Ebony Fingerboard Alternatives

How they work & how to use them

ALLIANCE

Fusion 360 render by R.Rouleau

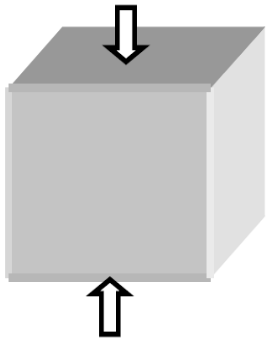
Environmental impacts

When looking for alternatives to ebony, keep in mind some of the environmental issues we would like to avoid.

- **Endangered Species:**
  - Overlogging
  - Wasteful logging: unpredictability of natural materials leading to waste
  - Development: roads, agriculture, construction
  - Climate Change: Disease, pests, Ecosystem Shifts
- **Global Warming:**
  - Fossil Fuel Consumption
  - Petroleum Based products including some resins
  - Manufacturing VOC
  - Transportation Carbon Footprint
- **Pollution:**
  - Plastics that don't breakdown in environment
  - Harmful manufacturing products including:
  - Urea, Formaldehyde & Petroleum

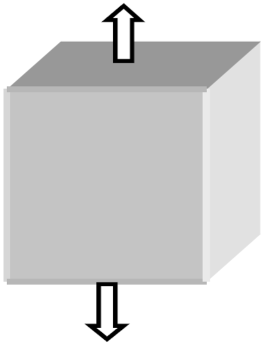
Measuring the strength of a material

Engineers have devised ways to measure specific types of strength for wood that apply to fingerboard alternatives as well.



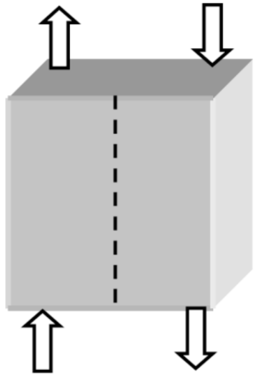
Compressive strength

Resistance to opposed converging forces applied parallel to the grain.



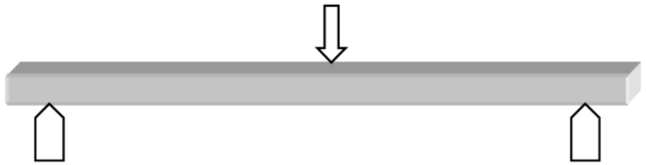
Tensile strength

Opposed diverging forces applied parallel to grain.



Shear strength

Offset, opposed converging forces applied parallel to a material, linked to workability with cutting tools.



Bending strength

Load/force applied perpendicular to grain. Combined result of compressive and tensile strength working together.

"From these basic principles emerge some more elaborate mechanical properties such as **Stiffness** *(absolute strength of a beam resulting from material properties and shape of the beam) and* **Hardness** *(resistance to scratches and dents)"*

See HOADLEY, R. Bruce, (2000), Understanding wood. The Taunton press, chapter 4.

The violin neck as a cantilever beam

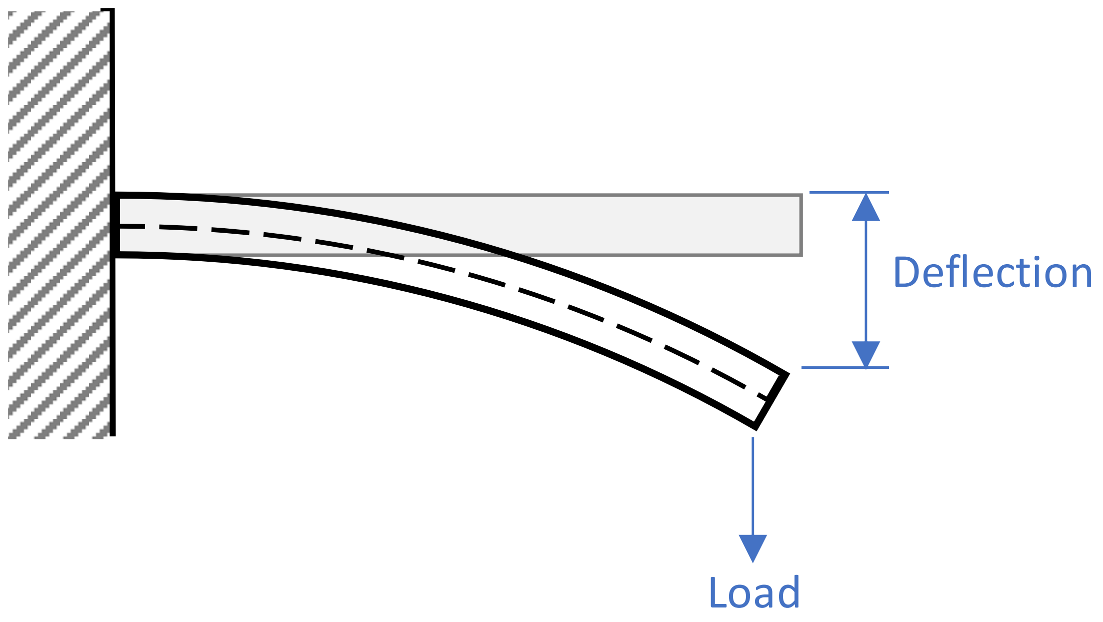
The neck of a violin is loosely similar to a cantilever beam.

