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SELECTED ASPECTS OF RESONANCE PROPERTIES OF DIFFERENT WOODS AND THE CONSTRUCTION OF STRING INSTRUMENTS

Abstract: Wood is the primary material used in the manufacture of string instruments. The quality of the resonance wood, together with the skills of the luthier- the violin makers, is one of the main factors influencing the final quality of the instruments. There are several important parameters used to evaluate the quality of the resonance wood. The most important are: wood structure, moisture content, density, elasticity, speed of acoustic wave propagation, and degree of vibration damping. There are many studies available in the specialist literature, results of these studies are presented in this article. Therefore, an in-depth analysis of the databases of scientific journals is the primary research method. The quality of the resonance wood, together with the skills of the violin makers, is one of the main factors influencing the final quality of the instruments.

Keywords: resonance wood, violin, quality of resonance wood

Introduction

Wood has many uses in which its quality plays an important role – one of them is violin making. Violin making "is one of the most difficult branches of applied

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arts, because it binds the artist's thought with the necessary knowledge and application of scientific laws" [Panufnik 1926]. The wood used for this purpose is called resonance wood. The quality of the resonance wood, together with the skills of the luthier, is one of the main factors influencing the final quality of the instruments. This is especially important for the wood used to make soundboards [Carlier et al. 2018]. Choosing the appropriate wood is an issue to which all violin-making theorists and practitioners devote a lot of attention, based on their own experience and knowledge passed on through tradition – the basis is the analysis of the structure and properties of the wood from which the world-famous instruments were made.

Some physical parameters are important when choosing a resonance wood. Part of them are easily measurable with specific measuring instruments but some of them can be rated only by a professional luthier using his experience. The wood of various types of trees is used for violin making - the selection of the appropriate species for the production of individual elements is the result of accumulating experience of generations of luthiers. The quality properties of wood, even of the same species, vary depending on the geological and atmospheric conditions in different regions of the globe. Still, they can also vary significantly even within the immediate vicinity [Bridge 2000].

Correlations between the anatomical characteristics of the soundboard and its mechanical and acoustic parameters are presented in detail in the works of Bremaud, et al. [2011], Buksnowitz, et al. [2007], Dinulică, et al. [2021], Wegst [2006], Alkadivi, et al. [2018] and Spycher et al. [2008].

The conditions for achieving the positive sonic properties of the entire instrument are [Bucur 2006] [Buksnowitz et al. 2007] [Harajda and Łapa 1997] [Dinulică 2021]:

- the ability of resonance plates to vibrate over the entire frequency range
- achieving the correct amplitude of vibrations of the resonance plates
- appropriate speed of propagation of vibrations
- appropriate vibration distribution on the soundboards

The fulfillment of these conditions requires the proper selection of wood and its proper treatment.

The aim of the paper is the description selected important parameters, especially resonance, used to evaluate the quality of the resonance wood for string instruments construction.

Research Methodology

Method-wise, this article critically analyses the subject literature. The research aimed to determine the most important parameters described in the literature for the quality assessment of resonance wood used in the production of string instruments. In this respect, this is a theoretical article. As for the materials used, the authors referred to the in-depth analysis of scientific journal databases as the main sources of data. In summary, we intend that this text should be treated as a study of literature leading to the formulation of a list of important parameters for the quality assessment of resonance wood.

Results by issues

1. Types of wood uses in violin construction

The violin consists of the following parts: a - scroll and pegbox, b - pegs, c - neck, d - belly, e - fingerboard, f - strings, g - ribs, h - bridge, i - tailpiece, j - “f-holes”, k - chinrest [Fig. 1].

