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NOTE

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Physical and mechanical properties required for violin bow materials II: Comparison of the processing properties and durability between pernambuco and substitutable wood species*

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Abstract Pernambuco (*Guilandina echinata* Spreng. syn *Caesalpinia echinata* Lam.), which has been used for a material of violin bows, was compared with substitutable wood species from the viewpoint of processing properties and durability. The properties required for bow material are discussed. The shearing strength of pernambuco was higher than that of the other wood species at the same specific gravity. High shearing strength seems to be effective for preventing damage to the head (top part) of the bow. The presence of extractives affects the thermal softening of wood material, but ease of handling and permanent retention of form are not particularly superior for pernambuco, although it does have a high extractives content. A peculiarly low loss tangent (tan δ) of pernambuco can probably be attributed to the large amount of extractives, rather than the mean microfibril angle.

Key words Pernambuco · Violin bow · Shearing strength · Processing property · Mean microfibril angle

Introduction

The heartwood of pernambuco (*Guilandina echinata* Spreng. syn *Caesalpinia echinata* Lam.), a Brazilian hardwood, has been used to make violin bows for more than 200 years. In previous studies[1,2] we compared the physical and mechanical properties of pernambuco with those of some substitutable wood species and tried to clarify why pernambuco is suitable for bows. Because the loss tangent (tan δ) of pernambuco is exceptionally low among the wood species examined, it was suggested that a low tan δ value is a necessary condition for bow material. It was also found that a low tan δ could be attributed to a large volume of extractives in pernambuco, and that the tan δ may be affected not only by the quantity of the extractives but also by their chemical structure and location in the wood structure.

Though the vibrational property is closely related to the suitability of bow material, the ease of handling during the manufacturing process and durability also seem to be important. For example, a curvature, which offers tensile force to the horse hair, is created in the bow by heating. Thus the ease of handling and permanent retention of this deformation may also be required. The top part of the bow (called the "head") is easy to break along a longitudinal direction when it is carelessly handled, so the strength of the head is another important factor.

In this paper the physical and mechanical properties of pernambuco and some promising wood species were investigated. From a comparative study of pernambuco and other wood species, the conditions required for bow material were explored, especially from the viewpoint of their processing properties and durability. The factors controlling vibrational properties were also examined.

Materials and methods

Materials

The specimens were cut from heartwood of the following five wood species.

Pernambuco (*Guilandina echinata* Spreng. syn *Caesalpinia echinata* Lam.)
Family: Leguminosae
Color: yellowish to reddish

Massaranduba (*Manilkara bidentata* A. DC. syn *Mimusops bidentata* A. DC. Chev.)
Family: Sapotaceae

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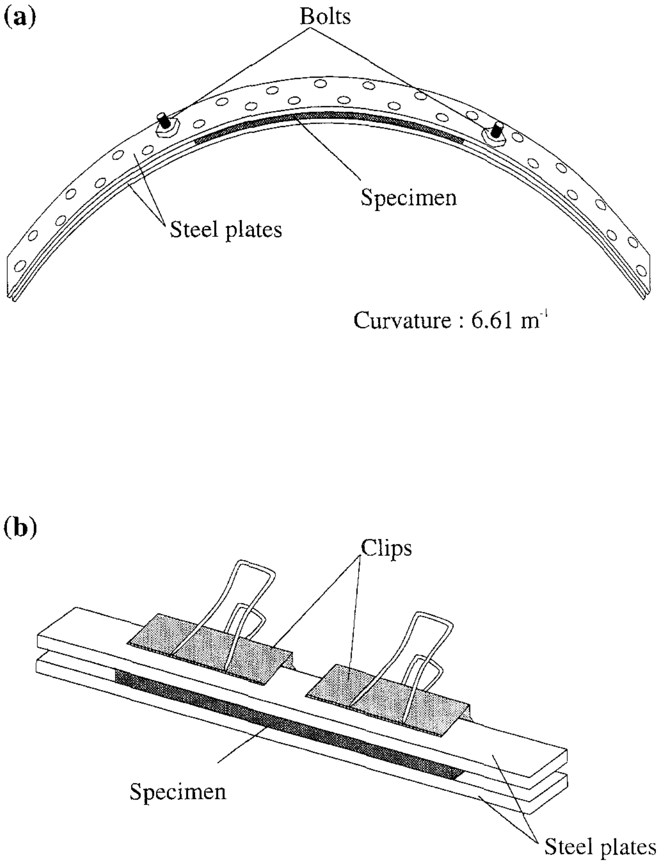

