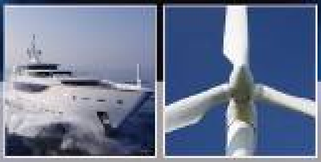
Introduction to cores



ALCAN COMPOSITES CORE MATERIALS
2009

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1. What cores do

Core materials enhance panel stiffness by dramatically boosting the Moment of Inertia as a result of increasing the panel thickness. In that respect the core acts much like the web of an “I” beam, separating the load bearing flanges. If greater Moment of Inertia were achieved by simply increasing the amount of glass laminate, then weight would also increase proportionally. Lighter weight cores achieve this increase at substantially less weight. However, there are slight differences in the performance between the two. If the amount of glass laminate is increased, the stiffness will increase by the cube of the increase in thickness. This is the old ‘bh^3over 12’ argument. If core is used to increase moment of inertia with the amount of glass being constant, then the “Parallel Axis Theorem” dictates that stiffness increases by the square of the increase in thickness (remember the moment of inertia for cored laminates is dependent on the square of the distance between the centroids of the skins). Thus a cored laminate will always be thicker (and substantially lighter) than a single skin laminate of the same stiffness. Since stiffness in composites is almost always the required design criteria, then strength is seldom an issue. However, we will look at this in more detail later.

2. What Core Properties are most Important

If the core exists to connect two load bearing skins, it is obvious that as the panel is placed in bending, one of those skins will be put in tension and the other in compression. The core must resolve these loads by acting in shear. Therefore the primary properties in choosing a core for a sandwich laminate are the **shear strength**, which determines the failure load, and the **shear modulus** which contributes to the panel stiffness.

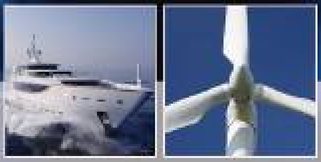
Also, since we can build laminates with very thin high performing skins and one of those is in compression then the buckling of that skin becomes a factor, which

means the **compression strength** and **modulus** of the core enters the picture in order to prevent the skin from wrinkling into the core. In the same respect the **bond strength** of the skin to the core is a factor to prevent skin from pulling away from the core. Bond Strength seldom appears on a manufacturer’s product data sheet since it dependent on the laminating resin and molding process however, the tensile strength of a core is sometimes an indicator of bond strength, since a good bond should fail in the core. However, this may not apply to some very fine celled foam cores.

3. Properties of Secondary Importance

If the strength of a cored laminate is often determined by the shear strength of the core, it is important to know how the material will handle overloads and impacts. Therefore, if this core would have a “plastic” range, where after the yield strength is reached, the core would continue to deform but not break then considerable more energy could be absorbed by the laminate before failure. Cores with the ability to absorb large amounts of energy before breaking are often referred to as linear cores, and are evidenced by **shear elongation** figures greater than 40%. The ABS High Speed Craft rules allow the use of a lower safety factor when ‘linear cores’ are used in a laminate. However, cores with higher shear elongation often suffer from lower shear strength and modulus, lower compression strength, or higher density, or all of the above.

In addition to the primary load factors described above, there are several secondary properties that can influence the selection of a core material. Since the primary reason to use a core is to increase stiffness without increasing weight, the amount of **resin absorption** by the core becomes a factor. Resin absorption will increase the weight of the core. The amount of resin absorption in foam cores is dictated by the cell size and the cut configuration. Obviously, the larger the cut cell content on the surface of the core (this is the size of the half cells that have been exposed during



the cutting of the core into thinner sheets) the more resin will be required to fill these half cells, and the greater the increase in weight. However, as noted above, if the cell size is too fine, although less resin will be absorbed, the **skin to core bond strength** will decrease since there is less mechanical contact with the resin. This also becomes a factor with **“friable” foams** such as polyurethane, where the surface of the core will be deposited on your fingers as you rub it. This friability obviously impedes a good skin to core bond.