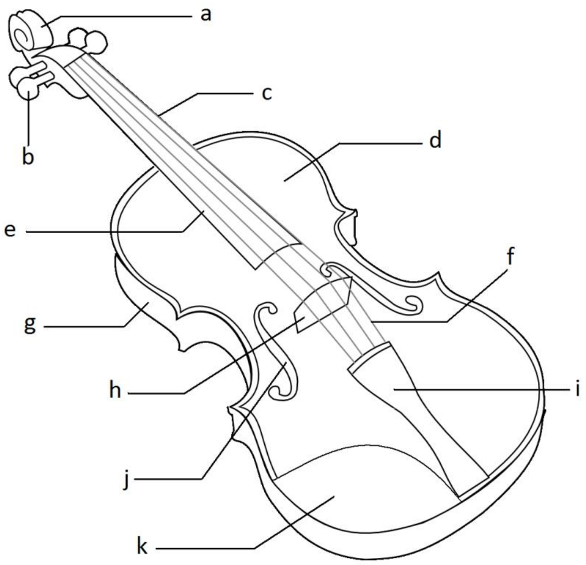

Fig. 1. Violin parts

Tables 1 to 3 show the different types of wood (hardwood, softwood, exotic) most commonly used in violin construction according to [Barducci and Pasqualini 1948], [Krzysik 1978], [Haines 1979], [Harajda and Łapa 1997].

Table 1. Hardwood uses in violin making

Tree species	Latin name	The use of wood
Norway Maple	*Acer platanoides*	back, ribs, neck, bridge
Sycamore Maple	*Acer pseudoplatanus*	
Downy Birch	*Betula pubescens*	
European White Birch	*Betula verrucosa*	
Apple Tree	*Malus domestica*	tailpiece, pegs, chinrest
Black Cherry	*Padus serotina*	
European Pear	*Pirus communis*	
European Plum	*Prunas domestica*	
White Poplar	*Populus alba*	corner and lower blocks, boards,
Canadian Poplar	*Populus canadensis*	
White Willow	*Salix alba*	
Small-leaved Lime	*Tilia cordata*	
London Plane	*Platanus acerifolia*	bridge
Oriental Plane Tree	*Platanus orientalis*	

Table 2. Softwood uses in violin making

Tree species	Latin name	The use of wood
Silver Fir	*Abies alba*	belly, bass bar, soundpost, boards, corner and lower blocks
European Spruce	*Picea excelsa*	
White Spruce	*Picea glauca canadiensis*	
Siberian Spruce	*Picea obovata*	
Siberian Pine	*Pinus sibirica*	

Table 3. Exotic wood uses in violin making

Tree species	Latin name	The use of wood
Fernambuco Wood	*Caesalpinia echinata*	bows
Boxwood	*Buxus sempervirens*	tailpiece, pegs, chinrest
Ceylon Ebony	*Diospyros ebenum*	tailpiece, pegs, chinrest, nut, fingerboard
Indian Rosewood	*Dalbergia latifolia*	tailpiece, pegs, chinrest
Bahia Rosewood	*Dalbergia nigra*	

Each part of the violin must be made of a specific type of wood considering its properties.

Scroll, pegbox, neck, ribs, back and bridge are usually made of sycamore wood. Sycamore wood is hard, stable and dense and, additionally, has appropriate acoustic properties – relatively high speed of propagation of the acoustic wave. The bridge can be also made of fine-grained plane wood due to the great forces it carries between the strings and the soundboard.

Violin sound box can be compared to the kettle drums – backs and bottom have to be hard and stable, but the membrane has to be light and elastic. For this reason the top soundboard is almost always made of spruce because this wood is light, durable, has excellent resonance properties and doesn't contain as much resin as other softwood. Spruce is also used in the construction of the sound post – a dowel that transmits vibrations between soundboards.

Fingerboard and pegs must be made of very hard wood. Historically, violin makers used ebony and rosewood, but nowadays rosewood is no longer used due to the restricted trade law. Wood used for fingerboard has to be strong, hard and fine-grained because it should not be distorted by the metal strings. Pegs can be also made of hard boxwood or plum.

Tailpiece can be made of a variety of materials including different types of wood, polymer and metal depending on the acoustic properties of the instrument.

2. Wood structure

Wood is a heterogeneous material - its structure is diversified in different parts of the trunk. The growth of the wood mass depends on the changing growth conditions, including the prevailing climate. Each growth ring consists of two parts: early wood coming from the spring and summer period when growth is comparatively rapid, and latewood, which increases during the autumn and winter and is denser [Capon 2005] [Dinulica 2019]. The macrostructure of wood according to Ashby [Ashby and Jones 2013] is schematically presented in Fig. 2.