Fig. 1. Devices for fixation (**a**) and forced recovery (**b**) of the curvature

Growing district: Brazil
Color: light to dark reddish brown
This wood is sometimes used in bow making.

Kerandji (*Dialium* spp.)
Family: Leguminosae
Growing district: Malaysia, Indonesia
Color: light to yellow brown
Bows made of this species are comparable to those made of pernambuco and are experimentally commercially available.

Pao rosa (*Swartzia fistuloides* Harms)
Family: Leguminosae
Growing district: West Africa
Color: dark red to rose red
This species is under investigation for use as a bow.

Blackbutt (*Eucalyptus pilularis* Sm.)
Family: Myrtaceae
Growing district: Australia
Color: whitish or pale brown
This wood is abundant but has not yet been used effectively.

Specimens of pernambuco, massaranduba, and kerandji were cut from a lot of bar-shaped materials that were eliminated when manufacturing bows because of their partial defects. The specimens of pao rosa and blackbutt were prepared from several pieces of board-shaped or bar-shaped timbers. The number of specimens is shown in Tables 1, 2, and 3 (see below). The specific gravity of oven-dried wood was measured for the bending and shearing tests.

Shearing test

Specimens of 35mm (longitudinal direction, L) × 20mm (radial direction, R) × 10mm (tangential direction, T), which had a notch of 10mm (L) × 10mm (R) × 10mm (T) were used. The specimens were sheared parallel to the tangential plane by means of a compression test apparatus (Mori Shikenki Seisakusho, Tokyo, Japan), and the maximum load was measured. The shearing rate was about 1 mm/min. Shearing strength was calculated by dividing the maximum load by the shearing area. The tests were carried out in a surrounding atmosphere.

Thermal softening test

All of the wood species were ground with a Wiley mill to pass through a sieve with 355-μm apertures but not a sieve with a 150-μm apertures. Half of the wood meal was extracted with ethanol-benzene (v/v 1:2) for 6h by a Soxhlet's extractor; both the extracted and unextracted wood meals were used for the thermal softening test. The wood meal was stuffed into a glass tube (2mm diameter). The height of the stuffed wood meal was about 10mm. The change of the height during heating was measured as the volumetric change through a differential transformer. The temperature range and increasing rate of temperature change were 50°–300°C and 2K/min, respectively.

Tests for bending property and retention of the curvature

A specimen measuring 150mm (L) × 12mm (R) × 2mm (T) was heated at 280°C for 90s in an oven, placed between curved steel plates (curvature 6.61), and fixed by bolts (Fig. 1a). The whole device was cooled under atmospheric conditions. Ten minutes later the steel plates were removed, and the curvature of the specimen was measured. The specimens were then placed in a desiccator maintained at 20°C and 66% relative humidity (RH). After 2 weeks the specimen was held between flat steel plates and pinched by clips (Fig. 1b), after which the change of the curvature that occurred with the passage of time was measured.

X-ray diffractometry

The mean microfibril angle (MMA) was evaluated by X-ray diffractometry. Specimens of 1mm (L) × 0.8mm (R) × 2mm (T) were used. It is known that Cave's method[3] and an improved Cave's method[4] are convenient for determining the MMA of a cell wall.