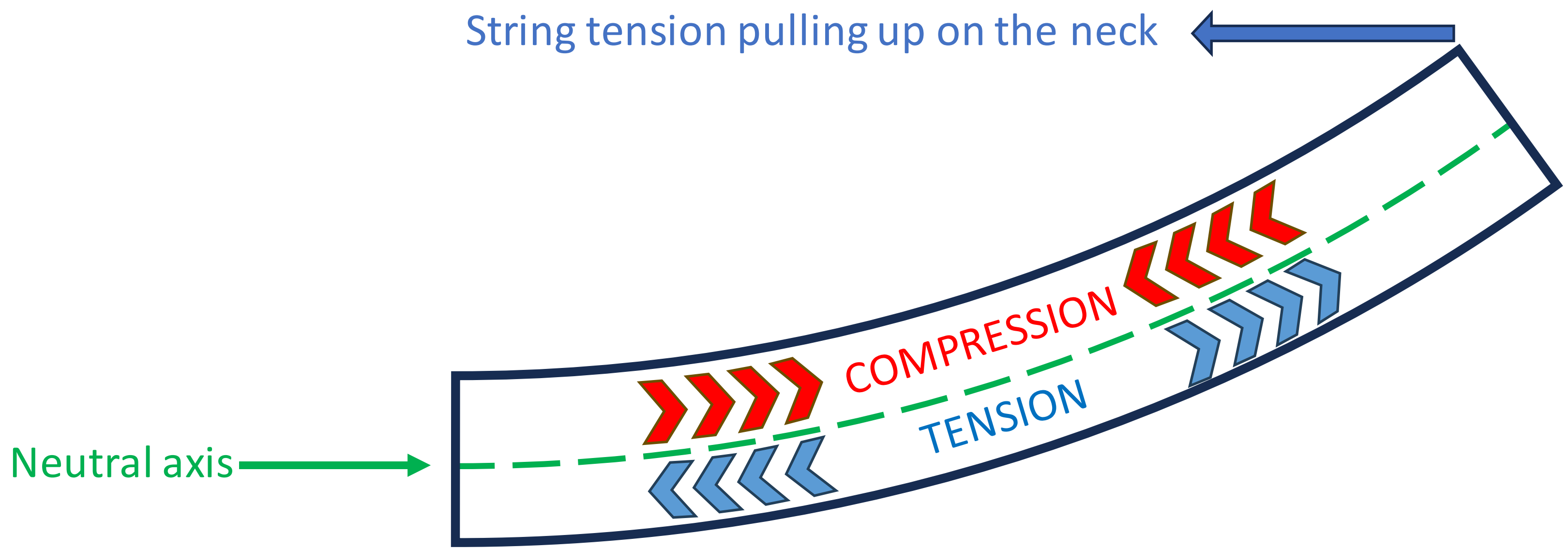
A cantilever beam is a structural element that extends horizontally and is supported on only one end. The unsupported end is known as the cantilever, and it extends beyond the support point. Cantilever beams are often used in construction to support balconies, roofs, and other overhangs. On the violin, the heel of the neck, attached to the body, would be the fixed end.

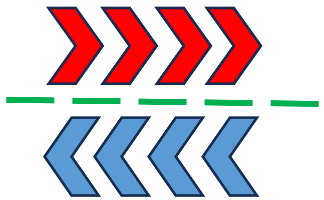
Most Cantilever forces push the end downwards as in the diagram. On the violin, the force of the strings pulls the end of the neck and fingerboard upwards, creating an upwards deflection at the end of the fingerboard that can impact the string height as the fingerboard bows.

"The fingerboard material is being used to strengthen the neck; to prevent the neck from bending and breaking due to the force of the strings."

Cantilever Deflection of a beam under load







"Glue joint between fingerboard and neck vulnerable to resulting shear forces."

Compression & Tension Forces

The tension of four strings, at the end of the fingerboard pulls upwards on the nut end of the fingerboard. The force of the strings bends the neck and fingerboard upward putting two types of stress across the length of the fingerboard and neck. The lower half of the fingerboard experiences tensile stress – the upper half experiences compressive stress. The two together are called bending stress.

Because the fingerboard forms the upper half, the compressive strength is important. Remember, the compressive strength goes parallel to the grain in wood.

Determining the strength of a material and the stiffness of a component

Stiffness and **mass** of a component are the two main considerations when engineering high performance structures. While mass is easier to figure out and measure, strength is not as trivial to assess in a workshop situation. Although the terms **strength** and **stiffness** are often commonly used interchangeably in the workshop, they in fact refer to two different aspects of engineering.