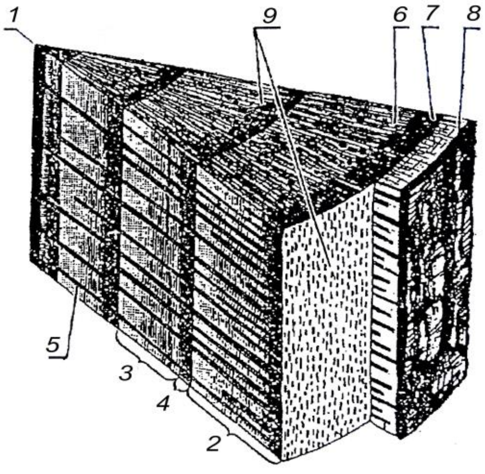

Fig. 2. The macrostructure of wood Based on [Krzysik 1978]. 1 – pith, 2 – annual ring, 3 – earlywood, 4 – latewood, 5 – resin canals, 6 – vascular cambium, 7 –phloem, 8 – bark , 9 – medullary rays.

The structural properties of wood depend on the climatic and soil conditions in which the trees grew [Bucur 1992]. The entire history of the tree is described in growth rings [Bieler 1953]. The areas of Italy, Switzerland, Tyrol, Subcarpathia [Panufnik 1926], and the Bosnia and Romanian Carpathians [Harajda and Łapa 1997] are considered optimal for the growth of resonance wood. The selection of the resonance wood takes into account the share of late wood and the width of the rings [Bremaud et al. 2011]. Wood with wide rings is less often chosen for the construction of string instruments, but mainly due to aesthetic requirements. The proportion of latewood is considered a more important parameter [Spycher et al. 2008].

Wood from trees of different species has a different internal structure which influences the way the wood is used to build different parts of the instruments. For example, the sycamore and maple wood used to build the bodies of the instruments has a wavy growth ring structure, which requires consideration when composing the body of the instrument [Alkadivi et al. 2018]. On the other hand, for the construction of elements requiring high hardness and strength, very durable species are used, such as rosewood, used to build pegs, tailpieces or chinrests, and ebony, from which fingerboards are made [Harajda and Łapa 1997].

3. Moisture content of wood

The relative moisture content of wood is defined as the ratio of the mass of water contained in the wood to the mass of wood completely free of water and is expressed as a percentage. Freshly cut wood, under appropriate conditions, gradually reaches the optimal level of moisture content. After some time, the wood becomes resistant to accidental changes in air humidity. Panufnik [1926] writes that the resonance wood "after cutting and sawing on the so-called resonances cannot be used until after seven years of drying up." Freshly cut wood stored in the air loses part of its moisture and, depending on the temperature and air humidity reaches 13-22% of moisture content [Table 1] [Krzysik 1978]. It is assumed that for resonance wood the moisture content should be 8-12% at approx. 20 ° C with a relative air humidity of 45-65%. This value is given in the standards. Dry wood is stronger and has better acoustic properties due to the faster propagation of acoustic waves. It is also easier for violin makers to work with.

Table 4. The moisture content of wood depends on temperature and air humidity

Air humidity [%]	Air temperature [°C]										
	0	10	20	30	40	50	60	70	80	90	100
100	29,0	28,5	28,3	28,1	28,0	27,9	27,0	27,1	25,0	24,1	23,0
90	21,0	20,6	20,2	19,7	19,1	18,7	18,0	17,0	16,0	14,3	13,3
80	17,5	17,0	16,3	15,7	15,0	14,4	13,6	12,6	11,7	10,7	10,0
70	13,6	13,2	13,0	12,6	12,1	11,5	10,8	10,0	9,2	8,4	7,8
60	11,3	10,8	10,5	10,3	10,0	9,5	8,9	8,2	7,5	6,8	6,2
50	9,6	9,2	9,0	8,6	8,2	7,8	7,4	6,7	6,2	5,7	5,2
40	8,2	8,0	7,6	7,2	6,8	6,4	5,9	5,4	5,0	4,6	4,1
30	6,3	6,1	5,9	5,7	5,4	5,0	4,6	4,2	3,9	3,3	2,9
20	4,7	4,5	4,3	4,1	3,9	3,6	3,3	3,1	2,8	2,5	2,1
10	2,7	2,7	2,6	2,6	2,5	2,4	2,2	2,0	1,8	1,6	1,2

With a change in moisture content, the volume of wood changes significantly [Fig. 3] [Michejda 1956].