A point-focused X-ray beam (Cu-Kα X-ray, power 30mA × 40kV) was applied to the tangential surface of

Table 1. Properties of specimens subjected to the shearing test

Specimen	No.	Specific gravity in oven-dried state mean ± SD	Shearing strength (MPa) mean ± SD	σ_s/ρ (MPa) mean
Pernambuco	15	0.940 ± 0.052	22.5 ± 2.4	24.0
Massaranduba	13	1.075 ± 0.032	23.9 ± 1.9	22.2
Kerandji	14	1.016 ± 0.047	21.1 ± 1.9	20.8
Pao rosa	13	1.082 ± 0.025	19.7 ± 1.2	18.2
Blackbutt	31	0.825 ± 0.124	18.0 ± 3.0	21.8

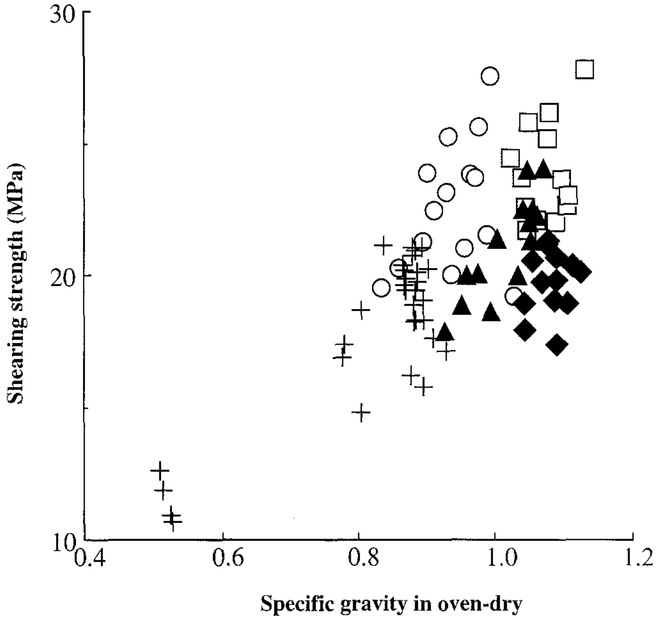

Fig. 2. Relation between specific gravity in the oven-dried state and shearing strength. *Open circles*, pernambuco; *open squares*, massaranduba; *filled triangles*, kerandji; *filled diamonds*, pao rosa; *crosses*, blackbutt