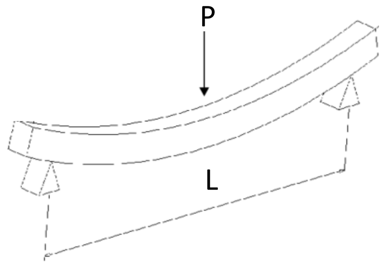
The Strength Of A Material is defined by its intrinsical ability to oppose deformation under a force (geometry independant property). Strength can be expressed as Young's modulus or modulus of elasticity *E (MOE),* which represents the deformation per unit length of a sample under a force. The higher the value for *E* the more force you need to bend the material. The simplified equation to determine *E* in static bending under a load is :

$$E = \frac{k \cdot PL^3}{yI}$$

E = MOE in Pascals (Pa)
K = test configuration dependant constant :
use 1/4 for three-points bending
and 1/3 for cantilever configuration at midspan
P= load as a force (N = kg x 9.81)
L = span (meter)
y = deflection (deformation measured in meter)
I = moment of inertia (cross-section geometry)

The Stiffness is the absolute strength of a component based on both its shape (geometry dependant property) and the modulus of elasticity *E* of the material it is made of. It can be evaluated by multiplying the Moment of Inertia of a component with the MOE of the material. This means of course, that the geometry of components can be precisely adjusted according to variations in *E* to reliably produce constant stiffness.

$$S = E \cdot I$$



"Luthiers are traditionally trained to empirically control both parameters by carefully selecting their piece of wood and adjusting the shape, size and graduations of the components."

Density, specific gravity and mass of a component

The **mass** of a component has a huge impact on the performance of a musical instrument. Not only does a heavy instrument is cumbersome, but mass can impede the acousitcal performance.

Bowed and plucked stringed instruments have been developped by generations of luthiers using exotic hardwoods for fingerboards, so substituting this material can have a significant impact on the sound. Matching the properties of ebony is thus very important to offer a suitable and appealing composite alternative.

Density *(ρ)* is a simple mass to volume ratio usually expressed in kilograms per cubic meter (kg/m^3) or pounds per cubic foot (lb/ft^3).

The average density of ebony ossillates around 1000 kg/m^3.

Specific Gravity *(SG)* is the ratio of a material's density with the density of a liquid (usually 1000 kg/m^3 for water at 4°C or 39°F). Specific gravity has no unit because it is the result of a ratio between two identical types of measurements. It thus overcomes conversion errors between different measurement systems.

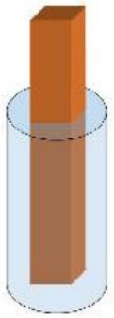
The average specific gravity of ebony is about 1.0

Measuring **Density** and **specific gravity** of a rectangular section sample :

$$\rho = \frac{M}{bld}$$

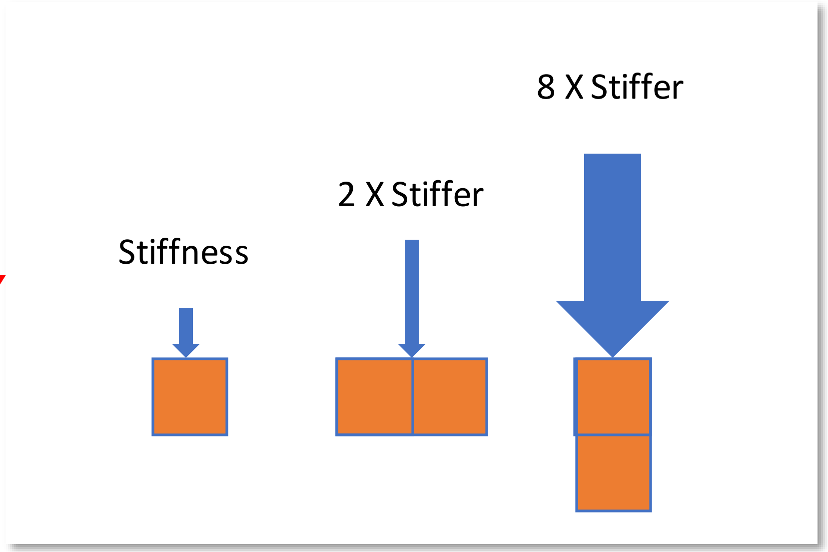
ρ = density, in kg/m^3
M = mass in kilogram
b,l,d = product of the width, depth and length of a sample, in meters

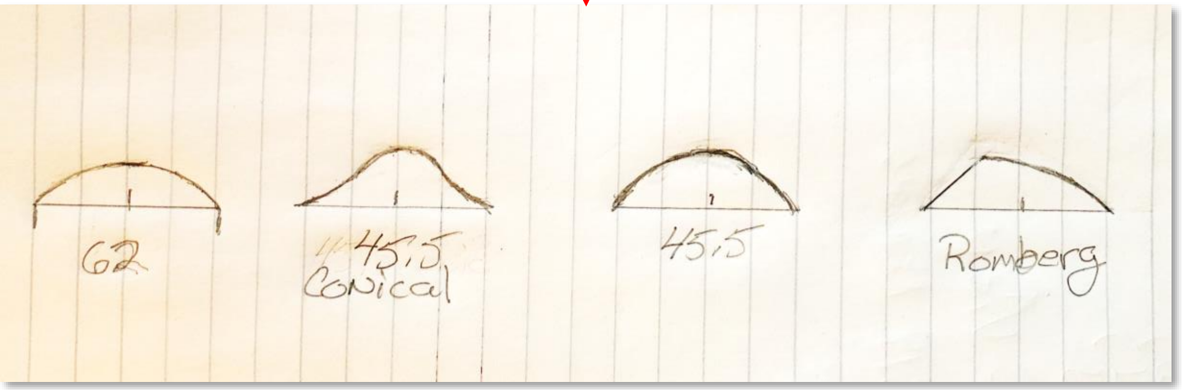
$$SG = \frac{\text{submerged length X liquid's density}}{\text{total length X water's density}}$$



Achieving Stiffness With Shape

- We can alter the stiffness of a fingerboard by changing the shape of its section (Moment of Inertia). Higher arcs have more stiffness than lower arcs (of the same width). Similar changes to stiffness of a fingerboard can be made by altering the scoop shape and depth on the underside of the fingerboard.
- For the player, a steeper arc on the outer edges of the fingerboard is more difficult for fingering. Compromises like the conical 45.5 radius example can maximize stiffness and facilitate playing.