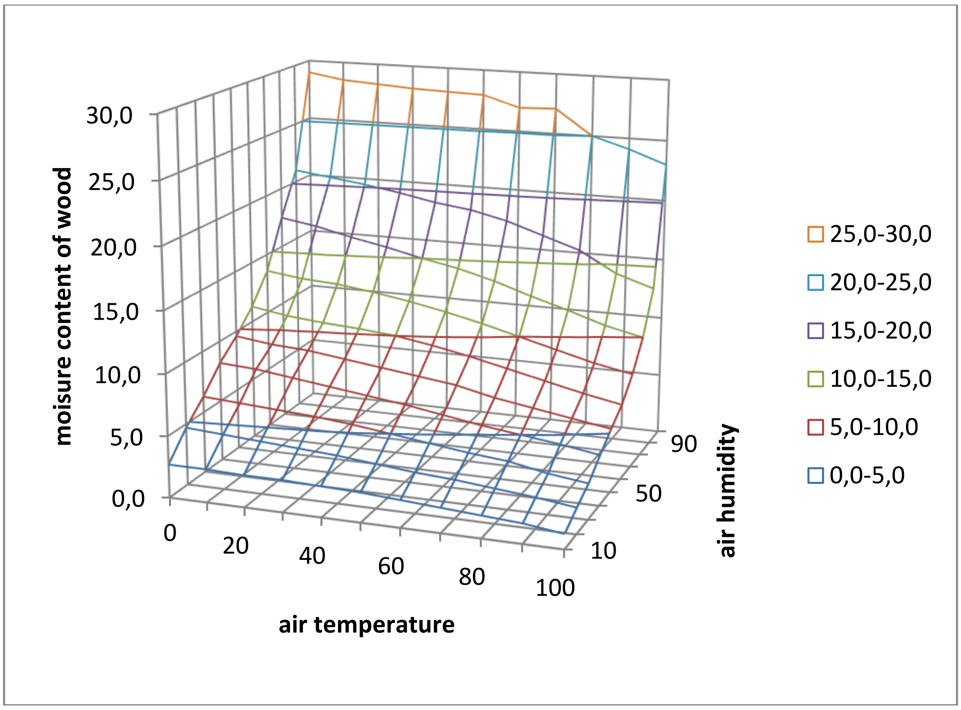

Fig. 3. The dependence of wood volume on its moisture content.

Source: figure based on data from [Michejda 1956].

4. Wood density

Wood is a heterogeneous material and there are significant differences between the density of early and latewood. For this reason, there is a positive correlation between the share of late wood and the average wood density. Therefore, the wood density also depends on the width of the annual rings - as their width increases, the density of the wood decreases. In addition, different types of wood have different densities [Table 5].

Table 5. Average early and late wood densities for different species [Harajda and Łapa 1997]

Tree species	Average density [kg/m^3]	
	late wood	early wood
Beech	935	502
Oak	925	330
Sycamore	750	502
Fir	625	277
Lime Tree	566	361
Pine	830	343
Spruce	601	307

5. Wood elasticity

Elasticity is a property of solids that can undergo various deformations under the influence of force. Elastic deformation occurs when the body returns to its original shape when the deforming force ceases. The maximum stress at which the solid retains its elasticity is called the yield point. Below the yield point, there are elastic deformations, and above this limit - are permanent deformations.

The acoustic properties of resonance wood are influenced, among others, by elasticity in deflection, as this largely determines the ability of the wood to vibrate. There are several methods of testing the modulus of elasticity of resonance wood. The most common method is based on deflection of samples with dimensions of 20 x 20 x 300 mm resting on rounded supports with a spacing of 8 cm, using weights of 10 ± 1 kg [Schelleng 1982]. The following simplified formula is commonly used to calculate Young's modulus in violin making [Harajda and Łapa 1997]:

$$E = \frac{Fl^3}{4a^3bx} \tag{1}$$

where:
E – the modulus of elasticity [$\mathrm{Pa} \cdot 10^9$]
F – the force exerted on an object under tension [N]
l – the original length of the object between supports [m]
a – object thickness [m]
b – object width [m]
x – deflection [m]

Many factors affect the elasticity of wood - primarily the wood species [Table 6] and its moisture content and density [fig. 4] [Kollmann and Krech 1960].

