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WOOD FOR THE GUITAR

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INTRODUCTION

The selection of materials for use in stringed musical instruments is undoubtedly one of the most important factors affecting their tone quality. Tradition dictates that materials are chosen from a narrow range of wood types. It is difficult to assess the acoustical merit of these choices, though measurements of material properties usually indicate that the choice is judicious. For example, European spruce, which is used for the soundboards of nearly all stringed musical instruments, is characterised by a high stifness, a low density and a low internal damping; these three attributes make it an ideal choice on purely acoustical grounds. But the reasoning for the choice of spruce is perhaps the exception rather than the rule, for whilst most other 'tone woods' have acoustically-desirable properties, one suspects that the overriding reason for their choice is the beauty of their appearance. Flamed maple for violins and Brazilian rosewood for guitars are two prime examples.

Instrument makers impose further stringent requirements on the selection of materials. Makers have established, by trial and error, a set of empirical rules which dictate which particular pieces of wood are selected and which are rejected. The acoustical foundation of these rules is much more firm. Wood which is skew cut (off the quarter) or exihibits significant fibre run-out is rejected, thus ensuring maximum stiffness, and grain spacing is used as an indication of stiffness and density. Experiments have shown that there is a high correlation between makers' choices and acoustical desirability [1]. Makers rarely use more than their trained hands and eyes to select materials.

The construction of an instrument also has an extremely important bearing on its tone quality. The thicknesses of the plates and sides, their sizes and the nature of the strutting (including the bridge) are the most important variables. Makers are usually very conservative about their constructional techniques, favouring tried-and-tested designs which they know will yield instruments of consistent qualities. Economically, consistency is much more important than producing the occassional 'superb' instrument, but then being unable to repeat it. A skilled maker is able to 'fine tune' individual plates to accommodate changes in their material properties. He is unlikely, however, to have a fundamental understanding of how to tackle a new variety of wood. Improvements are made to the design over long periods and the knowledge gained is all too often lost unless the maker works in the apprenticeship system.

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There have been many experiments by makers to introduce radically new designs or new materials. The acoustical reasoning behind these experiments is often muddled and confused, and the results are open to abuse and misinterpretation. A rare and thoughtful example of a good experiment is one undertaken by guitar maker Paul Fischer, who has investigated alternative materials for the back and sides of guitars [2]. He selected these woods based on his experience of the use of Brazilian rosewood. Measurements of the acoustical properties of these materials are presented in this paper.

The most important aspect of any experiment is to change only one variable at a time, hence the careful and consistent choice of materials by makers and thier general reluctance to depart from their favoured design. The greatest obstacle preventing easy interpretation of an experiment is the difficulting of being able to produce two identical instruments in the first place. This is an area where science might be able to provide some assistance. We are currently developing a numerical model of the guitar, which is able to predict the acoustical response of an instrument from information about its dimensions and the properties of the materials used in its construction [3]. This model effectively provides us with an infinite stock of exactly similar (or different) wood which can be worked to precise dimensions. The model has already provided valuable data concerning the importance of changes in plate thickness and strut heights.

In this paper my object is to review some of my own work which has involved measurement of wood properties. My principal interest has been to try to establish quantitative relationships between the materials and construction of a guitar and its final tone quality. My interpretaion of these measurements is, at times, in contradiction to commonly-held views, and I am led to a much more fundamental question of "just what sort of wood do we want for guitars?". The problem stems from the inevitable subjective evaluation of musical instruments. The sound of the guitar is 'fixed' by the attitude of musicians and makers, and this dictates to a large extent the materials suitable for its construction. They are not necessarily the most acoustically desirable.

Finally, it should be noted that this paper deals with the 'acoustical' properties of guitars, i.e. their dynamic mechanical action, and not their appearance, their feel, nor the stability and working properties of the woods. These latter quantities are extremely important to the success or failure of a guitar.

RESULTS AND DISCUSSION

Wood for the Soundboard

I have confined these measurements to European spruce, it being the most popular wood for soundboard construction. Table 1 shows measurements of the material properties of four samples of spruce used in guitars of my own construction. The measurements were taken from narrow strip samples cut along and across the grain from waste regions of the boards. This popular measurement technique is described by Haines [4,5], who gives examples of data derived from most of the common 'tone woods'. The measured quantities are the Young's modulii along and across the grain ($E_{\parallel}$ and $E_{\perp}$), their associated damping coefficients (logarithmic decrements) and the volume density (ρ). For a full treatment of orthotropic materials as found in guitars, the complex in-plane shear modulus (G) and Poisson's ratio (ν) are also required, but these cannot be obtained from strip samples [6]. Though incomplete, the data presented here are sufficient to give a good indication of the suitability and working of the materials.

Table 1. Mechanical properties of European spruce selected for guitar soundboards.

Sample	Density kg m^{-3}	Young's mod in MPa		Logarithmic decrement	
	ρ	$E_{\parallel}$	$E_{\perp}$	$\delta_{\parallel}$	$\delta_{\perp}$
No. 9	406	13040	380	0.020	0.067
No. 11	420	11140	1100	0.022	0.058
No. 12	403	12120	910	0.021	0.057
No. 13	518	13670	240	0.026	0.080
Haines *	460	13000	760	0.021	0.064

* Average measurement from Haines [4].

