ONE WAY TO KEEP WOOD FROM GOING THIS WAY AND THAT

Can chemical treatment make wood more reliable for instrument makers?

By Roger M. Rowell

While the acoustical properties of wood are adversely affected by moisture, they can be stabilized and improved through chemical modification. This technology may provide the means to produce quality wooden musical instruments from common, inexpensive, native woods without having to rely on tropical hardwoods whose quality has been going down as their cost has been going up.

The moisture content in wood depends on the relative humidity of the environment the wood is exposed to. This is because the wood cell wall contains biopolymers (carbohydrate polymers of cellulose and hemicelluloses and phenolic polymers of lignin) that contain hydroxyl and other oxygen-containing groups that attract moisture (hydroscopic) through hydrogen bonding. This moisture swells the cell wall and the wood expands until the cell wall is saturated with water (fiber saturation point). Moisture beyond the fiber saturation point is free water in the void structure and does not contribute to further expansion. This process is reversible and the wood shrinks as it loses moisture. The hemicelluloses are the most hydroscopic polymer in the cell wall, followed by lignin, the surface of cellulose, and finally the crystalline cellulose molecule itself.

The properties of wood are different in all three growing directions (anisotropic) of the tree: lengthwise (longitudinal), from the center out (radial), and along the annual rings (tangential) (Figure 1, 17).

The density of wood varies from lower values (for southern pine, 0.33 g/cm^3) in the earlywood (cells added in the spring) to higher values (for southern pine, 0.70 g/cm^3) in the latewood (cells added in the summer and early fall). The higher the density the more swelling that will occur when moisture is added to the cell wall. Latewood cells swell about twice as much as earlywood cells. Since the tangential cell wall is thicker than the radial wall, more tangential swelling occurs than radial swelling. Volumetric tangential swelling is in the range of 8-12%, radial 4-6%, and, in most species, no swelling occurs in the longitudinal direction (8).

Cellulose, hemicelluloses, and lignin are distributed throughout the wood cell wall, and each layer varies in the proportion of these three polymers (Figure 2). The middle lamella is mostly lignin; however, the bulk of the lignin content in the whole cell wall is in the S1, S2, and S3 layers. The S2 layer is the thickest layer and has the highest carbohydrate content. Cellulose, along with minor amounts of hemicellulose and lignin, constitutes the microfibrils, which are oriented in different directions in each cell wall layer. Microfibrils in the S2 layer are nearly parallel to the cell axis and swell mainly in the transverse direction as moisture increases. Microfibrils in the S1 and S3 layers are oriented more perpendicularly to the cell axis and tend to restrain transverse swelling of the cell wall in much the same way as cross-laminated veneers do in plywood. These restraining forces define the elastic limit of the cell wall and do not allow the wall to swell beyond a certain limit.

Figure 3 shows how this difference in swelling and shrinking affects the way wood is cut for musical instruments (17). Tangential grain direction is kept to a minimum to minimize changes in the wooden members dimensions. Because of the variability in swelling both in different wood directions and in different species, it is important not to mix grain directions or species when constructing a wooden musical instrument.

It is impossible to restrain wood from

Figure 1: Cross-sectional view of wood:
R=radial, T=tangential, L=longitudinal, X=transverse.

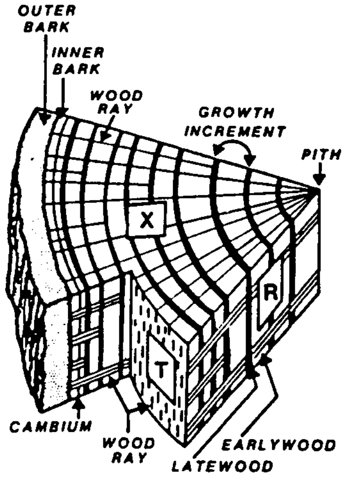


Figure 2: Schematic of the general wood-cell wall architecture:
P=primary wall, S1; S2, S3=layers of the secondary wall;
ML=middle lamella.