Table 6. The modulus of elasticity in deflection of various wood species

Tree species	The modulus of elasticity [$\mathrm{Pa} \cdot 10^9$] Barducci and Pasqualini [1948]	Novoderzhkin [1964]	Krzysik [1978] max. – av. – min.
Silver Birch	14,0	–	16,5
Iron Birch	–	16,8	–
Palisanderwood	11,0	–	–
Sycomore	7,3	–	6,4 - 9,4 - 15,2
Silver Fir	–	10,3	6,6 - 11,0 - 17,2
Caucasian Fir	–	10,3	–
Common Silver Fir	–	8,3	–
Siberian Fir	14,5	8,8 - 8,9	–
Norway Maple	9,9	–	11,3
Mahogany	10,0	–	13,5
Walnut	10,5	11,5	12,5
Scots Pine	–	9,0	6,9 - 12,0 - 20,1
Siberian Stone Pine	9,5	9,5 - 11,5	–
European Spruce	13,5	8,5 - 9,4	7,3 - 11,0 - 21,0
Siberian Spruce	–	9,7 - 9,8	–
Black Poplar	11,0	10,8	9,1
Canadian Popolar	11,5	8,0	4,0 - 8,8 - 11,7

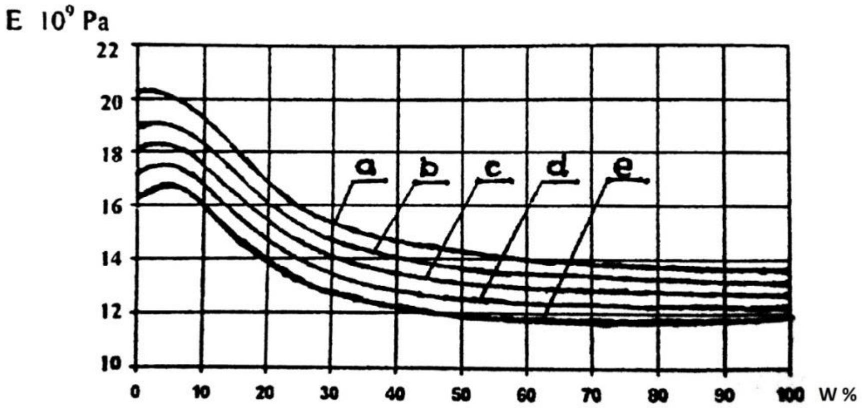

Fig. 4. Dependence of the modulus of elasticity from its density and moisture content [Kollmann and Krech 1960]. Where: a – 520 kg/m^3, b – 500 kg/m^3, c – 480 kg/m^3, d – 460 kg/m^3, e – 440 kg/m^3

Another significant factor influencing resonance wood and its acoustic properties is a growth ring arrangement. Growth rings are never starred perfectly perpendicular. Kulikov [1939] considers that the correct growth ring arrangement is a priority feature of good resonance wood.

In practice, violin makers are forced to use wood with densities and elastic modules falling within wide limits of variability. Hill [1975] argues that even the "Stradivarius could not afford such a meticulous material selection as violin makers today." This does not mean that this issue can be underestimated because the principles of resonance wood selection were also respected by the most important champions of violin making, but accurate measuring options were not available to them.

6. Acoustic properties of resonance wood

The task of the resonance box is not only to amplify the amplitude of the acoustic wave produced by the vibrating strings but also to properly shape the quality of this wave, which affects the quality of the sound of the entire instrument following the accepted aesthetic requirements. The whole process should take place in the shortest possible time and enable the performer to freely realize all the performance details, in particular in terms of intonation, dynamics, and timbre. The most important for implementing these performance aspects in terms of resonance wood are: the speed of acoustic wave propagation, acoustic resistance, and damping of the vibration energy of the resonance box [Harajda and Łapa 1997].