Differences in Ebony

This chart shows the diversity of physical characteristics between "ebony" species. Physical characteristics can also change within a species depending on the environmental conditions the trees grow in. Access to water, sunlight, competition with other plants/trees, disease and other natural factors can impact a trees' growth.

Ebony Wood Species	Specific gravity	Compressive Strength (MPa)	Bending Strength (MPa)	Modulus of Elasticity (GPa)	Janka Hardness (N/mm^2)
Ceylon Ebony *Diospyros ebenum*	0.915	63.5	128.6	14.07	10.79
Macassar Ebony *Diospyros celebica*	1.121	80.2	157.2	17.35	14.14
Texas Ebony *Ebenopsis ebano*	0.965	74.1	152.3	16.54	12.56
"Brown" Ebony (Guayacan) *Libidibia paraguariensis*	1.160	81.3	158.0	18.70	15.97
Gaboon Ebony *Diospyros crassiflora*	0.955	76.3	158.1	16.89	13.7
Source : https://www.wood-database.com/?s=ebony					

Temperate Hardwoods vs. Ebony

Of the Temperate Hardwood Species, Hickory has the closest strength characteristics to Ebony. There are a few other, less common temperate species similar to Hickory.

Sources :
The Wood Database
Wood handbook: Wood as an engineering material

Wood Species	Specific Gravity*	Compressive Strength (Mpa)	Modulus of Rupture (Mpa)	Modulus of Elasticity (Gpa)	Janka Hardness (N/mm^2)
Ebony spp.	**1.00**	**73.3**	**148.0**	**16.1**	**12.9**
Alder, Red	0.41	40.1	68.0	9.5	2.6
Ash spp.	0.56	48.1	95.0	11.0	5.3
Aspen spp.	0.39	32.9	60.5	9.0	1.6
Basswood	0.37	32.6	60.0	10.1	1.8
Beech	0.64	50.3	103.0	11.9	5.8
Birch, Yellow	0.62	56.3	114.0	13.9	5.6
Butternut	0.38	36.2	56.0	8.1	2.2
Cherry	0.50	49.0	85.0	10.3	4.2
Chestnut	0.43	36.7	59.0	8.5	2.4
Elm Spp.	0.53	43.9	90.0	10.3	3.8
Hickory spp.	0.72	62.3	135.5	15.0	8.6
Hophornbeam	0.79	53.5	97.2	11.7	8.3
Hornbeam	0.79	44.8	112.4	11.7	7.9
Oak, Red spp.	0.63	47.0	99.0	12.5	5.7
Oak, White spp.	0.67	48.6	94.0	11.6	6.0
Poplar, yellow	0.42	38.2	70.0	10.9	2.4
Sassafras	0.46	32.8	62.0	7.7	-
Soft maple spp.	0.51	43.1	83.0	10.6	4.0
Sugar maple	0.63	54.0	109.0	12.6	6.4
Sweetgum	0.52	43.6	86.0	11.3	3.8
Sycamore	0.49	37.1	69.0	9.8	3.4
Walnut	0.55	52.3	101.0	11.6	4.5

Man-Made Alternatives

Climate change, increased production and demand for string instruments and consistency make man-made materials an attractive alternative to ebony for contemporary fingerboards.

Alternative Fingerboard Products

Over the past 10 years, several alternative products have been developed. As we test and learn more, that trend should continue.

Name	Material	Resin	Process	Sustainability
Corene	Wood.	Phenol-Formaldehyde	Milled?	Information Needed
Flaxwood	Fir Tree - grain structure broken.	"Acoustical binding material"	Injection Molded	Sustainably sourced wood
Gaiatone	Post Consumer, recycled paper.	Non-petroleum resin	Milled	FSC Certified
Obsidian Ebony	Hardened and stabilized base wood (vacuum impregnated with a proprietary polystyrene polymer).	Styrene polymer	Normal tooling	Sourced in North-America
Ebonprex	Densified Beech wood veneers layered.	Yes - unknown	Milled	PEFC Certified
Sonowood	Densified Beech, Maple & Spruce.	No Resin	Milled	Swiss Sustainably certified
Sound Composites	Carbon Fiber Core with Graphite tooling layer & maple shim for gluing.	Yes - unknown	Molded?	NA

Sonowood

- Sonowood is made from temperate wood that has been compressed to the density of ebony. Spruce, maple, and beech are the most successful woods so far. The “densified” wood has similar strength , characteristics to ebony – but is harder and more consistent.
- It was the first successful, pure wood alternative developed.

