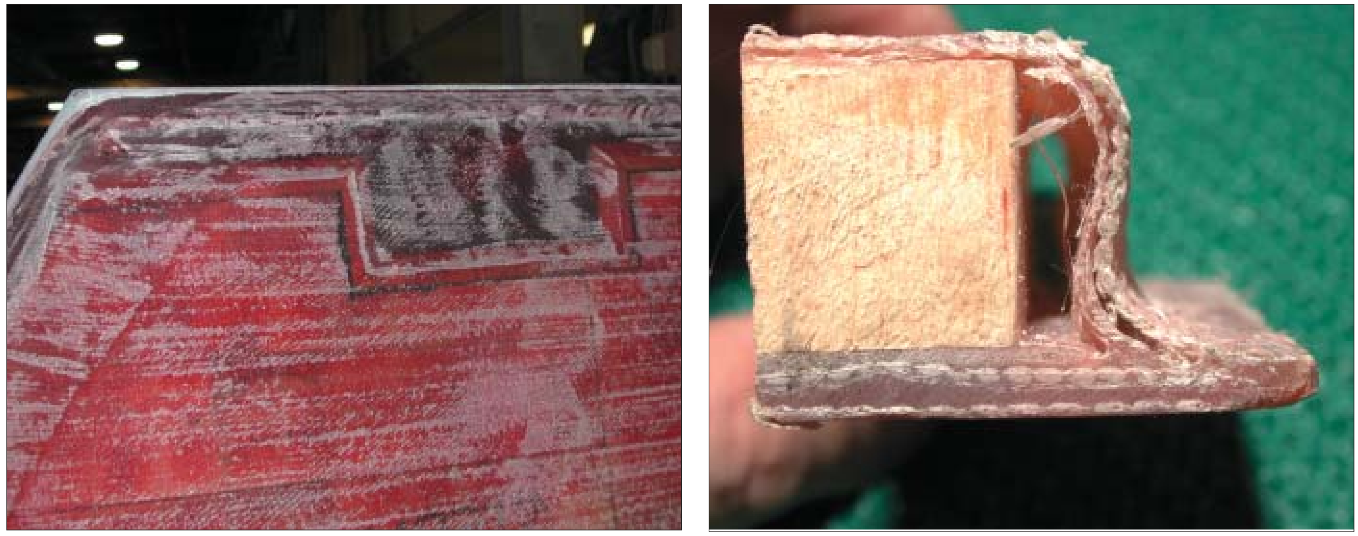
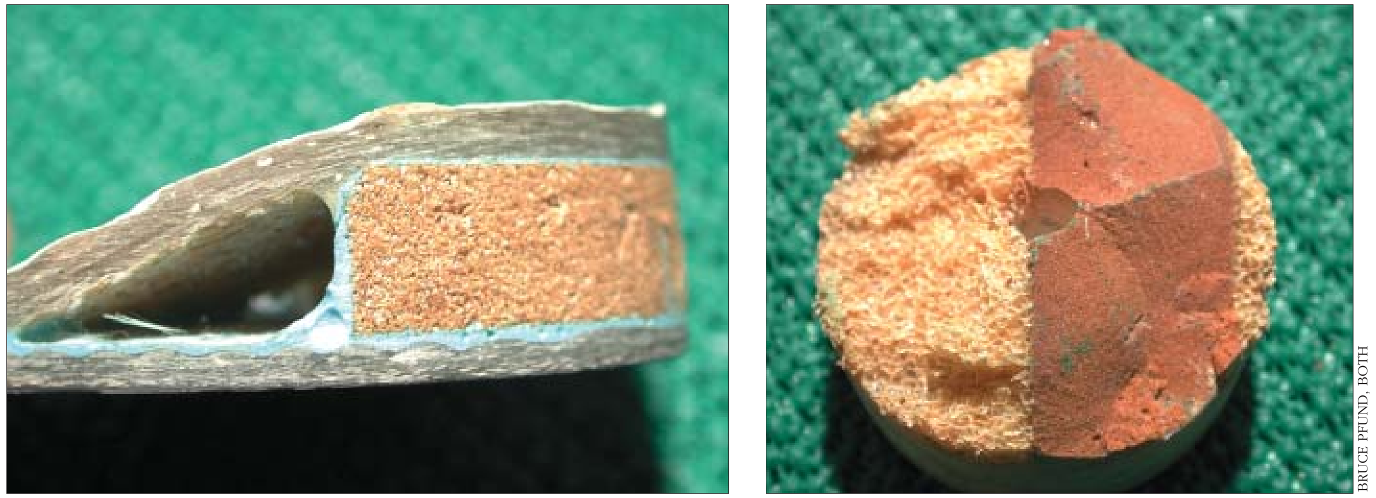