The speed of acoustic wave propagation depends on the elasticity and density of the wood (eq. 2). Since the modulus of elasticity in wood depends on the grain direction, the wave velocity is also different for different directions. The speed of the acoustic wave is also different for late and early wood due to their different density. It is necessary to indicate the wood moisture content and also the temperature and air humidity in the measuring room [Wegst 2006]. The speed of acoustic wave propagation is not the only and sufficient criterion to assess the suitability of resonance wood, but of course the higher the speed of the wave, the better - it has a positive effect on the sound of the instruments. It is however one of the most important factors in the evaluation of resonance wood used in the practice of violin making. For longitudinal waves in rod-shaped samples, the speed of acoustic wave propagation can be calculated from the formula [Harajda and Łapa 1997]:

$$c = \sqrt{\frac{E}{\rho}} \tag{2}$$

where:

c – speed of acoustic wave propagation [m/s]
E – the modulus of elasticity along the fibers [Pa]
ρ – density of wood [kg/m^3]

To measure the speed of acoustic wave propagation through wood, many luthiers use a device called *a Lucchimeter* which uses ultrasound to measure the time it takes for an acoustic wave to travel through the wood.

The energy of the vibrating string transmitted through the bridge and the resonant body spreads through the air in the form of an acoustic wave, and partly, due to friction inside the resonance plates and other parts of the body, is converted into thermal energy. A violin maker who builds an instrument to obtain the strongest and structurally richest sound possible treats this second part of the energy as wasted. The amount of wasted energy depends on the instrument's design and the selected material, while the conversion of the kinetic energy of vibration into thermal energy results from the friction of cell membranes of adjacent groups of cells. The water content in wood is of great importance for this process – the lower the water content the less energy is wasted. To present the degree of vibration damping, the logarithmic damping decrement is often used, which is the natural logarithm of the ratio of two successive amplitudes of freely decaying vibrations. It should be noted that this measure is a characteristic value for the entire vibrating system, and not only for the material itself. For practical purposes, the following equation (eq. 3) can be used [Harajda and Łapa, 1997]:

$$\delta = \frac{c}{\rho} \tag{3}$$

where:

δ – logarithmic decrement [$m^4 \cdot s^{-1} \cdot kg^{-1}$]
c – speed [m/s]
ρ – density [kg/m^3]

The logarithmic damping for the degree of vibration damping takes lower values for waves parallel to the direction of the fibers and higher for perpendicular waves. It also depends on the frequency of the waves. [Harajda and Łapa, 1997].

Table 7. The logarithmic decrement for parallel and perpendicular waves.

Wave frequency	logarithmic decrement (δ) for parallel and perpendicular waves	
	parallel	perpendicular
low	0.016 – 0.032	0.050 – 0.083
high	0.050 – 0.075	0.062 – 0.090

7. The influence of wood age on its acoustic properties

The optimal age at which a tree can be felled for resonance wood is considered to be 100 to 200 years, but not all support such old wood, believing that it gradually loses its elasticity [Panufnik, 1926]. Therefore, it cannot be assumed that the older the tree, the more suitable it is for violin making - there are opinions that after 150 years the aging process of the wood may begin and there are unfavorable changes in the sound of the violin making instruments made of it [Klein 1998]. Regardless of the age of the wood, it is still recommended to season the resonance wood for at least five years [Panufnik 1926] [Karoń 1969].

The chemical composition of spruce and maple wood aged 100 to 700 years was tested and the cellulose content remained unchanged regardless of the age of the samples, while in the old samples a lower lignin content was observed. Changes in physical properties over time were also studied - special attention was paid to moisture content and the coefficient of vibration damping [Yankovsky 1967] [Pischik, Felitov, and Burkovskaya, 1971] [Pischik 1971, 1972].

Fig. 5. Dependence of the energy loss coefficient η (η=δ/π) on relative moisture content H for spruce wood. [Pischik 1972]. Where: a – 150 yrs., b – 200 yrs., c – 300 yrs., d – 300-400 yrs., e – 500-700 yrs., s – limit for fresh wood.

Figure 5 shows the changes in the energy loss coefficient depending on the moisture and age of the spruce wood. Older wood has a lower loss coefficient, but it turns out that wood moisture content is a factor more significant than its age, although these are related parameters because wood hygroscopicity decreases with age [Obataya, 2017]. The research [Pischik 1972] shows, above all, the complicated nature of the interdependencies of various wood properties - they do not prove acontraindication to the use of old wood, but at the same time do not indicate the age of the wood as the most important quality parameter that is decisive in the selection of resonance wood. The observed changes in the sound of old instruments over time do not have to be solely the result of changes taking place in the wood - they may, however, occur as a result of the adaptation of individual parts of the instrument and the equalization of stresses [Čufar et al. 2017]. The age of wood is also related to the process of its relaxation - the process of decreasing physical stresses in the structure of wood related to the sagging of wood tissues and cell membranes over time [Topham 2000]. The time it takes the body to go from imbalance to internal equilibrium is called the relaxation time. The equilibrium state is different from the initial state, which significantly affects the quality of the sound, especially the timbre of the instrument. This should be borne in mind especially when it comes to new instruments. Achieving stabilization of all internal stresses of the new instrument is also favoured by playing these instruments [Kuryłowicz, J., 1984].