Limits to Sonowood

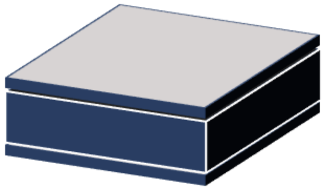
- For Now:
  - Cost – is higher relative to some commercial wood and paper composite alternatives. It is more stable and harder than ebony but is currently the first commercial solid wood alternative.
  - Bass – Sonowood compresses thick pieces of wood to achieve the density of ebony. For basses, the volume of wood needed is cost prohibitive.
  - Black Color – For violin and viola only, a rich brown-black color is available. A consistant, pure black remains elusive.

Composite Materials

Provide luthiers with strong physical advantages to ebony. The uniformity of man-made materials gives luthiers strength, durability and longevity we do not have with ebony. We will find it easier to work with these material if we are open to new tools and approaches.

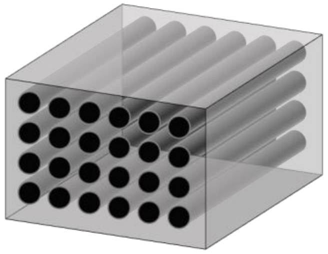
Types of composites

Laminar composite



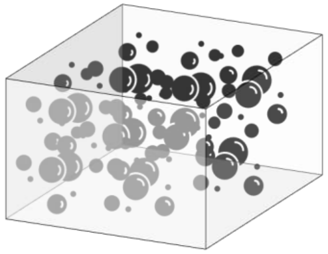
A composite material that consists of two or more layers of different materials that are bonded together

Fiber-reinforced



Composites with chopped or continuous fibers

Particulate composite



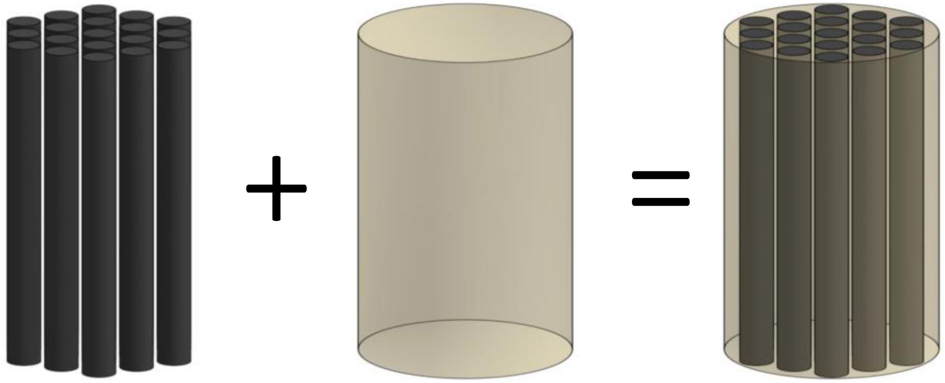
Composite with embedded particles

https://www.carbonscientific.co.uk/blogs/news/what-are-smart-modern-and-composite-materials-and-why-are-they-useful

Carbon fiber bows are a familiar form of fiber reinforced composite in the string instrument world. New fingerboard alternatives use carbon fiber, paper (virgin or recycled), wood fiber, flax fiber, or densified wood as the fiber and phenolic, phenol formaldehyde or bioresins for the matrix materials.

FIBER REINFORCED COMPOSITES

FIBERS
(carbon fibers, fiberglass, aramid)
+
MATRIX MAERIAL
=
FIBER REINFORCED MATERIAL



https://www.darkaero.com/knowledge/coposites/what-is-a-composite/

Composite products include:

- **Ranprex – Densified beech veneers laminated with synthetic resin**
    - ***PEFC certified material***
- **GaiaTone – recycled compressed paper & non-petroleum resin**

    FSC certified Material
- **Corene – paper pulp & phenol formaldehyde resin**
- **Sound Composites - carbon fiber core with graphite skin & synthetic resin**

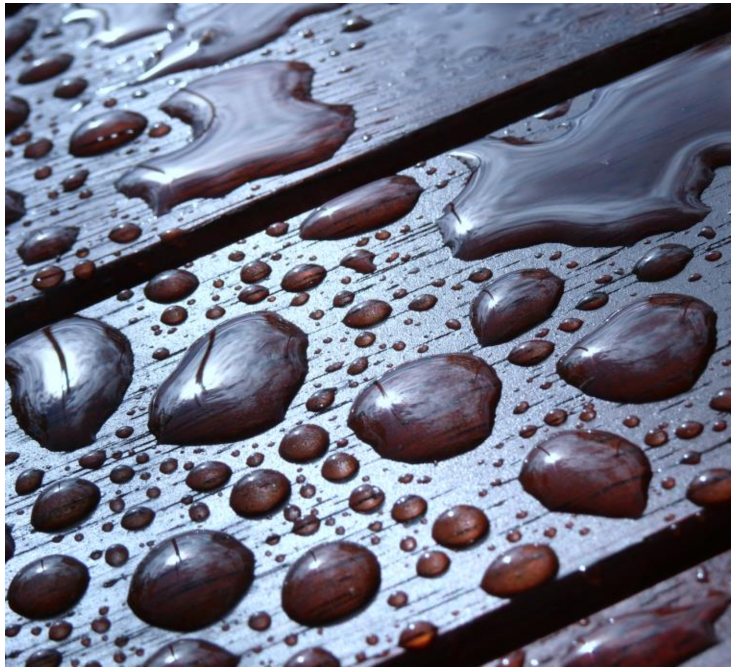
Advantages of Composites

Most composites are as hard or harder than ebony.