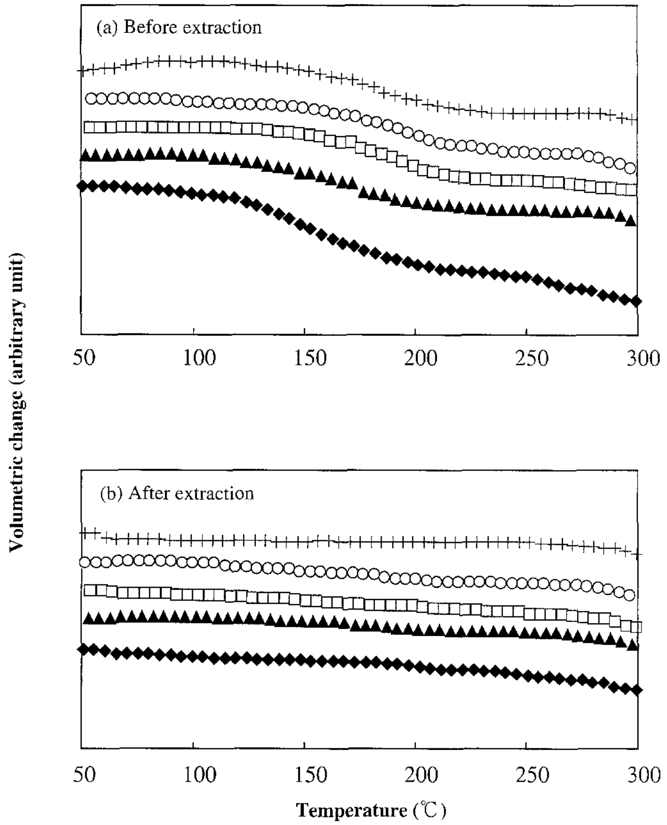

Fig. 3. Thermal softening of wood meals. Symbols are the same as in Fig. 2

each specimen. An X-ray diffraction apparatus (RINT2200V; Rigaku Denki, Tokyo, Japan) was used. An imaging plate (Fuji Film Blue IP) was set behind the specimen to record the X-ray diffraction pattern. The MMA was calculated from a diffraction intensity distribution around (200) arc using Cave's method.

Results and discussion

Shearing strength

One of the most serious problems with bows is a broken head, which is mostly caused by careless handling. For example, if the bow collides perpendicularly with a wall or the floor, the hook-shaped head may be subjected to a shearing impact.

Figure 2 shows the relation between specific gravity in an oven-dried state and the shearing strength of tangential sections of all the wood species. It was found that the shearing strength is proportional to the specific gravity; the shearing strength of pernambuco was somewhat higher than that of the other wood species at the same specific gravity. Though the massaranduba has the highest shearing strength (Table 1), when the shearing strength is divided by the specific gravity (σ_s/ρ), that of pernambuco was highest. In fact, it has been pointed out that bow heads made from kerandji, whose shearing strength is lower than that of pernambuco, easily break. Pernambuco, with its high shearing strength, seems to satisfy one of the requirements for bow material.

Thermal softening

During the manufacture of bows the stick is heated with a gas flame at a considerable temperature to create the curvature. When examining the suitability of bow materials, the

Table 2. Curvature immediately after removal of bending device

Specimen	No.	Curvature (m^{-1}) Mean ± SD
Pernambuco	8	4.12 ± 0.19
Massaranduba	5	4.87 ± 0.09
Kerandji	5	4.66 ± 0.65
Pao rosa	5	6.07 ± 0.25

ease with which the wood can be bent in the flame and permanent retention of the form must be taken into consideration.

We previously reported that pernambuco and pao rosa, which contain large amounts of extractives, showed lower softening temperatures than the other wood species.[2] This finding suggests that extractives affect the softening temperature of wood. Thus the thermal softening of extracted and unextracted wood meal were measured, and the relation between the softening temperature and the extractives content was examined.

The results are shown in Fig. 3. For unextracted wood meals of all wood species, significant decreases of volume were observed between 150° and 200°C. Pao rosa, which has a large amount of the ethanol-benzene extractives, especially showed a marked change. On the other hand, the volume changes in extracted wood meals were only slight, irrespective of the wood species.

In a previous paper[2] we proposed that the decrease of dynamic Young's modulus around 200°C was attributed to the softening of extractives, which restrained the free movement of the cellulose chain. The results of the thermal softening test supports that proposal.

Ease of bending and retention of the curvature

As mentioned above, it was found that extractives affect the softening of wood material. Thus a curvature was made in the specimen by a method similar to that used for bow manufacturing, and the change in the curvature was measured when the specimen was forcibly straightened. Blackbutt was not subjected to the test because it is so weak in terms of bending that experiments under the same conditions as used for the other wood species were impossible.

Table 2 shows the curvatures of each wood species immediately after bending in the drying oven. The curvature varied among wood species despite using the same implement. Pernambuco had the lowest curvature.

Figure 4 shows the change in the curvature over time when specimens were straightened between two flat steel plates. The line for pernambuco had a gentle slope and was located on the upper part of the graph. Thus pernambuco tends to maintain its curvature compared with other wood species, although the difference between pernambuco and other wood species is only slight. Therefore it is difficult to assert that pernambuco keeps its curved form more than the other wood species. Ultimately, the ease of bending in the flame and permanent retention of the form are not always the primary characteristics on which to base the selection of wood for bow material.