Conclusions

The in-depth analysis of scientific databases allows for establishing a list of several important parameters used to evaluate the quality of the resonance wood. The most important are among others: wood structure, moisture content, density, elasticity, speed of acoustic wave propagation, and degree of vibration damping. The quality of the resonance wood, together with the skills of the violin makers, is one of the main factors influencing the final quality of the string instruments.

References

Alkadivi A., Carlier C., Wahyundi I., Grill J., Langbour P. and Bremaud I., [2018] Relationships between anatomical and vibrational properties of wavy sycamore Sycamores. IAWA - Intern. Assoc. Wood Anatomists J. 39:63-86. https://hal.archives-ouvertes.fr/hal-01667816

Ashby M. F., Jones D. R. H., [2013]: Wood Structure and Properties. Engineering Materials 2: 494. https://doi.org/10.1016/C2009-0-64289-6

Barducci, J. and Pasqualini, G., [1948]: Misura dell' attrito interno e delle constanti elastiche del legno [Measurement of internal friction and elastic constants of the wood]. Zanichielli, Bologna.

Bieler, K., [1953]: Holz als Werkstoff. Fachkunde für das Holzgewerbe [Wood as a material. Expertise for the wood industry], Westermann, Braunschweig.

Bremaud I., Gril J. and Thibaut B., [2011] Anisotropy of wood vibrational properties: dependence on grain angle and review of literature data. Wood Sci Technol 45(4):735–754

Brémaud, I., Diversity of woods used or usable in musical instruments making. PhD thesis, Montpellier II University, Montpellier, France, 2006. Available ed.: https://www.researchgate.net/publication/278635491_Diversity_of_woods_used_or_usable_in_musical_instruments_making_Experimental_study_of_vibrational_properties_in_axial_direction_of_contrasted_wood_types_mainly_tropical_Relationships_to_features_of_mi/link/5b5511870f7e9b240ffd6c05/download

Bridge, M. [2000]: Can dendrochronology be used to indicate the source of oak within Britain? Vernacular Architecture, 31, 67-72. doi: 10.1179/030554700786049831

Bucur V., [1992] Anatomic structure of curly maple. Rev For Fr 44:2–8

Bucur V., [2006] Chapter 7—Wood species for musical instruments. Acoustics of wood. Springer, New York, pp 171–214

Buksnowitz C., Teischinger A., Müller U., Pahler A. and Evans R., [2007] Resonance wood [Picea abies (L.) Karst.]—evaluation and prediction of violin makers' quality-grading. J Acoust Soc Am 121(4):2384–2395

Capon, B. [2005]: Botany for Gardeners [2nd ed.]. Timber Publishing, Portland, pp. 66–67. ISBN 978-0-88192-655-2

Carlier, C., Alkadri, A., Gril, J. and Brémaud, I. [2018]: Revisiting the notion of "resonance wood" choice: a decompartementalised approach from violin makers' opinion and perception to characterization of material properties' variability. Wooden musical instruments - Different forms of knowledge: Book of end of WoodMusICK COST Action FP1302, 31 October 2018.

Čufar, K., Beuting, M., Demšar, B. and Merela, M., Dating of violins—The interpretation of dendrochronological reports. J. Cult. Heritage 2017, 27, S44–S54, doi:10.1016/j.culher.2016.07.010.

Dinulica, F., Albu, C. T., Vasilescu, M. M. and Stanciu, M. D., [2019] Bark features for identifying resonance spruce standing timber. Forests 10(799):1–19.

Dinulică, F., Stanciu, M. D. and Savin, A., Correlation between Anatomical Grading and Acoustic–Elastic Properties of Resonant Spruce Wood Used for Musical Instruments. Forests 2021, 12, 1122, doi:10.3390/f12081122.