Wood/Composite	Botanical name	Janka Hardness [1]	Brinell Hardness
Sonowood		-	**115.0** [4]
African blackwood	*Dalbergia melanoxylon*	16.3	112.0 [2]
Ziricote	*Cordia dodecandra*	-	70.0 [2]
Vertical birch plywood	***Betula spp.***	-	**59.4** [3],[5]
Ranprex (Ebonprex)*	***Fagus spp.***	-	**59.0** [5]
Ebony	***Diospyros spp.***	**12.9**	**58.0** [2]
HDF		-	**48.9** [3]
Indian rosewood	*Dalbergia latifolia*	10.9	43.0 [2]
Obsidian ebony	***Acer saccharum Marsh***	**8.5**	- [4]
Black locust	*Robinia pseudoacacia L.*	7.6	37.0 [3]
Merbau	*Intsia bijuga (Colebr.) Kuntze*	7.6	33.2 [3]
Maple	*Acer saccharum Marsh*	6.5	31.0 [3]
Common beech	*Fagus sylvatica L*	5.8	26.7 [3]
Oak	*Quercus robur L*	5.0	26.2 [3]
Iroko	*Milicia excelsa (Welw.) CC Berg*	5.3	19.5 [3]
Pine	*Pinus sylvestris L.*	2.4	13.0 [3]

*Estimated values from documentation on similar composite

More stable in changing temperature and humidity.