Left–Note the mitered inside and outside corners on the tapered edge strips, and the complete kerf fill in the core of this infused hull. ***Right—***Woven and knit reinforcements don’t register well against square core edges, especially on thick cores. Chopped-strand mat, whether from a roll or a choppergun, is not much more effective.*

PEARSON COMPOSITES, WARREN, RHODE ISLAND (BOTH)



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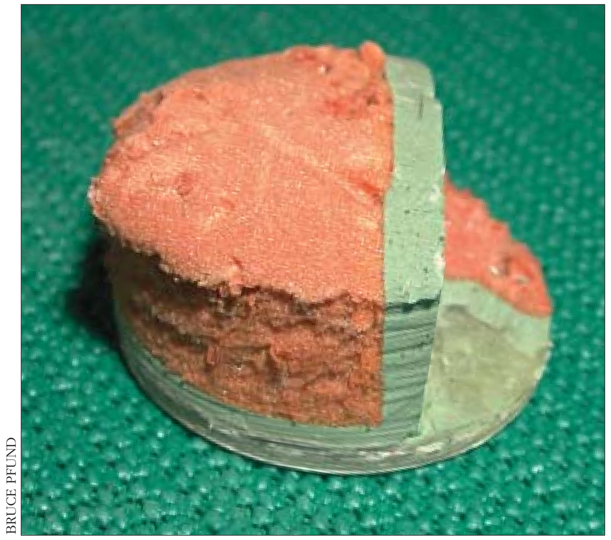
Left—*The void shown here caused a linear band of print-through on the exterior of a black-gelcoated topsides panel. A putty bevel might have printed, too. A tapered foam edge strip, from the same density foam, would transition the panel's thermal properties more gradually.* ***Right—****When the adhesive thickness in the butt joints between core panels approaches or exceeds the thickness of the core, it is probably too thick. For putty filling, butt seams 50% narrower (or less) than the core thickness are preferable. For infusion, tight fits are better—provided resin flow paths are not smaller or more restricted than elsewhere in the core's flow channels.*

tapered edge-strip will be installed requires extra prep, but prevents priming resin and putty from spreading out onto the laminate surface, where it could reduce the secondary-bondline adhesion of the second skin.

The third technique is to taper the core edge with a putty fillet. Tape off the laminate, and perhaps the core surface, to prevent putty smear onto surfaces that will receive additional laminates.



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Here, the gap between core sheets is about one-third the core thickness. Note the thick putty bondline between core and skin. Most core-bedding adhesives cure effectively at 3/32" to 1/16" (2mm to 1.5mm) or less. More adhesive than necessary just goes along for an expensive ride. Careful core fitting and tight seams make better sense.

Core Bedding in Mat and Resin

Core adhesives are a book-scale topic, so I will touch on only the basics. Following are four basic points to keep in mind:

- Core must be correctly bedded into the adhesive within the adhesive's gel-time limits.
- Adhesive must be applied in the correct thickness for a particular core's contours and process method—hand layup, vacuum-bagging, or prepreg.
- There must be 100% contact between core and adhesive, with proper air bleed.
- The priming resin and/or adhesive must be properly cured.