Haines, D. W., [1979]: On musical instrument wood.

Harajda, H. and Łapa, A., [1997]: Akustyczne zagadnienia lutnictwa, cz. I: Dobór drewna [Acoustic issues of violin making, part I: Selection of wood]. Akademia Muzyczna im. I. J. Paderewskiego w Poznaniu.

Hill, W. H, Hill, A. F. and Hill, A. E., [1975]: Antonio Stradivari. Życie i dzieło (1644-1737) [Antonio Stradivari. Life and opus (1644-1737)]. Polskie Wydawnictwo Muzyczne, Kraków.

Karoń, J., [1969]: Poznaj skrzypce [Get to know the violin]. Polskie Wydawnictwo Muzyczne, Kraków.

Klein, P. and Pollens, S., The Technique of Dendrochronology as Applied to Violins Made by Giuseppe Guarneri del Gesù; Giuseppe Guarneridel Gesù: London, UK, 1998.

Kollmann, F. and Kreich H., [1960]: Dynamische Messung der elastischen Holzeigenschaften und der Dämpfung [Dynamic measurement of the elastic wood properties and damping]. Holz als Roh- und Werkstoff 18 [2], Febr., 41-53.

Krzysik, F., [1978]: Nauka o drewnie [Wood science]. Polskie Wydawnictwo Naukowe, Warszawa.

Kulikov, N. P. [1939]: Vliyaniye kososloya na kachestvo dechnoy drevesiny yeli [Influence of growth rings inclination on the quality of spruce timber]. Trudy NIIMP, Moskwa.

Michejda, Z., [1956]: Wstęp do technologii drewna lutniczego [Introduction to the technology of resonance wood]. Polskie Wydawnictwo Naukowe, Warszawa.

Panufnik, T. [1926]: Sztuka lutnicza [The art of violin making]. Wydawnictwo Kasy im. J. Malinowskiego, Warszawa.

Pischik, I. I., [1971]: Utochennaya formula dlya ocenki akusticheskikh svoystv drevesiny [Refined formula for assessing the acoustic properties of wood]. Listok Tekhn. Inf., 46, Moskva.

Pischik, I. I., [1972]: Vliyanie temperatury i vlazhnosti na akusticheskie svoystva i vyderzhannoy drevesiny [Influence of temperature and moisture content on the acoustic properties of aged wood]. Minist. Drevoobrabatyvayuschey Promyshlennosti SSSR: Lesn. Prom. 7. Moscow.

Pischik, I. I., Fefilov, V. V. and Bukovskaya Yu. I., [1971]: O khemicheskim sostave i fizicheskikh svoystvakh svezhey i vyderzhannoy drevesiny [About the chemical composition and physical properties of fresh and aged wood]. Lesnyi Zhurnal, 6, 89-93.

Schelleng, J. C., Wood for violins. Catgut Acoust. Soc. Newsletter 1982, 37, 8-19

Spycher, M., Schwarze, F. and Steiger, R. [2008]: Assessment of resonance wood quality by comparing its physical and histological properties. Wood Science and Technology, 42[4], 325-342. https://doi.org/10.1007/s00226-007-0170-5

Topham, J. and McCormick, D. A., Dendrochronological investigation of stringed instruments of the cremonese school (1666–1757) including “The Messiah” violin attributed to Antonio Stradivari. J. Archaeol. Sci. 2000, 27, 183–192.

Wegst, U. G. K., [2006] Wood for sound. American Journal of Botany 93(10):1439-1448. https://doi.org/10.3732/ajb.93.10.1439

Yankovsky, B. A., [1967]: Razlichiye akusticheskikh parametrov nievyderzhanoy i starinnoy drevesiny [The difference in acoustic parameters of unseasoned and antique wood]. Akustichesky Zhurnal, 13, 148-150.

List of standards

BN-69/9221-05 Drewno liściaste rezonansowe
BN-70/9221-06 Drewno rezonansowe z drzew iglastych
PN-D-95070:1956 Drewno rezonansowe z drzew liściastych
PN-D-95071:1963 Drewno rezonansowe z drzew iglastych
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BN-67/7111-14 Tarcica liściasta do wyrobu instrumentów muzycznych

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