Max-Planck-Institut für Metallforschung

Heisenbergstr. 3, D-70569 Stuttgart, Germany

MAX-PLANCK-GESELLSCHAFT

Materials for Violin Bows
What are the Alternatives for Pernambuco?

Ulrike G.K. Wegst, Stefan Oberhoff and Manfred Weller

INTRODUCTION

The violin bow as we know it today is thought to have been developed by the French bow-maker François Tourte in the second half of the 18th century. He changed the shape of the bow from one that resembled an archery bow to that with the opposite, a convex, curvature (Figure 1). This convex shape, termed the camber, is an important structural property of the bow. It influences both the bow hair tension and the bending stiffness of the bow. In addition to the change in shape, Tourte is also thought to have been the first to recognise the qualities of what is still the preferred material for bows, the tropical wood Pernambuco (*Caesalpinia echinata*, syn. *Guilandia echinata*), a wood which first reached Europe as a dyewood for red cloth in the 16th century. Today, this tropical wood faces a high risk of extinction in the wild. This fact was the motivation to investigate and compare the static and dynamic material properties and performance of 13 alternative materials with that of Pernambuco (Table 1) and to explore whether they are alternative materials for violin bows.

Table 1: Alternative woods for violin bows.

Trade name	Botanical name	Origin
Pernambuco	***Caesalpinia echinata* L.**	**Brazil**
Braúna	*Melanoxylon brauna* Schott	Brazil
Ipe	*Tabebuia spp.*	South America
Karri	*Eucalyptus diversicolor* F.v. Muell.	Australia
Maple	*Acer spp.*	Europe
Massaranduba	*Manilkara bidentata* A. Chev.	South America
Óleo vermelho	*Myroxylon balsamum* Harms	Brazil
Roxinho	*Peltogyne catingae* Ducke	Brazil
Sawo	*Manilkara kauki* (L.) Dubard	South-East Asia
Snakewood	*Brosimum guianense* (Aubl.) Huber	South America
Swartzia	*Swartzia spp.*	South America
Arizeiro (a palm)	*Bactris gasipaes* Kunth	South America
Bamboo (a gras)	*Guadua angustifolia* Kunth	South America
CFRP	Carbon-fibre reinforced polymers	Synthetic

DESIGN REQUIREMENTS FOR VIOLIN BOWS

A violin bow should not only produce the best possible sound on an instrument, but should also make it easy for the player to achieve it. The ease with which a good sound is achieved, the bow´s playability, depends on both the bow´s shape, such as its camber and point of balance, and the properties of the bow-material, such as its mass, its stiffness and its mechanical damping. Since the damping performance of the bow material is thought critical for the bows playability — a low-loss bow will provide a faster response to rapid changes in bowing direction and in techniques in which the bow leaves the string — and since damping is thought to have a significant effect on the violin´s sound, we focus, in this study, on a comparison of the loss coefficient of alternative bow materials with that of Pernambuco.

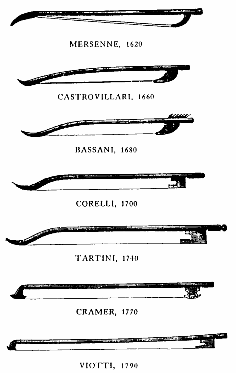

Figure 1: Development of the violin bow (Fétis, 1856)

EXPERIMENTS

The Young´s modulus, *E*, and the mechanical loss coefficient, η (or internal friction, $\eta \equiv Q^{-1}$) were measured using a resonant bar technique in the 1-2 kHz range. All wood samples were selected by bow-makers to ensure that the alternative materials were thought suitable by the criteria usually applied to Pernambuco. Rectangular specimens of 50 mm in length, 5 mm in width and 1 to 1.5 mm thickness were machined and their densities measured. They were sputtered on one side with a 300nm thick layer of silver to make them conductive for electrostatic excitation of the flexural eigenvibrations. The samples were mounted horizontally and supported at the nodes of oscillation by two thin wires of 0.3mm diameter. As resonance frequency, the sample´s 1st eigenfrequency, was excited and maintained by an AC voltage applied to the electrode directly above the specimen using a computer controlled system (Figure 2; Weller and Török, 1987). Measurements were carried out in a vacuum of about 10-2 mbar. From the sample´s resonance frequency, dimensions and density, its Young´s modulus was calculated. The loss coefficient of the material was determined from the decay of the amplitude of the eigenvibrations.