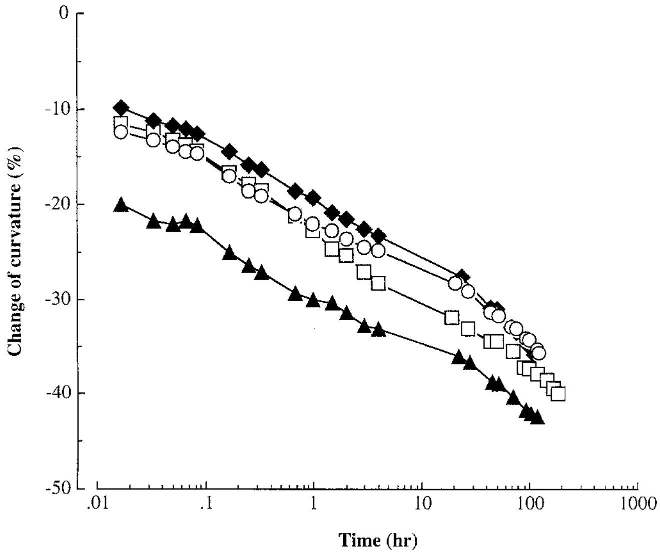

Fig. 4. Changes of the curvature with the passage of time. Symbols are the same as in Fig. 2

Mean microfibril angle

The middle layer in the secondary wall (S_2 layer) comprises 80% or more of the volume of the cell wall of wood fiber, and some of the physical properties of wood depend strongly on the microfibril angle of the S_2 layer. The tan δ is also affected by the microfibril angle of the S_2 layer. It has been reported that specimens with a large microfibril angle have a larger tan δ value.[5,6] Though the high extractives content of pernambuco is responsible for a low tan δ value, the microfibril angle must also be taken into consideration.

The MMA estimated by Cave's method is shown in Table 3. The tan δ values and extractives contents are from a previous paper,[2] where other parts of the same specimens were used. Though the wood species examined here have a high specific gravity, it is probable that the calculated values for the microfibril angle are lower than the true values because the thick cell wall may increase the diffraction intensity. The MMA in Table 3 is available only when high-specific-gravity species are compared.

The MMA values for pernambuco and massaranduba were nearly equal, although the tan δ for pernambuco was less than half that for massaranduba. From the viewpoint of the MMA, tan δ for pernambuco and massaranduba ought to be equal; therefore it is thought that the large amount of extractives in pernambuco lowers its tan δ. On the other hand, among the five wood species examined the tan δ for pao rosa was not particularly large, although its MMA was high. This point is explainable if a large amount of extractives involved in pao rosa lowers the tan δ.

Table 3. MMA, tan δ, and extractives content

Specimen	No.	MMA (°)	tan δ	Extractives content (%)	
				Hot water	Ethanol-benzene
Pernambuco	5	12.53	4.12×10^{-3}	13.0	9.2
Massaranduba	5	12.58	10.04	6.5	4.2
Kerandji	5	9.50	5.74	7.3	5.4
Pao rosa	5	21.24	7.41	10.2	21.2
Blackbutt	5	8.91	6.20	6.0	1.7

The values for tan δ and content of extractives are from Matsunaga et al.[2] where other parts of the specimens were used.

Conclusions

Physical and mechanical properties of pernambuco were compared with those of alternative wood species in terms of their use for bow material. The results obtained were as follows. The shearing strength of pernambuco was higher than that for the other wood species at the same specific gravity. A high shearing strength effectively prevents damage to the bow's head. Shearing strength seems to be required for bow material, but it is not the most important property. The presence of extractives affects the thermal softening of wood material. However, the ease of handling and permanent retention of the curvature when pernambuco is used are not markedly superior. Consequently, these properties are probably not the most important properties when selecting bow material. The low tan δ value of pernambuco seems to be attributable to the high extractives content rather than to the small microfibril angle.

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