Chopped-strand-mat bedding layers are the old standbys for core bedding in hand layup, and can be very effective—if the part's outfitting prevents water intrusion, and if service conditions are tolerant of unfilled-kerf construction. As mentioned earlier, complete kerf-fill with neat resin is next to impossible with hand layup into wet chop, because the low-viscosity resin drains out of the kerfs, especially when the cored surfaces are not horizontal. That's why viscous putties were developed that will "hang" on vertical surfaces in thicknesses up to 3/8" (9.5mm).

Nonetheless, wet chop, combined with properly treated and primed core materials, remains a common method for installing core in hand layup. What sometimes occurs when contour-cut core is placed on curved fixtures to open up the kerfs for priming is that resin drains through the kerfs to the core's back side and begins to dissolve the scrim adhesive, making it difficult to transport and place the core sheets in the tooling.

"Cookie-sheeting" primed core sheets around the shop on polyethylene-film-covered thin aluminum or

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A thin piece of plywood bowed between two wooden cleats makes a simple core-kerf-wetout fixture. Placing a dogleg overhang at the fixture's opposite side secures the loose end of the sheet for bending.

plastic stock works fine. You can run a simple test to predict whether or not hand-carry techniques will work in your shop: Soak the scrim in resin, and then try to pull off the blocks. Run the test across your shop's temperature and gel-time ranges.

On the subject of scrim for another moment: David Jones and I recommend checking the core manufacturer's processing specifications when it comes to laying sheets of contour-cut core "scrim-down" into wet resin or putty. The scrim absorbs resin from the wet-mat bondline or requires extra priming when placed in certain core-bonding putties. Jones and I have seen failures both at open-layup and vacuum-bagged core-to-skin bondlines. These failures were due to the core being laid scrim-down, with little or no scrim-side priming. Clues to this type of failure are if the scrim stays attached to the core, rather than to the chop layer, when the panel fails. The scrim remains attached to the core because the scrim adhesive was not fully dissolved.

The subject of selecting a specific putty or adhesive for core bonding is beyond the scope of this article. Nevertheless, any putty or glue—whether it's stiff and needs the core to be primed before bonding, or is a less-viscous formulation that effectively wets the core's surface—must have the following conditions to be effective.

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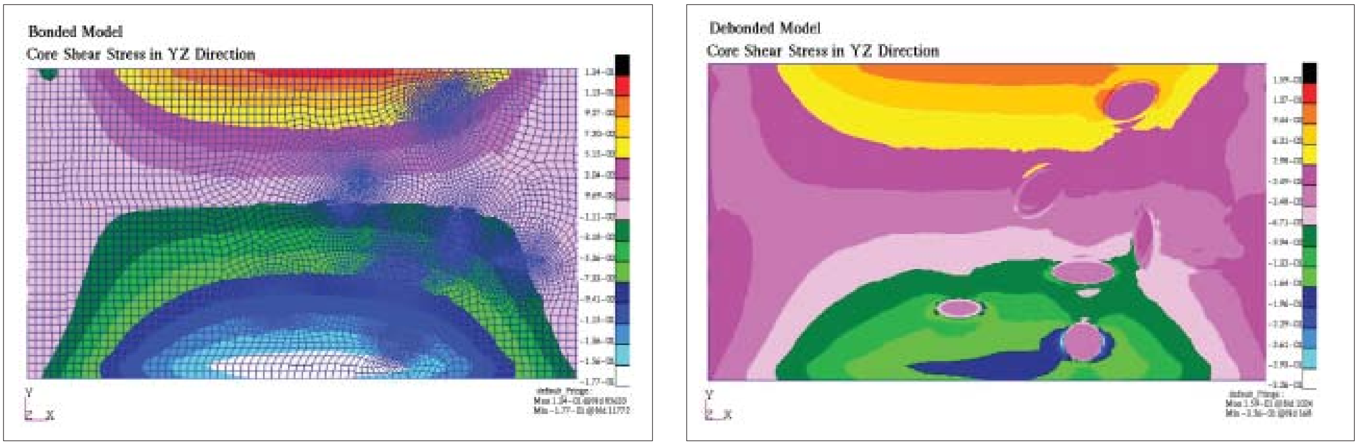
Left—*This foam core was installed scrim-out into a wet-chop bonding layer. The chop, though, was not wet enough to dissolve the scrim's styrene-soluble hot-melt adhesive network on the core surface. The kerfs in the coupons removed had no visible resin in them, indicating that the bondline face of the core was probably never effectively primed with resin.* ***Right—****The core block failures were completely within the core—the preferred failure mode—except where the core was not in contact with the wet-chop bedding layer.*