The experiments were carried out in two conditions of the wood, bamboo and palm samples: dry and air-dry. The dry state was defined as that after the samples had spent 12 hours in a vacuum of 7·10-7 to 2 10-6 during the sputter process. The air-dry state was defined as that reached once the samples, which had spent at least three weeks in a controlled climate of 20°C and 65 % relative humidity, had reached a state of constant mass. The Carbon-fibre reinforced polymer (CFRP) samples were tested in the dry condition only, since they were found to absorb less than 0.5 wt. % of moisture.

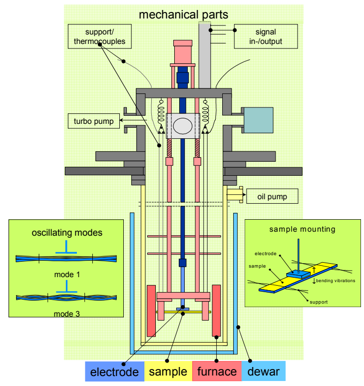

Figure 2: Experimental setup for resonant bar measurements, kHz-apparatus for free amplitude decay.

RESULTS

Mechanical properties

The density, Young´s modulus and loss coefficient of pernambuco and 13 alternative materials are listed in Table 2 and 3. Graphs plotting Young´s modulus, *E*, against density, ρ (Figure 3) and Young´s modulus, *E*, against the loss coefficient, η (Figure 4) illustrate the results. Pernambuco stands out in both cases: it has an exceptionally high Young´s modulus for its density and the lowest loss coefficient of all materials tested.

Figure 1 shows that Swartzia, the palm Arizeiro and the outer, denser parts of the bamboo tube can match the density and Young´s modulus of Pernambuco. All other woods that exhibit a density similar to that of Pernambuco have a Young´s modulus which is significantly lower than that of Pernambuco. Bows made from these would be more flexible for their weight and would need to be stiffened geometrically through an increase in bow stick diameter which would also result in an increase in weight. CFRP has a density comparable to that of Pernambuco, but also a comparatively low modulus. One way to increase stiffness without increase in weight in this case would be to manufacture a hollow bow — a strategy well suited for a composite material, but less applicable to woods. The low loss coefficient of Pernambuco is more difficult to match than its density and Young´s modulus. Here, Swartzia and CFRP come close.

Combining these criteria, Swartzia is, on purely mechanical grounds, the most promising alternative material for Pernambuco, but Arizeiro and bamboo should be considered, too.

Moisture content and extractives

Matsunaga *et al.* (1996) investigated this and showed that the extractives of Pernambuco indeed are the cause of its exceptionally low loss coefficient. They suggested that the water adsorbed to the extractives lowers internal friction (Matsunaga *et al.*, 2000a). Our own experiments support this hypothesis. Comparing the loss coefficient of dry with air-dry wood, we also found a pronounced effect of moisture content. All woods, palm and bamboo, with the exception of snakewood, had a significantly higher loss coefficient in the dry than in the air-dry state (Table 3). Also in this comparison. Pernambuco stands out as the wood with the highest ratio — and a trend becomes apparent indicating that the lower the damping in the air-dry state, the larger the ratio of the loss coefficients. It would be interesting to investigate how well this ratio correlates with the actual amount and type of extractives present.

Concerning the materials substitution problem, another experiment by Matsunaga *et al*. (1999, 2000a,b) is important. They showed that Sitka spruce (*Picea sitchensis*) impregnated with the water-soluble extractives of Pernambuco also showed reduced damping. Thus, given that an alternative wood which falls within the desired range of density and Young´s modulus can be impregnated with these or similar extractives. Its loss coefficient could be improved. This method of impregnation would make many more woods potential candidates for Pernambuco substitution and is therefore worthy to be pursued further.