Since surface area is indeed a factor in the amount of resin absorbed by the core, it is obvious that the more you cut the core in order to contour it, the greater will be the amount of resin absorbed by the core and the greater the increase in weight of the core. This is especially true if the core is applied to a curved surface and the “kerfs” (more later) open up, further increasing the amount of resin required to fill these open kerfs. Also the more core you cut away to make it flexible, the more resin must be used to ‘replace’ this material. This is especially true when comparing saw cut to knife cut kerfs. (see later section on cut configurations). However, irrespective of the kerf type, every time you cut a core, the more open or half cells you expose to resin, and the more resin is absorbed. Obviously, true open cell foams should never be used for cores. However, some very light density foam cores, when exposed to the higher pressures of infusion or RTM can suffer from cell wall failure and sections of these cores can, like a sponge fill with resin. Needless to say, this should be avoided!

Cores are often exposed to **high temperatures**. This can be experienced during the lamination process from the exotherm of the curing resin, especially during infusion, or during the elevated temperatures with pre-preg or post curing if epoxy resin is used. However, cores also experience high ambient temperatures in service especially if dark colored gelcoats are used on hull sides of sail or power boats (reverse transoms of sailboats are especially vulnerable) or on the “black masks” of sport fishing boats. Cores that experience too much heat suffer from either **loss of di-**

mensional stability, that is they shrink or expand, or from a complete loss of physical properties, causing the whole laminate to distort or even fail! “Fresh” PVC cores also suffer a phenomena called **“out-gassing”** where entrapped CO_2 in the cells from the manufacturing process is forced out by elevated temperatures to form bubbles or blisters between the core and the skin that can lead to delamination, especially when the heat of the sun further expands these blisters. Sounds like the “bends” in divers where an increase and then decrease of pressure will cause nitrogen to bubble out of the blood into joints. Outgassing can also prevent proper bonding with pre-pregs. Outgassing is often prevented by using “aged” foam or heat-treating before lamination.

The chemical resistance of the core to catalyzed laminating resin is also an important factor, especially with regard to styrene in polyester resins. Some foam cores are more prone than others to soften and shrink when exposed to styrene or more probably the styrene vapors during the lamination process. This is often the case with under-catalyzed resins trapped in the open kerfs of foam cores. The styrene in the resin will often attack the exposed surface of the kerf causing a phenomenon known as “hour glassing”. However, this is also sometimes seen during infusion if excessively long geltimes are used and the styrene “boils off” as the resin front progresses through the laminate

Flame, Smoke and Toxicity (FST) properties are seldom published on a data sheet but can be of importance for specific applications, such as passenger carrying vessels. This applies not only to the tendency of a core to burn by itself (not be self extinguishing), but also to retain its properties at elevated temperatures, as well as its tendency to give off smoke and toxic gasses when burned. Urethanes and SAN’s fare worse in this regard, PVC’s are somewhat better although still poor performers, while balsa, even though a wood product, fares best.

Thermal and sound insulation properties are important. Cored laminates do not transmit noise and vibration as much as single skin laminates. This is true for engine induced vibration and noise as well as “wave slapping” noise, either while running or more importantly at a quiet anchorage. The same is also true of thermal insulation properties, either isolation from cold water temperatures against the hull bottom, or the heat of a Florida sun on the deck and hull sides, especially if a dark color. Most core manufacturers will publish the “R” values of their cores, but the acoustic properties may be more difficult to obtain.

Classification Society Certification such as Lloyds, American Bureau of Shipping (ABS), and Det Norske Vertitas (DNV) all certify materials used in ship construction. Most commercial builders, and numerous builders of large yachts, require one of the above certifications of at least the materials used, if not certification of the whole vessel. When using a certified core material, you can be assured that the published core properties are accurate and verified, and that there are quality assurance systems in place to ensure consistency of production. That is not to say that non-certified cores are dangerous, but by all means consider the source, and when in doubt, verify.

