# Technical Bulletin 0119: Balsa versus Polyisocyanurate (polyurethane) in Composite Core Applications

## PURPOSE

This Technical Bulletin is another in the series of white papers aimed at providing our clients, engineers, composite manufacturers, laminators, and friends with objective information on our products and those of our competitors. A surprisingly large number of potential buyers of composite materials are unaware of how polyisocyanurate (polyiso) rigid foam (a modified polyurethane with improved characteristics) compares to balsa wood, and thus are unaware of the advantages of polyiso in new applications. This Bulletin is intended to help engineers and end-users better understand balsa versus polyiso in composite applications. We strive to be accurate and solicit comments from readers.

## PREMISE

Balsa wood is a natural cellular material with excellent stiffness and strength-to-weight ratios, as well as reported energy absorption characteristics. The "end-grain" portion of a balsa timber can be cut into small blocks and glued together to create a sheet. Balsa is an orthotropic material with quite oblong cells, resulting in different mechanical properties measured across each of the three mutually perpendicular axes. The quality and physical characteristics of end-grain balsa blocks can vary considerably with its origin and processing. Additionally, end-users must consider the manufacturing process whereby small blocks are glued together to form a *sheet*: 1) The orientation of each block (i.e. considering the strength in that dimension), 2) the adhesives, 3) other processing such as scrim/fabric backing, and 4) whether the reported physical properties apply only to a certain dimension of small blocks or to the sheet as a whole. End-grain balsa is relatively expensive since it is a natural resource, must be glued into sheets, and imported.

Polyisocyanurate (sometimes also referred to as PIR) is a thermoset rigid foam manufactured as continuous bunstock typically 4 feet wide (but on special order up to 52 inches), up to 28 inches high, and any length up to 24 feet - - easily cut into sheets or fabricated into shapes. In general, polyiso has less strength and stiffness than end-grain balsa products, but is considerably lighter and has physical properties more homogeneous across all *locations* in the substrate. Polyiso, having more isotropic characteristics than balsa, also has strengths that are more comparable when measured across any *dimension*. This, combined with other physical properties, can make polyiso a superior substrate in many composite applications. For instance, polyisocyanurate as an alternative to balsa can achieve lower weight, better R-value, improved flame/smoke resistance, higher volume production, shorter lead times, wider ranges of dimensions and tolerances - - all at a lower cost.

The premise of this paper is not that polyiso can replace end-grain balsa in all applications - - but rather that there is a subset of lightweight composite applications can benefit from polyisocyanurate's unique physical properties, lower cost, and other characteristics as presented herein.

Sidebar:
A study evaluated the low velocity impact responses and mechanical properties of balsa wood and polyurethane foam core materials and their sandwich panels, which were applied as the impact limiter of a nuclear spent fuel shipping cask. For the urethane foam core tensile, compressive, and shear mechanical tests were conducted. For the balsa wood core, which showed different material properties in different orthogonal directions, nine mechanical properties were determined. The impact test specimens for the core material and their sandwich panel were subjected to low velocity impact loads using an instrumented testing machine. The experimental results showed that both the urethane foam and the balsa wood core (except in the growth direction (z-direction) had a similar impact response for the energy absorbing capacity, contact force, and indentation. Furthermore, it was found that the urethane foam core was more suitable as an impact limiter material owing to its lighter weight, resistance to fire, availability, and low cost.[1]

## BACKGROUND ON CORE MATERIALS

Core materials (sometimes referred to as *substrates*) are used extensively throughout the composites industry to create lightweight composite (traditionally, *sandwich construction*) products with better resultant physical properties (e.g. *stiffness*) than could be otherwise achieved. For example, a core sandwiched with face and back-skin laminates can readily achieve an increase in strength(s) and stiffness by a magnitude of 3.5 times and 7 times respectively with only a 3% weight increase. Other properties such as thermal conductivity (inverse of thermal resistance or R-value) and flame/smoke resistance can also be improved by use of optimal core materials. Elasticity of the final product may also be important in some applications, and the core material is often the deciding factor.

The "*sandwich*" typically consists of a face-skin laminate, the core material, and the back-skin laminate. Common composite cores may include (among many others) end-grain balsa wood sheets, polyurethane or polyisocyanurate, PVC foam, PET, polystyrene, non-woven core fabrics, and various types of honeycomb materials including aluminum. Skins such as fibrous carbon, fiberglass, fiber/resin, metal, or wood/cellulose-based skins. The resultant properties of the sandwiched materials may also be influenced by the *patterning* of the substrate/skins - - such as using honeycomb, waffle, corrugated, striated[2], or other patterns.

While sandwich-construction is a traditional option, advanced composite technologies and approaches, with new innovative substrates, enable opportunities to create new composite structures with physical properties far superior to traditional options.