Surfaces and materials being bonded must be dry and free of any contaminants. For laminate substrates, that means the core must be installed within the laminating resin's secondary-bonding window, or that the surface must be prepared by grinding. If you're laminating with epoxy, you can scrub the laminate with a ScotchBrite pad and hot, soapy water to remove amine blush, which might compromise secondary bonding. After abrasive prep, vacuum the surfaces until dust free, and tack-rag just before the core-bedding adhesive is applied.

It's critical in a putty system that the core be firmly pressed into it prior to the start of the putty's gel and



HIGH MODULUS, BOTH

Two finite-element-analysis plots, from Downs-Honey's IBEX presentation, modeling the effects of a local debond in a topsides panel on a large high-performance boat. The ***left*** *plot shows the core-shear stress distribution in the panel with a complete and undamaged bondline. The stress is approximately 0.133 mP [megapascals] at the top edge, and about -0.170 mP at the bottom. Higher stress occurred at the bottom due to a laminate-schedule change. The* ***right*** *plot has hot pink where the core-shear stress is zero—in the debonded area where the core and skins are not connected. The stress-distribution pattern has changed a great deal from the first plot. In the second, the top peak is 0.159 mP, and down at the bottom it is 0.326 mP. The high-stress region has moved from the bottom edge in number one to both sides of the debonded area modeled in number two. The core-shear stress is approximately doubled around the debond.*

exotherm cycles, and remain so throughout the gel and preliminary hardness development. Failure to get complete contact produces a never-bond.

With core-priming resins, the timing gets even more complicated, because ideally both the priming resin and the putty adhesive should be ungelled when core contact is established. Determining gel times for priming resins and adhesives under core materials can be tricky, because the core both seals off the adhesive from air-inhibition effects and acts as an insulator, quickening the onset and speed of the exotherm cycle. Back in the 1980s and early '90s, Airex R62.80 foam cores came with a surface treatment of cobalt accelerators to speed gel times under the core, which is what led to development of a special test for under-the-core gel times.

I have mentioned the "core-block test" in previous articles in *Professional BoatBuilder*, but it bears review because it is a simple and effective way to determine, record, and display "open" as well as "under-the-core" adhesive gel times. (See "Problems in Cored Construction," PBB No. 70, page 92.)

Vacuum-Bagging

Core-bonding processes are perhaps the most influential factors in producing high-quality core-to-skin "blind" bondlines. Vacuum-bagging produces the best-quality panels (after press-molded ones), but it's not a foolproof process, and can introduce a whole new set of problems into the equation: overbleed, squeeze-out, and priming procedures, to name a few. For the sake of our discussion here, let's assume that the vacuum system and controls are well thought out, the appropriate process materials selected, and the crew reasonably

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Left*—Poor honeycomb-core-to-outer skin adhesion is evident in this panel, from the boat whose FEA analysis is shown on the facing page.* ***Right****—When the outer skin is cut, and big sections of core drop off and reveal shiny bondlines, it's a good indication of secondary-bonding problems.*

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The core-block test is a simple way to determine open as well as under-the-core geltimes. Prime the core with resin and trowel out the adhesive according to directions. Place individual blocks in two rows. About two-thirds of the way through geltime, start rotating one block every three minutes. At some point the rotation will become more difficult, and the next block to be checked three minutes later will have locked up. That's geltime under the core. Drag a scraper through the core adhesive not covered by core—it may not have gelled. Record relevant shop and material conditions and nail the test board on the shop wall for further reference.

experienced in the many intricate steps of vacuum-bagged core installation.