Of increasing interest is the cores **“green”** credentials, that is, it’s Carbon Foot Print or the results of its Life Cycle Assessment or Analysis. Balsa cores, for example are a renewable resource, while some foam cores, such as PET’s contain recycled components, or are recyclable themselves. Both Renewability and Recyclability are driving factors in producing a “green” composite.

When choosing a foam core you will be faced with different chemistries either a **Thermoset or Thermoplastic** core, or more generally a Linear or a Cross-Linked (X-linked) core as described briefly at the beginning of this section Thermoset cores are essentially “locked in” to their shape after a chemical reaction takes place so that the long chains of polymer molecules are “linked” together were they cross. A thermoplastic core maintains long molecular chains in a somewhat independent fashion with no cross linking at the intersection points, and can be much more ductile and more easily thermoformed. X-linked PVC and urethane cores are examples of cross-linked cores, while Linear PVC, SAN, and PET are theromoplastic cores.

4. Available Core Materials

4.1. Plywood

As mentioned above, when fiberglass skins were first introduced into the boating industry in the 50s and 60s it was often to cover plywood construction, and often only on the outside. In this application it is the plywood that is actually taking the majority of the load with the FRP skin often only isolating the plywood from contact with water. In this application the plywood is not a core. However, it wasn’t long before these same boats were starting to be built in molds and plywood was used between to load bearing skins, often being cut into smaller 4” x 4” squares.

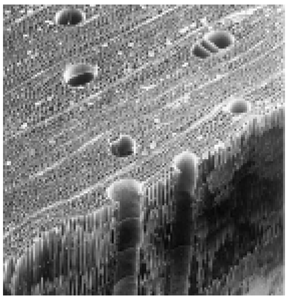
Although inexpensive and generally easily available around boat shops (especially scrap), plywood is not a good core. Right of the bat, at about 35 to 40 lb/ft^3, it’s heavy. It will also easily transmit water in the direction of the grain, and when wet, will swell perpendicular to the laminate surface, causing shear failures of the skin or cosmetic problems. Because of the nature of the orientation of the wood fibers parallel to the skins, plywood also has low shear values and lower compression strength in that direction. It is no accident that it was the transition from flat grain to end-grain that made balsa such a successful core material.

Being a wood product, and susceptible to water migration throughout the plywood, plywood will decay over time if it gets wet. This is most often the case with wet plywood stringers and transoms. In the 90’s the plywood companies addressed this with the introduction of chemically treated plywood with warranties against decay.

However, while still inexpensive, plywood does suffer a weight penalty when compared to other core materials and has often been supplanted by high density urethanes at about half the weight for transoms and stringers, with no tendency for decay.

4.2. Balsa

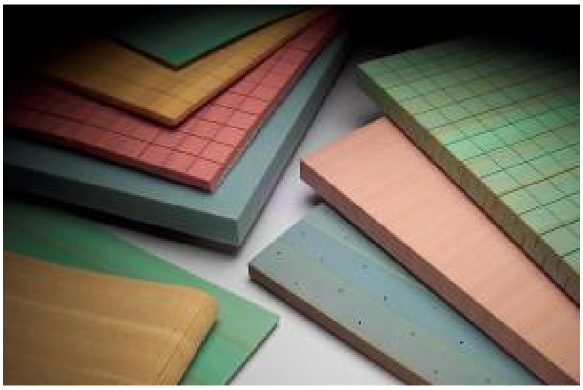
As mentioned above, balsa was the first, and still one of the most popular true structural core materials. The breakthrough that transformed balsa from a light weight wood to a true structural core was the conversion from a “flat grain” configuration to an “end grain” configuration” by gluing balsa lumber into large blocks and then cutting the sheets across the grain. In this way the grain structure of balsa was oriented perpendicular to the surface and perpendicular to the structural skins. The natural cell structure was now oriented in the same way as a honeycomb, greatly increasing the shear and compression properties. As resin seeped into the cut cells of the end grain, the bonding strength and skin adhesion also increased dramatically.