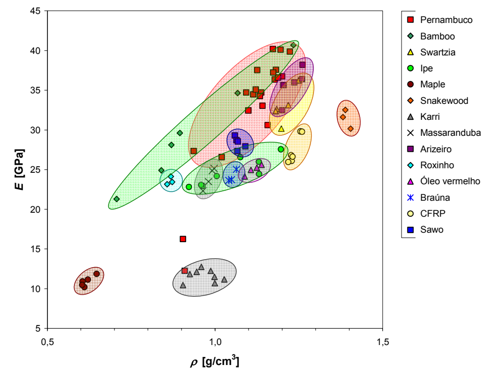

Figure 3: Young´s modulus, *E*, plotted against density, ρ.

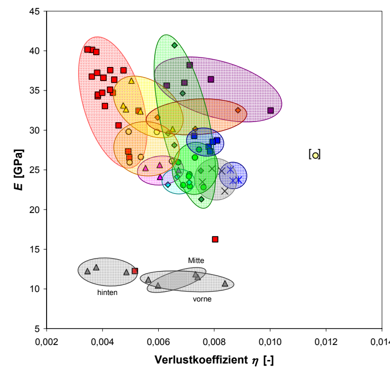

Figure 4: Young´s modulus, *E*, plotted against loss coefficient, η.

Table 2: Experimental results.

Material	Material	Density (air-dry)		Young´s modulus (air-dry)		Loss coefficient (air-dry)
		ρ_{min} [g/cm³]	ρ_{max} [g/cm³]	E_{min} [GPa]	E_{max} [GPa]	$\bar{\eta}_{air\text{-}dry}$ ± s.d. [-]
Pernambuco		**0.90**	**1.22**	**12.2**	**40.2**	**$4.4 \pm 0.1 \cdot 10^{-3}$**
Swartzia		1.18	1.25	30.1	36.2	$5.3 \pm 0.3 \cdot 10^{-3}$
CFRP		1.22	1.26	25.9	29.8	$5.5 \pm 0.3 \cdot 10^{-3}$
Karri		0.90	1.03	10.4	12.7	$5.9 \pm 0.6 \cdot 10^{-3}$
Óleo vermelho		1.09	1.14	24.1	25.6	$6.1 \pm 0.2 \cdot 10^{-3}$
Roxinho		0.86	0.87	23.1	24.1	$6.7 \pm 0.2 \cdot 10^{-3}$
Bamboo		0.71	1.23	21.3	40.7	$6.9 \pm 0.2 \cdot 10^{-3}$
Ipe		0.92	1.20	22.8	27.6	$7.2 \pm 0.1 \cdot 10^{-3}$
Snakewood		1.38	1.40	30.1	32.5	$7.4 \pm 0.8 \cdot 10^{-3}$
Arizeiro		1.20	1.26	32.5	38.2	$7.7 \pm 0.6 \cdot 10^{-3}$
Sawo		1.06	1.09	27.3	29.3	$7.8 \pm 0.1 \cdot 10^{-3}$
Massaranduba		0.96	1.00	22.3	25.1	$8.0 \pm 0.2 \cdot 10^{-3}$
Braúna		1.04	1.06	23.6	25.0	$8.7 \pm 0.8 \cdot 10^{-3}$
Maple		0.60	0.65	10.2	11.8	-

Table 3: Loss coefficient of dry and air-dry woods and their ratio.