## THE INFORMED DECISION

Interestingly the biggest challenges often cited in selecting supplier/partners and their products are not the complexity of the science. Rather, the challenges reside within the realm of *business/markets/manufacturing prowess*. According to a study conducted by ***Materials Today***, and recently affirmed by Dyplast Products, the challenges for composite engineers and end-users relate more-so to:

- Mass production/automation techniques that influence price (the price for composite materials often limits the applications).

[1] https://inis.iaea.org/search/search.aspx?orig_q=RN:44072488; International Nuclear Information System
[2] Striation (such as the direction of fibers) can result in different properties as measured in different directions.

- Standardization, design standards, quality control, rapid/high-volume production, and good technical support/backup from suppliers.
- Support from materials suppliers technically; and to help support the ultimate application.
- Trust of the information from suppliers.
- Awareness of the benefits of existing composite structures within industries, and their limitations.
- Innovation: don't necessarily rely on the *traditional* product, when better/lower cost options are available.
- Corporate Aptitude: there are many players, some small; there are some excellent ones, yet others may be questionable either because of their manufacturing standards, or their motivations may not be compatible.
- Long-term Lifecycle Net Cost approaches are often insufficiently analyzed - - and Initial Capital Cost then becomes, unfortunately, the driving decision-making factor.

# BALSA VS. POLYISO AS COMPOSITE CORES

## Balsa

Balsa wood core material typically comes from international plantations such as in Ecuador or Papua New Guinea. Trees are felled, cut into timber or peeled as veneer, and dried. The balsa wood is then sorted by quality and density, and end-grains cut to small blocks which can then be glued into sheets, or each can be bonded to a light scrim fabric that holds blocks together during lamination. Sheets are often measure 2 feet x 4 feet at most, and can be further limited in thickness.

*Figure 1: Baltek Structural Balsa Core*

End-grained Balsa has a "high-aspect ratio" - - in other words directionally aligned cells with grain oriented in a particular direction. The elongated, prismatic cells have a length (grain direction) that is up to approximately 16 times the diameter. The result is that the various strengths and other properties may vary across the x, y, and z dimensions. For example, balsa wood can have a tensile strength of 10,600 psi in the axial direction and only 145 perpendicular to grain. Since many small blocks are glued together with different orientations, the final sheet product is intended to represent a more blended set of the physical properties. The manufacturer, however, must accurately represent to the end-user the physical properties of the final "sheet" and the ASTM standards by which properties are measured.

With densities of end-grain balsa generally between 6 and 18 pounds per cubic foot (96-288 kg/m$^3$) [with a nominal density closer to 10 lb/ft$^3$] this material is quite heavy compared to many composite core alternatives[3], yet this "wood" can exhibit excellent stiffness and bond strength when manufactured properly. Balsa is compatible with traditional woodworking methods, including drilling, turning, milling, and sawing to close tolerances. Note, however, that since a sheet of end-grain balsa is comprised of multiple blocks with different grain orientation, the typical issues relating to cross-cut versus ripping apply. Balsa will, of course, burn when subjected to high temperatures, and the scrim backing on some balsa composite products will deteriorate before the balsa will burn (at approximately 240°F (115°C)).

Additionally, end-grained balsa has a relatively poor thermal resistance (R-value) of ~2, while the aged R-value of 2 lb/ft$^3$ polyisocyanurate is closer to 5-6, offering almost three times the thermal performance at a much lower weight. Product

[3] Polyisocyanurate density typically ranges from 2-6 lb/ft$^3$ (32-96 kg/m$^3$)

datasheets and/or Safety Datasheets should be consulted to determine the characteristics of the substrate being considered.

Finally, end-grained balsa is quite expensive, with dramatic differences in price - - ranging from a few dollars to over $50 board foot in some cases [depending on density, quality, etc.]. Limited supply can also result in delayed delivery times; and since balsa is imported it can be subject to tariffs and/or more complex logistics.

## Polyisocyanurate (a modified polyurethane)

Polyisocyanurate rigid foam is manufactured as large *bunstock* in a continuous *free-rise* process that results in a bun up to four feet wide and up to 28 inches tall (depending on density) and virtually any length. Dyplast polyiso products range from densities of 2 $lb/ft^3$ [ISO-C1/2.0) to 6 $lb/ft^3$ (ISO-C1/6.0] - - or in metric from 32-96 $kg/m^3$. Sheets can be cut into virtually any size, and subsequently tapered, edge-routed, or alternatively shaped. Blocks can be easily fabricated into special shapes via CAD/CAM processes. Dyplast polyiso is manufactured under strict quality control protocols, and in compliance with applicable ASTM Standards. The physical properties of Dyplast polyiso have been tested by third-party, independent labs; and the Quality Control program is audited by a certified third-party, independent laboratory. Each production lot of polyiso bunstock is tested in an inhouse laboratory to ensure compliance/consistency with Dyplast's QC Program.