Sources

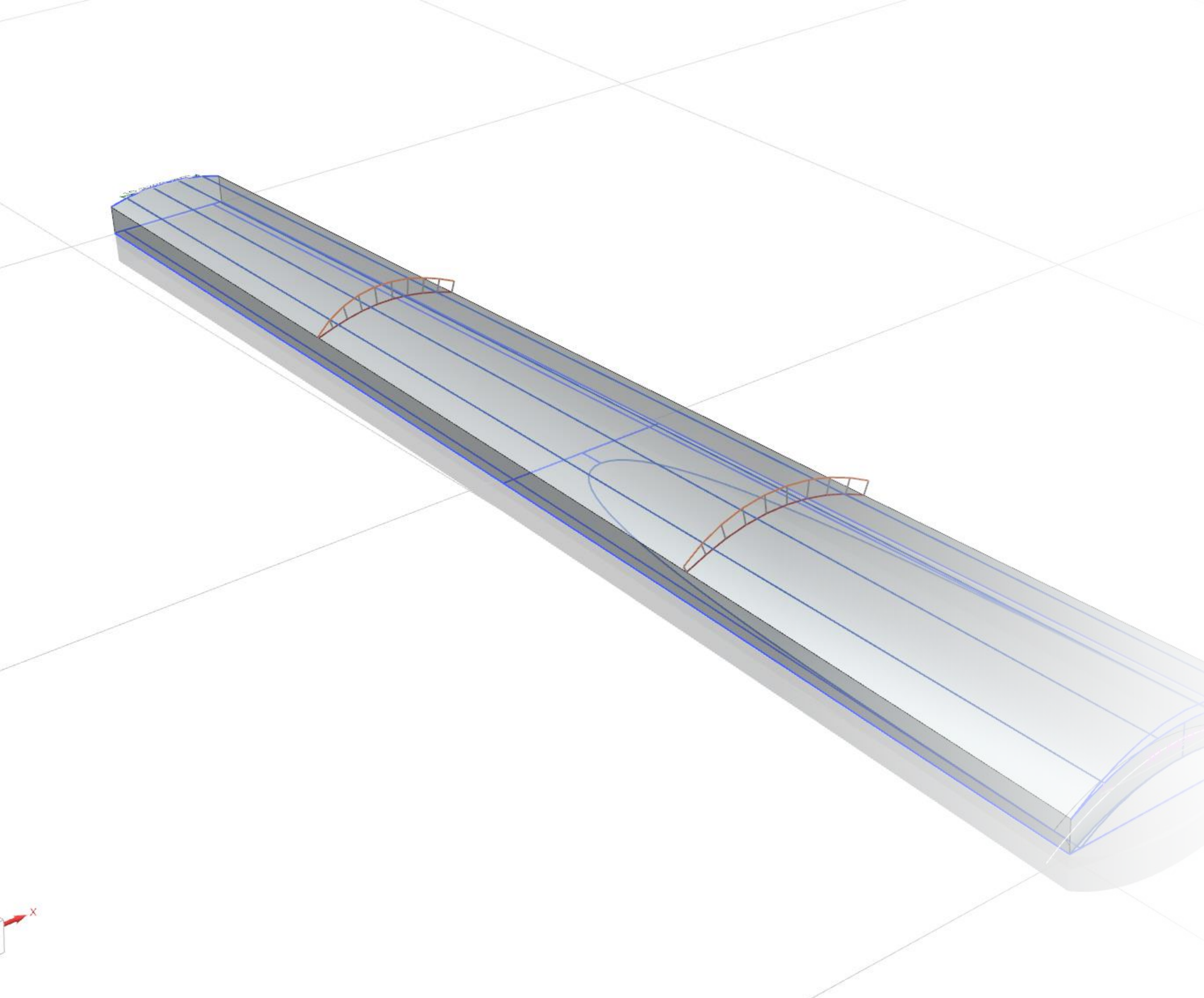
[1] Wood Database

[2] R. Sproßmann, M. Zauer, A.Wagenführ

[3] M. Sydor, G. Pinkowski and A. Jasińska

[4] Values provided by the supplier

[5] Ranca srl Hi-tech laminated wood



CAD design : courtesy of Vermont Violins

CAD – Computer Driven Fingerboard Models

Consistent materials make it possible to produce accurate fingerboards with injection molds or milling machines we couldn’t produce with ebony. CAD modelling gives us the ability to balance playability with the strength characteristics necessary in a fingerboard. CNC milling machines enable us to reproduce accurately the complex curves – scoop lengthwise and changing arcs widthwise – of the fingerboard in new materials like densified wood and composites. The scooped fingerboards can save luthiers time making instruments and in some restoration projects.

BIO Resin VS Phenol-Formaldehyde Resin
Avoiding new environmental Problems

	BIO	PETROLEUM
Raw Material	**Lignin & vanillin most popular, other options include sucrose, vegetable oils, rosin**	**phenol (usually petroleum based) with formaldehyde (a reactive gas derived from methane)**
Uses	**coatings, adhesives. Composites, packaging**	
Petroleum content	**none**	**yes**
Environmental Concerns	**Greenhouse gases associated with sourcing, production & transportation**	**Phenol in phenol-formaldehyde resin can be highly toxic by skin absorption and inhalation, and can severely burn skin. If these resins are improperly cured and contain residual formaldehyde, they may cause irritation and allergic reactions.**
Restrictions	**none - focus on sustainable sourcing**	**The International Agency for Research on Cancer (IARC) classifies formaldehyde as a human carcinogen**
Bio-Degradable	**with white rot fungus – not ideal**	**no**

Comparison of ebony with 3 composites

Material		Density kg/m³	Modulus of Elasticity GPa	Compression Strength MPa	Bending Strength (Modulus of Rupture) Mpa	Sound Velocity m/s
Ebony spp.		1 000 (+/- 8%)	16.1 (+/- 8%)	73.3 (+/- 9%)	148 73.3 (+/- 9%)	4 012 (+/- 3%)
Gaiatone	z axis	1 400	-	312.5	-	3 500
	x axis	-	11.9	160.0	167.8	
	y axis	-	11.4	155.6	147.6	
Sonowood	Spruce	1 240	38.2	129.0	223.0	5650 (+/- 12%)
	Maple	1 360	24.7	113.0	219.0	4800 (+/- 12%)
	Beech	1 360	27.2	113.0	228.0	4800 (+/- 12%)
RanPrex	ML15EL	1 250 (+/-4%)	16.0	145.0	190.0	5000
	ET	1 250 (+/-4%)	16.0	130.0	170.0	

Average values (variation)

New Tooling for New Materials

Harder materials such as Corene and Gaiatone last longer (fewer fingerboard dressings), but dull blades faster than the softer temperate hardwoods most carpentry blades are designed for. Like high mineral content ebony, they require frequent tool sharpening. We could rethink the tools and design blades which work better with harder materials, such as [powdered metal alloys used in high performance tool blades.]

Photo : courtesy of Vermont Violins

Tools for Compressed Materials

- The vertical edges of compressed, layered materials work differently than the wood we are used to. End mill bits, sanding tools including routers, oscillating spindle sanders and hand-held sanders or Dremels quickly remove material. Practice the speed and pressure needed with different tools to remove material smoothly rather than creating scalloped edges. When sanding, control the dust with a small vacuum or larger dust collection system and wear a mask.

Adjusting Edges

“Flap Wheels” and End Mill Bits are two useful Dremel Tool attachments for quickly flattening or removing material from the edge of fingerboards. Flap wheels come in different grits (80, 120, 220) and sizes and quickly remove material with the coarse grits or polish material with finer grits. End mills act like a small grinder, removing material more quickly than the flap wheel.

Photo : courtesy of Vermont Violins

Video Examples of End Mill and Flap Wheel

Sanding Blocks

Sanding blocks which have flat sides and a side with the same curve as the fingerboards can make dressing the surface of alternative materials fast and easy.

Using open pores abrasives specifically designed for manual sanding or composite materials is highly recommended (ex.: Norton A275 or Norton M920).

Don’t hesitate to ask your specialised supplier about the available options.