The use of end grain balsa also greatly reduced, if not eliminated, the ability of moisture to wick along the grain structure to allow water transmission through the whole core as was the case with flat grain balsa (and plywood). That is not to say that moisture transmission is not a concern with balsa cores, since as with all cores, moisture can be transmitted through the laminate by an unfilled kerf system (more later). However, balsa being a wood product, it is susceptible to decay if not properly installed or maintained. Recent research has shown that wet balsa in and of itself experiences measurable and predictable decreases in shear and compression strength maxing out at about a 20% reduction in strength. However, the strength of balsa is so much higher than equivalent foam cores that a reduction in properties may not be a factor. However, once decay sets in, that’s another matter.

Balsa cores are available in three basic density ranges - 6 LB (BALTEK® SB.50), 10 LB (BALTEK SB.100), and 15 LB (BALTEK SB.150), as well as in a treated variation called BALTEK Gold. Due to the “Bell Curve” density distribution of balsa within a tree, about 80% of balsa produced is the standard SB.100 variation, with about 12% being the lighter SB.50, and 8% the heavier SB.150. The primary supplier of balsa today is still Alcan Baltek Corporation.

4.3. Foam Cores



The evolution of foam cores in the boating industry is an evolution in chemistry. However, our primary interest as designers and engineers is in the mechanical properties rather than the molecular structure, so little time will be spent here in discussing the composition and manufacturing process of these various foams. However, all structural foam cores have one thing in common – they are all closed cell foams that do not absorb liquids. For obvious reasons, open cell foam cores have little application as structural cores in boatbuilding. Sponges, yes - cores, no. So let’s look at the available foam cores in the approximate order in which they were introduced.

4.3.1. Linear PVC

The first foam core introduced into boat building was a linear PVC still known as Airex. Back then it was AIREX® R62, and now it is R63 with improved properties and higher styrene resistance. Tom Johannsen, who would later go on to develop and introduce SAN cores, was the person most responsible in the introduction and adoption of Airex in North America in the late 60’s and early 70s. The best property of linear PVC foam is its damage tolerance. The shear elongation of the foam is more than 70%. It also exhibits some of the highest skin to core bond strengths of any core. These properties combine to create a laminate that is very difficult to break under impact. The foam will distort without failure, but still recover to its original shape if the ultimate strength is not reached. However the price that is almost always paid for this is lower strength and modulus in both shear and compression for a particular density. In some cases this reduction in properties can be partially overcome by increasing density. The other disadvantage of linear foams is that they tend to be more temperature sensitive. They cannot be used with dark gel coats and should not be used on decks.. Linear cores can, as alluded to above, be more sensitive to attack by styrene vapor.

Currently, the only linear PVC on the market is Alcan Composites’ AIREX R63.
The first foam cored hulls built, most notably the Peter Hatfield designed Porpoise III out of Vancouver, and the Jay Paris designed 50’ Questar in 1967 utilized Airex R62.

4.3.2. X-Linked PVC

The next evolution in foam core development occurred in the ‘70s with the introduction of Cross Linked PVC’s which increased the strength and stiffness of the core by cross linking the long chain polymer molecules together usually by the addition of isocyanates. High elongation was sacrificed for increased static properties. This does not mean you can’t design ‘impact laminates’, you simply need to increase the

density of the foam and use higher safety factors. This also meant that the foam was far more tolerant of high temperatures and could be used in hull side and deck applications. However, when pre-pregs began to make their way into boat building from aerospace in the 80’s and 90’s the phenomena of “out gassing” was discovered It is very important when laminating X-Linked PVC’s with pre-preg to adequately “age” or post cure the foam to eliminate the entrapped gasses near the surface in order to eliminate or at least reduce the potential for out-gassing. Today high temperature versions of x-linked PVC are available that reduce or eliminate the stability and outgassing problems with pre-preg or high temperature operation.