At that point, what does the cautious construction-process analyst think about?

The bag must be sealed to the tooling and sufficient vacuum drawn for long enough to clamp down the core. That immediately raises a few questions. How much vacuum does it take, and how much time under that amount of vacuum is necessary? It depends on the vacuum system: a higher-capacity pump would take less time to evacuate a big bag, giving the core crew more time to lay out additional core panels. For a close look at vacuum-bagging details, see "Setting Up a Reliable Vacuum System," PBB No. 83, page 34.

The most basic bag-induced problems in cored construction are: either too much squeeze or not enough. Either condition can result from how the vacuum system is operated, or from the other factors I have indicated in this article: rough substrates, very stiff cores that create core bridging, or poor core fit that inhibits resin flow during infusion.

So, how much vacuum is enough? For infusion, more is generally better

The supplementary laminates for the hull strakes, at the top and bottom of the photo, produced a very uneven inner surface on the outer skin. The plain 100 kg/m³ PVC foam core could not bend enough to register into the thick putty layer, even under high vacuum levels. The surface texture of the putty regions indicates that the core contacted, partially and only briefly, and then pulled away before the putty gelled.

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Vacuum bagging is not a foolproof method for producing high-quality core-to-skin bondlines. In the example here, too much bag squeeze forced resin out of the mat layer and up into the kerfs. Although kerf fill was excellent, the bondline mat was too dry to effectively adhere to more than about half of the core's surface—the balance was unbonded.

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during the flow stage of the process. It generally takes some testing to determine appropriate "dwell" vacuum levels—that is, after the shot is complete but before the resin gels. Some interesting work is being done with "double-bagging" infused parts to address problems that occur during the zero-flow phase of the process. Vacuum is drawn in the standard infusion bag, and the part is shot. Next, a second bag, sealed outboard of the infusion's "wet" bag, is drawn down. Its uniform squeeze can be used to prevent the bulge of excess resin that sometimes occurs in single-bag infused laminates after fiber wetout and air bleed are complete.

For bagging plain core with through-the-thickness perforations, you'll need just enough vacuum to pull a small amount of adhesive through the bleeder holes to the core's back surface. More squeeze will only pull more adhesive through the back side; the "mushroom" of putty at each bleeder hole will have to be ground off before the other skin is laminated to the core. For contour-cut core, selecting the correct vacuum is a bit trickier: Are you going for face-bondline contact only, or are you trying for complete kerf-fill? Watch the kerf network; you should be able to monitor the adhesive appearing at the core's upside surface, and back off on the vacuum at that point.

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Successful cored construction requires attention to every detail from the start of the process to the finish. Ignore one step, and a cascade of problems result. Extra adhesive doesn't ensure a good bond when excessive vacuum squeezes it out to the edges of the part. Crudely fitting tapered edge-strips to core perimeters may save time in getting the part ready to infuse, but how much time does it take to rework an island of core-and-laminate that didn't get wet out because the resin front bypassed the region, flowing instead through a low-resistance gap at the core's edge?

High-quality cored construction is not indestructible. The best a boatbuilder can produce is cored panels that fail under overload conditions in the preferred fashion—*in the core*, not in the bonds between core and skins. Cored panels with healthy core-to-skin bondlines, and especially those with well-sealed penetrations or fully filled kerf systems, will have long, trouble-free service lives.

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Getting good kerf fill—while avoiding excessive resin transfer out of the bondline mat—requires lots of resin and a light touch on the vacuum regulator. Vacuum levels are raised just until resin bleeds through the kerfs onto the upside of the core, and then held at that level or slightly less. Bondline hard spots and bridging conditions will also affect kerf fill.

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