Material	Loss coefficient		Ratio
	dry	air-dry	dry / air-dry
	$\bar{\eta}_{dry}$	$\bar{\eta}_{air\text{-}dry}$	$\bar{\eta}_{dry} / \bar{\eta}_{air\text{-}dry}$
	[-]	[-]	[-]
Pernambuco	**6.9** $\cdot 10^{-3}$	**4.4** $\cdot 10^{-3}$	**1.55**
Roxinho	$9.7 \cdot 10^{-3}$	$6.7 \cdot 10^{-3}$	1.45
Swartzia	$7.0 \cdot 10^{-3}$	$5.3 \cdot 10^{-3}$	1.32
Karri	$7.5 \cdot 10^{-3}$	$5.9 \cdot 10^{-3}$	1.28
Ipe	$8.6 \cdot 10^{-3}$	$7.2 \cdot 10^{-3}$	1.21
Óleo vermelho	$7.2 \cdot 10^{-3}$	$6.1 \cdot 10^{-3}$	1.18
Braúna	$1.0 \cdot 10^{-2}$	$8.7 \cdot 10^{-3}$	1.17
Bamboo	$7.7 \cdot 10^{-3}$	$6.9 \cdot 10^{-3}$	1.11
Massaranduba	$8.8 \cdot 10^{-3}$	$8.0 \cdot 10^{-3}$	1.10
Sawo	$8.4 \cdot 10^{-3}$	$7.8 \cdot 10^{-3}$	1.08
Arizeiro	$8.0 \cdot 10^{-3}$	$7.7 \cdot 10^{-3}$	1.04
Snakewood	$7.1 \cdot 10^{-3}$	$7.4 \cdot 10^{-3}$	0.97

CONCLUSIONS

The experimental results described above show that Pernambuco is a wood with exceptional mechanical properties: it has a particularly high Young´s modulus for its density and a remarkably low loss coefficient. They also suggest that there are a number of alternative materials which, on purely mechanical grounds, could make as good violin bows as Pernambuco.

Acknowledgements

The authors wish to thank H. Gabriel, Erlangen for the generous supply of the wood species tested. Dr. J. Schulz of the Institut für Konstruktion und Verbundbauweisen. Chemnitz. Germany for the donation of the CRFP samples. M. Binder and H. Eckstein for their perfection in sample preparation, R. Völker and Dr. T. Wagner for sputtering the specimens, Dipl.-Ing. Rohlfing. FMPA Otto-Graf-Institut, Stuttgart for the permission to use of the climate chamber, and last but not least I. Grigorides for expert assistance with the damping experiments.

References

1. Fétis, F.J. (1865) Antoine Stradivari luthier célèbre. Paris.
2. Matsunaga, M., Sugiyama, M., Minato, K. and Norimoto, M. (1996): Physical and mechanical properties required for violin bow materials. *Holzforschung* 50: 511-517.
3. Matsunaga, M., Minato, K. and Nakatsubo, F. (1999) Vibrational property changes of wood by impregnation with water-soluble extractives of pernambuco (*Guilandina echinata* Spreng.). *J. Wood Sci.* 45: 470-474.
4. Matsunaga, M., Obataya, E., Minato, K. and Nakatsubo, F. (2000a): Working mechanism of adsorbed water on the vibrational properties of wood impregnated with extractives of Pernambuco (*Guilandina echinata* Spreng.). *J. Wood Sci.* 46: 122-129
5. Matsunaga, M., Sakai, K., Kamitakahara, H., Minato, K. and Nakatsubo, F. (2000b): Vibrational property changes of spruce wood by impregnation with water-soluble extractives of Pernambuco (*Guilandina echinata* Spreng.) II: structural analysis of extractive components. *J Wood Sci* 46: 253-257
6. Oberhoff, S. (2003): *Bögen für Streichinstrumente: Das elastische und anelastische Verhalten von Fernambukholz und alternativen Materialien*. Diploma thesis. Institut für Metallkunde, Universität Stuttgart: Stuttgart, Germany
7. Pitteroff, R. (1995): "*Contact mechanics of the bowed string*". PhD thesis. Department of Engineering. University of Cambridge: Cambridge, UK.
8. Wegst, U.G.K. and Ashby, M.F. (1996): Alternative woods for violin bows. *Newsletter of the British Violin Making Association*. 5: 7-14.
9. Wegst, U.G.K. (1996): "*The mechanical performance of natural materials*". PhD thesis. Department of Engineering University of Cambridge: Cambridge, UK.
10. Weller, M. and Wert, C. (1984): Cross-linking of macromolecules in coal. *Fuel*. 63: 891-6.
11. Wert, C., Weller, M. and Caulfield, D. (1984): Dynamic loss properties of wood. *J. Appl. Phys.* 56(9): 2453-8.
12. Weller, M. and Török, E. (1987): Automatic system for measurements of internal friction and elastic moduli. *J. Phys.* (Paris) 48: C8, 371-376.