4.3.3. SAN

Styrene Acrylonitrile cores make their entry into the boating market in the early to mid 90s, pioneered by Tom Johannsen. Tom called this product Core-Cell, and when ATC fell on hard economic times in 2002, the company was acquired by SP, which in turn was acquired by the Swiss based Gurit, which then changed the spelling to **Corecell®.** Since its original introduction, Corecell is now available in a number of different formulations.

A-Series is the original highly linear version with shear elongations in the 50% to 65% range. As with other linear cores, there is some sacrifice of static properties to achieve this level of elongation, with the result that Corecell densities tend to be on the high side of the tolerance to achieve higher properties compared to the X-Linked alternatives. Although more resistant to elevated temperatures than linear PVC, it still had trouble handling the temperatures required for pre-preg. Corecell also is cut from relatively thin buns, especially at the higher densities, necessitating the longitudinal gluing of sheets to create cores of increased thickness. In the past there was

also some difficulty in creating flexible scrimmed and cut configurations over 5/8” thick, necessitating the use of Double Cut and even Triple cut configurations.

P-Series is a post cured A-Series to introduce a level of thermal stability required for pre-preg.

T-Series is a variation of Corecell that is more thermally stable for use in pre-preg applications, but with substantially reduced shear elongation. Static properties are also generally lower and the very fine cell structure means the surface feels friable resulting in reduced skin adhesion. T-Series is often sold as an alternative to X-Linked PVC’s.

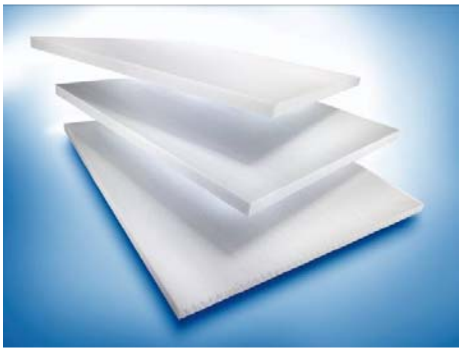
M- Series is a new variation just entering the market that is being targeted at the marine market as another alternative to PVC, but with higher elongation and static properties than T-Series, but at a slightly higher density than the equivalent X-linked PVC.

The Achilles Heel of Corecell has to be its FST properties, which are extremely poor. This may not be a problem in most marine applications, but can be a hindrance in passenger vessels or any boat designed to MCA. However, most FST regulations are derived for the finished panel, so if the core can be properly isolated from the flame source for the duration of the test, then this may not be an insurmountable problem.

It should be noted with regard to all linear cores, that this linear nature, decreases substantially every time the core is cut to make it contourable. It stands to reason that it is the resin in the cut kurf that then becomes the limiting factor in the shear elongation of a contourable linear core. To derive the full benefit of a high elongation linear core they should be used as rigid sheets with no cuts. The addition of kurfs is the great equalizer and reduces the elongation of all foam cores to about the same level.

4.3.4. PET

Polyethylene terephthalate is one of the most common polymers on the planet today. All plastic water and soda bottles are manufactured from PET. When extruded through a proper die and expanded, the result is a white foam that is both thermoplastic and recyclable. PETs come in a range of densities and are generally available in two series. AIREX® T90 for instance has very good FST properties, while the AIREX T92 series has better elongation and physical properties generally. However PETs, despite being thermoformable also have excellent thermal stability at higher temperatures, making them good candidates for pre-preg applications. However, to achieve physical properties comparable with PVC, higher product densities must be used. Also, even though the foam is thermoplastic, the shear elongation of PET is lower than other thermoplastic cores, being in the same range as PVCs.



One intriguing recent development with PET foam is their ability to bond with thermoplastic resins. Polypropylene or even PET resin encapsulated glass fiber thermoplastic skins can be thermally bonded to the PET core to create a truly thermoplastic laminate.

The “green” aspect of PET’s can be a major benefit, due to both their ability to incorporate recycled PET in their fabrication as well as to be eventually recycled or “upcycled” itself.