I used these measurements to assist in the working of plates Nos. 9, 11 and 12 and to try to achieve consistency in the final tone quality of the finished instruments. Relative thicknesses were calculated from values of $E_{\parallel}$ and ρ giving, respectively, working plate thicknesses of 2.6 mm, 2.9 mm and 2.8 mm. A similar treatment was carried out on the back-plate materials. Mode analysis of the finished instruments showed that a fair degree of success was obtained, though the effects of the low value of $E_{\perp}$ for sample No. 9 was evident at high frequencies. In retrospect, this defficiency might have been overcome by suitable bridge design.

Sample No. 9 would probably have been rejected by most experienced guitar makers because of its lack of stiffness across the grain, and sample No. 13 certainly would have been. This plate has been incorporated in an experimental instrument intended to service our numerical model. I was surprised to find that the plate gave a good response even though $E_{\perp}$ was extremely low. Perhaps the criterion for high cross-grain stiffness is not essential.

Finite Element Predictions

Table 2 shows results from our numerical model. The table demonstrates the effects of reducing $E_\perp$, but retaining all other properties constant. The effect, as would be expected, is to reduce the frequencies of modes which involve bending across the grain, and, to a lesser extent, those which involve twisting. Modes have been characterised as (n,m), where n and m are the number of vibrating regions across and along the plate. The calculations shown are for a plate without a bridge; the effects of reduced $E_\perp$ can be overcome to some extent by correct bridge design. The model has great potential for demonstrating the effects of changes in design and in material properties.

Table 2. Frequencies of top-plate modes calculated by the finite element method for two values of $E_\perp$. Other material properties were: $E_\parallel$=9225 MPa, ρ=420 kg m^{-3}, G=850 MPa and ν=0.37.

Mode	Frequency, Hz	
	$E_\perp$ = 852 MPa	$E_\perp$ = 426 MPa
(1,1)	200	197
(2,1)	260	248
(3,1)	361	330
(1,2)	450	445
(4,1)	484	424
(1,3)	589	583
(2,2)	612	601
(5,1)	643	549
(3,2)	759	735
(6,1)	834	701
(1,4)	862	855
(4,2)	891	844
(7,1)	1001	826
(6,2)	1301	1159

Materials for Backs and Sides

Makers usually speak in terms of the back of a guitar being 'a reflector of sound', but mode analysis of guitars shows that both the top plate and back plate exhibit similar resonance phenomena. At low frequencies some important interactions occur between the two plates, and correct matching of the plates is essential to 'normal' tone production. At higher frequencies the influence of the back is much reduced [7].

Brazilian rosewood, the most highly prized wood for guitars, is now in short supply. This prompted guitar maker Paul Fischer to investigate viable alternative materials. He selected seven woods worthy of further study and constructed guitars from these materials. We had the unique opportunity to analyse four of these instruments, and the following comments are based on these investigations as well as public reaction to the instruments at a demonstration in London in 1984.

Table 3 shows measurements made on samples of the selected materials. The most obvious similarities between the new woods and Brazilian rosewood is their high densities and low damping. For an acoustical reflector, a high ratio of $(E/\rho)^{1/2}$ is required. If this is indeed what is required, Orehla de Onca stands out as the best on an acoustical basis, and yet this particular instrument was not rated highly in comparison with the other six. The most favoured instruments were those made from Princewood and Kingwood, the two worst 'reflectors' of sound.

Table 3. Mechanical properties of alternative materials selected for backs and sides by guitar maker Paul Fischer [2]. Samples of Brazilian and Indian rosewood are shown for comparison.

Species (Common name)	Density kg m^{-3}	Young's mod in MPa		Logarithmic decrement	
	ρ	$E_{\parallel}$	$E_{\perp}$	$\delta_{\parallel}$	$\delta_{\perp}$
Cordia Trichotoma (Princewood)	793	8240	4670	0.035	0.047
Swartzia (Aruda)	838	17830	-	0.025	-
Zollernia Illicifolia (Orelha de Onca)	1095	26780	3320	0.015	0.038
Piptadenia macrocarpa (Angico)	824	-	2000	-	0.040
Machaeriam villosar (Santos Palisander)	909	15090	3560	0.022	0.051
Dalbergia cearenis (Kingwood)	1012	7670	-	0.026	-
Ferreira spectablis (Brownheart)	892	23000	-	0.019	-
Dalbergia nigra (i) (Brazilian rosewood)	1025	16770	-	0.018	-
Dalbergia nigra (ii) * (Brazilian rosewood)	830	16000	2800	0.017	0.038
Dalbergia latifolia * (Indian rosewood)	730	13000	2400	0.023	0.042

* Measurement from Haines [4].

The experiment by Paul Fischer is open to a number of interpretations. For example, the plates were worked to the same dimensions, irrespective of the different values of E and ρ. Further experiments might show whether or not the plates could be worked more simpathetically to exhibit the same vibrational characteristics as a rosewood plate. Ultimately, this is the wood against which all others will be compared.

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