Polyiso foam is a rigid, closed cell rigid foam with excellent thermal insulation and water/moisture resistant properties. The cells are very small with dimensions more uniform than balsa, resulting in physical properties (e.g. strengths) more comparable as measured along any axis. As a thermoset material, polyiso has much better fire and smoke properties as compared to polystyrene, polyvinyl, or polyethylene-based products which are thermo-plastics with a relatively low melting point. Polyisocyanurate is suitable for service temperatures ranging from deep cryogenic up to 350°F (177°C) continuous and 375°F (190°C) intermittent - - such as during the lamination process.

Polyiso cores have been at the heart of the marine industry for decades, and have been increasingly recognized as an optimal composite substrate in many applications - - particularly since it is quite inexpensive when compared to alternative products such as balsa. Polyiso prices currently can be lower than $1/board foot for lower-density polyiso (dependent on shipping of course), compared to balsa which can be multiple times more expensive.

## COMPARING PHYSICAL PROPERTIES

As mentioned, there are several different balsa products, with widely varying densities. Each product and density will have different physical properties, and each property may vary across the three dimensions of measurement.

There are also different ASTM standards and protocols for many of the physical properties of balsa and polyiso. One example is the compressive strength measurement standard, which for balsa is ASTM C365 and for polyiso is D1621. In some cases, different test methodologies can still result (in general terms) in *apples-to-apples* comparisons; in other cases not. The complexities of these analyses are beyond the scope of this paper.

Also, the composites industry employs a multitude of measurements and calculations to define the characteristics of a composite substrate as well as the final composite product. For instance, there are twelve constants (nine are independent) needed to describe the elastic behavior of wood: three moduli of elasticity E, three moduli of rigidity G, and six Poisson's ratios μ.

Additionally, there is bending moment, impact bending, bending stiffness, modulus of rigidity (or shear modulus), side hardness, modulus of rupture, kinking stress, and many many more. Unfortunately, it is challenging to predict the physical properties of the composite substrate by simply aggregating the properties of the components. Yet engineers skilled in composites can quickly identify the basic, requisite properties of each substrate and can make qualified extrapolation of performance - - typically followed by end-to-end qualification of particular alternative materials, manufacture of test specimens, and testing of single batch specimens. Thus, we offer polyisocyanurate as a likely fit for a host of applications otherwise filled by balsa - - particularly those requiring thermal performance.

Refer to www.dyplastcomposites.com for more information on physical properties, yet the following table compares a few of the properties typically examined.

| **Properties** Note1 | **End-Grained Balsa** | ISO-C1/6.0 | ISO-C1/2.0 |
|---|---|---|---|
| Density (lb/ft$^3$) | 10 | 6 | 2 |
| Compressive Strength (psi) | 1800 | 150 | 29 |
| Tensile Strength (psi) | 1900 | 131 | 36 |
| Tensile Modulus (psi) | ~480,000 | 4420 | 1601 |
| Shear Strength (psi) | 400 | 76 | 21 |
| Shear Modulus (psi) | 22,000 | 800 | 284 |
| Flexural Modulus (psi) | ~400,000 | 4610 | 590 |
| R-Value (1/2") | 1.1 | 2.3 | 2.7 |
| R-Value (1") | 2.3 | 4.5 | 5.4 |
| R-Value (2") | 4.5 | 9.1 | 10.8 |

1) Properties may be measured with different ASTM standards, assumed comparable in this Table.

# SUMMARY

End-grain balsa wood has been a traditional choice when it comes to applications that require a high stiffness-to-weight ratio. While balsa has extremely good stiffness properties, it remains quite heavy, quite expensive, and its availability can be problematic.

On the other hand, polyisocyanurate is quite the opposite!

- lightweight
- better R-value
- improved flame/smoke resistance
- higher volume production
- shorter lead times
- high dimensional tolerance
- wider ranges of dimensions and tolerances
- exceptional responsiveness
- - - all at a lower cost.

The traditional function of a "core" had been to distribute stress and loads from one "skin" across the thickness to the other. But with the advancement of composite technologies, the roles of *cores* and *skins* evolved. In some applications, "skins" have evolved into more complex substrates with an integral contribution to the ultimate stiffness of the composite itself. The roles of cores are expanding beyond simply *stiffness* - - allowing lower density cores, with higher thermal performance, and so on.

Advanced Composite Technologies are now morphing and expanding the very definitions of *composites*, and Dyplast is working with several clients having technologies that leverage the inherent properties of polyiso - - to achieve composite structures with strengths and thermal performance here-to-for not considered.

As stated earlier, the objective of this Technical Bulletin has not been to argue that polyiso can displace balsa wood's market position in all composite applications! Rather, we offer that there are many composite applications wherein polyiso is actually a material that offers superior advantages at lower costs.

Contact Dyplast Composites:
www.dyplastcomposites.com
info@dyplast.com
305-921-0100