David de Rothschild's Adventure Ecology Foundation is currently building a 60' catamaran in San Francisco entirely in PET, using PET fibres with PET resin and an AIREX T91 foam core in a structure that will encapsulate thousands of 2 litre PET water bottles for the primary floatation. When the vessel finishes her trans-Pacific passage in Sidney Australia, she is to be hauled and sent to a recycling centre where the entire vessel will be "up-cycled" back into PET polymer beads for reuse. .

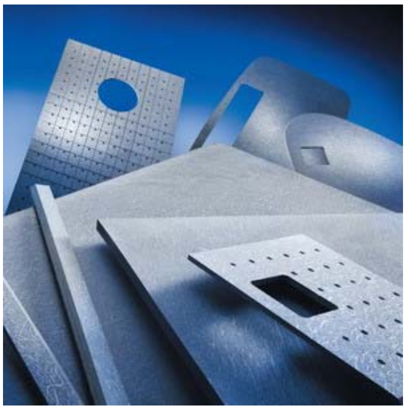
4.3.5. Polyurethane

High density polyurethane foam first made their entry into the boating market in the late 90's as replacements for plywood transoms. Although almost twice as heavy as their PVC equivalents, they are still about half the weight of plywood and less expensive than PVC foam. Recently there has been increased use of lighter density polyurethane in deck laminates of smaller, high-volume production boats where cost, not performance is the driving factor. Polyurethanes, being quite friable, historically suffer from lower skin adhesion, however, we are not seeing great areas of delamination in polyurethane cored decks, I suspect because of the additional bonding strength of the resin in the kerf system.

While polyurethanes have gained some acceptance for deck cores, we seldom see them used in hull cores, primarily due to their poor impact strength. Polyurethane cores are also not certified by any of the classification societies such as Lloyd's, ABS, or DNV. While there are uses for all cores in specific applications, lighter density Polyurethane cores should never be used in a highly loaded structure, especially something like a hull which sees fatigue loading as well.

4.3.5.1. Fiber Reinforced Polyurethane

Soon after the introduction of cast polyurethane as described above, fiber reinforced polyurethanes entered the market, again primarily aimed at displacing plywood transoms. Glass reinforced polyurethanes are generally available only in the higher densities, with a 10-lb/ft^3 variation from Alcan Composites (AIREX® PXc.145) being the lightest currently available. Glass reinforced polyurethanes are generally available in two glass reinforcement configurations. They can be filled with a combination of either all random glass fiber, or random glass fiber in the center and woven roving near each surface. The Alcan Baltek variation of the latter is AIREX PXw. This material is primarily suited for free standing panels without any load bearing skins, such as cockpit soles resting on longitudinal stringers. However, if used as a core material, even in a transom, with two load bearing skins on each side, then the woven roving should be eliminated in favor of random glass fiber through the whole thickness. This variation has lower flexural properties, but much higher shear and compression values that make it a far more appropriate material for a core between load bearing skins.



4.3.5.2. Glass Wrapped Polyurethanes

Recently introduced, this core consists of individual polyurethane rectangular pieces wrapped in fiberglass roving and then butted together and then bonded to each other with a fiberglass scrim in order to create a 4x8 sheet. Since the Polyurethane is such a low density, it only provides a form for the glass fabric, which when saturated with resin provides the shear ands compression properties. Obviously, since the glass between the foam blocks can’t be reached by hand lay-up, only vacuum infusion can be used to laminate this product. In addition, since the vertical glass components run in one direction only, the properties also only run in that direction only. In addition, this product can only be used in a rigid sheet since cutting these sheets to create a contourable configuration will also cut the fiberglass vertical glass, thus destroying the continuity of the structure.

Glass-wrapped urethane core is primarily supplied by Webcore™.