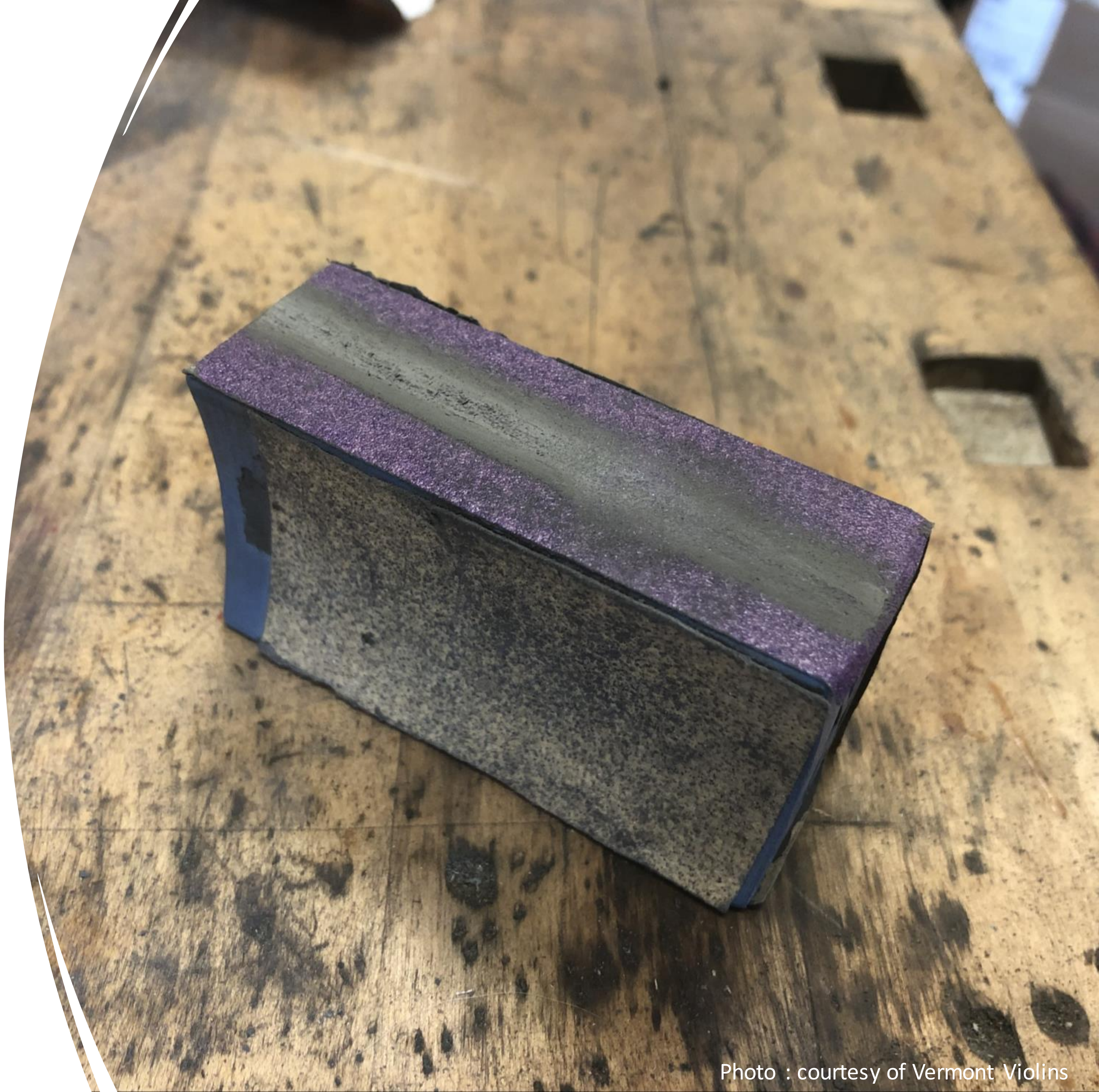


Photo : courtesy of Vermont Violins

Files and Rasps

Files and rasps are used to adjust necks and fingerboards with traditional materials. These tools can also work well with edges or ends of composite materials when planes dull quickly. Files and rasps will also work on the horizontal surfaces and can be useful for fitting alternative nuts and saddles.

Most files tempered to higher HRC than plane blades, offering good performance on tough materials. Good quality files are priced accordingly, and brands such as Grobet, Vallorbe or CORINOX^MD surpass other brands in terms of cutting power and durability.

Less traditionnal options could be explored, such as files specific for resins and composites or specialised files for skis.

Rasping Video for Edges

Glues

- Some alternative materials use glues other than hide glue. Carbon fiber composite fingerboards came with w maple shim attached to allow luthiers to glue with hide glue. Corene gives customers a fish glue alternative to use when purchasing their fingerboards. Paper based composites and densified wood materials typically work well with hide glue.

Another Option: Strengthen the Neck

Photo : courtesy of Thomas Coleman, luthier.

Many different wood species were originally used for fingerboards before the introduction of ebony in Europe. Most of these species have inferior mechanical properties compared to ebony, which can cause premature warping of the neck under the modern string tension, especially for larger instruments like the cello or bass.

To overcome this problem, luthiers have been adding carbon fiber rods in the necks to increase stiffness. Many bass and cello makers reinforce necks as a standard practice now.

Acknowledgement

This document has been made possible by the support and contribution of the following individuals.

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Boris Haug, Wilhelm Geigenbau (Switzerland)
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Elisa Scrollavezza, Renato Scrollavezza School of Violin Making (Italy)
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Kathy Reilly, Marcus Bretto, Ceile Kronick, Marit Danielson, Paige Henson & Claire Rowan at Vermont Violins (USA)
John-Eric Traelnes, Corene (Switzerland)
Annie Perkins, Sustainable Forestry Initiative (USA)
Daniel J. Weisshaar, Alliance International (USA)

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