4.4. Honeycombs

It was mentioned previously that end grain balsa achieves its superior properties due to the honeycomb shape of the cell structure. It stands to reason then that the only materials that can match or exceed the properties of end-grain balsa would be a high end honeycomb. However, not all honeycomb cores can be considered “high end”. Let’s start with the high end and work our way down.

4.4.1. Aluminum Honeycomb

Not all aluminum honeycombs are created equal, but the ones that are designed for aircraft applications have extremely high properties. Honeycombs are used in the aerospace market because they can be produced in very low densities, but still handle the high temperatures and pressures of pre-preg and press lamination without distorting. Very few foam cores can achieve this. However, honeycombs don’t provide a lot of bonding area to the structural skin, relying on an additional bonding film to create a critical “meniscus” or fillet around the cell walls of the honeycomb core. Aluminum honeycombs are not often seen in marine applications for obvious corrosion reasons. Only short lived high performance boats consider using aluminum honeycombs. The 1979 C&C designed and built Canada’s Cup winner Evergreen used aluminum honeycomb with carbon fiber skins on her deck. It was rumored that you could power her running lights from the galvanic current generated solely from her deck laminate! Perhaps it is no coincidence that no one seems to know where Evergreen is today!

4.4.2. Nomex Honeycomb

Nomex® or Polyimide-coated paper honeycombs also have their origin in the aircraft industry for high temperature and high pressure pre-preg applications. In their “over expanded” configuration honeycombs can be made to be contourable to compound

curvature. Unexpanded honeycombs will “potato chip” when bent. Not having the corrosion problems of aluminum and available in a contourable configurations, Nomex honeycombs are often used in high performance boats for America’s Cup and Volvo Ocean Racing where the same high temperature and pressure advantages of pre-pregs are used. It should be emphasized that due to the manufacturing process for both aluminum and Nomex honeycombs, the core properties are not homogeneous, varying in the length and width direction of the core. The product data sheet should give values for each direction.

However, over time any void in a laminate is susceptible to water migration and accumulation, and a honeycomb laminate is by definition full of voids. Therefore, as with aluminum honeycombs the use of Nomex honeycombs should be restricted to applications where performance is more important than longevity. Note that both aluminum and Nomex

4.4.2. Plastic Honeycombs

Generally extruded from polypropylene or polyethylene, plastic honeycombs made their introduction in the marine market in the late 80s. Since nothing will bond to these materials, a special scrim must first be thermally bonded to the honeycomb, which permits the resin to bond to the core. Unlike Aluminum and Nomex honeycombs, plastic honeycombs have very low physical properties and are used primarily because of their low price. Plastic honeycombs have a very low shear modulus, resulting in reduced stiffness. Generally, the thickness of a plastic honeycomb needs to be increased in order to match the stiffness of the same laminate using a PVC or balsa core. Although the base plastic can have a high elongation before failure, the plastic honeycomb itself will suffer wall buckling well before the properties of the base plastic is reached. As with low density polyurethanes, plastic honeycombs should never be used in a high stress application. Classification societies typically restrict their use to above the waterline.

4.4.3. Paper Honeycombs

Used only for lightly loaded flat panel interior applications, paper honeycombs are the least expensive core with the lowest physical properties. Obviously, they should never be used for structural applications.

4.5. Nonwovens and Print Blockers

Often referred to as “Pseudo” cores, Nonwovens such as Lantor Coremat® are often used as thin as 1 MM “print blockers” behind the skin coat of gelcoated laminates. But Coremat® is also available up to 10 MM (3/8”) to act as a thin core on decks and hull sides. One of the primary advantages of thick Coremat® is its ability to hold a screw, and to be thru-bolted without fear of water intrusion or crushing the core. Coremat® can also be applied in large areas to curved and very complex surfaces. It’s not the lightest core available because of the resin absorption, but is cost effective and if wet out properly from both sides, easy to install. However, Coremat® and other materials like it cannot be infused or used in closed molding. For this Lantor has developed a product called SORIC® to provide thin cores and print blockers for infusion. SORIC® does not collapse under pressure.