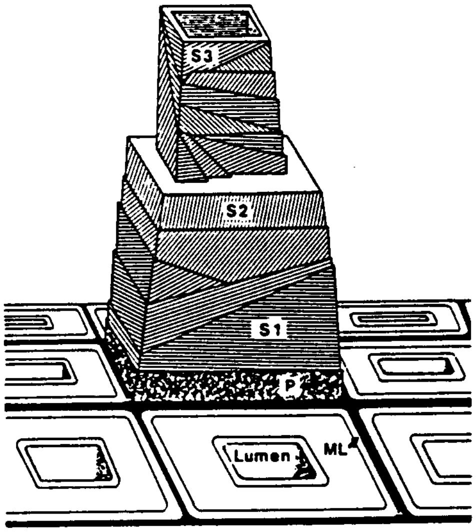
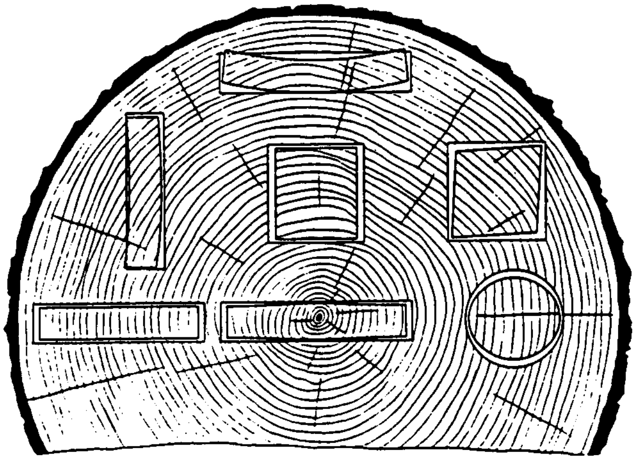


Figure 3: Characteristic shrinkage and distortion of flats, squares, and rounds, as affected by the direction of the growth rings.



swelling. The swelling pressure of wood is very large. Stamm reported a theoretical swelling pressure of 1,630 atmospheres or 24,000 lb/in^2 (14), and Tarkow and Turner found an actual swelling pressure of about half that value (16). The reason for the difference between theoretical and actual is that Tarkow and Turner did not compress the wood before measuring swelling pressure, so part of the release in pressure was into the void structure. The ancient Egyptians took advantage of this swelling pressure to quarry large stones by drilling holes for the desired size stone, driving dry wooden stakes into these holes, then adding water. The wood expanded and the swelling pressure of the wood split the rock from the face of the mountain.

Wood is a visco-elastic material in that it contains both crystalline components (about 70% of the cellulose molecules), which are more elastic, and non-crystalline components (about 30% of the cellulose, all of the hemicelluloses, and the lignin), which are more viscous. What this means in acoustical terms is that sound travels faster through the more elastic or crystalline portion of wood and more slowly through the more viscous or noncrystalline portion.

The sorption of water molecules between the wood cell-wall polymers acts as a plasticizer to loosen the cell-wall microstructure, which increases the viscose properties of wood (1, 12, 19). This affects the tone quality of wooden musical instruments because, as the moisture content increases, the acoustic properties of wood are reduced or dulled. As mentioned before, water molecules in the cell wall also cause the wood to swell, which increases the deformation of wooden parts. This is particularly bad for parts that are under stress caused by, for example, the strings of guitars and violins, the pin block in a piano, and in joints of instruments.

Historically, wood that takes advantage of natural qualities of that particular species has been selected for musical instruments (15, 13, 5). For example, Sitka spruce is selected for soundboards due to tight, uniform grain. Rosewood, teak, ebony, and bubinga are used for woodwinds due to their high content of waxes/oils/resins to reduce the rate of moisture sorption. Woods that are not naturally high in these are usually treated with penetrating oils and varnishes to reduce the rate of moisture sorption.

It is also possible to change the cell wall polymers chemically to decrease moisture sorption through reduced hydroscopicity, to improve dimensional stability to reduce swelling and shrinking, and to increase the elastic properties of wood for a more responsive instrument.

It is possible to reduce the hydroscopicity of wood by modifying the hydroxyl groups in cell wall polymers so they do not bond with water. Dimensional stability can be improved by bulking the cell wall with chemicals in such a way that the elastic limit of the cell wall has been reached, so that additional moisture does not cause swelling to occur. If moisture cannot plasticize the cell wall, the viscous properties are not increased. It is also possible to fill the void space (lumen) in the wood structure with a monomer that is polymerized *in situ* to exclude moisture, reduce the rate at which moisture can penetrate into the wood cell wall, and, if the polymer is hard, improve the elastic properties (9).

Many reactive chemicals have been used to bond to cell-wall hydroxyl groups (7). One chemical system that is easy to use is the reaction of acetic anhydride with wood-and the final product safe to come into contact with (10). The accessible hydroxyl groups are replaced with an acetate group that contains a by-product of acetic acid (vinegar). Since two things can not be in the same place at the same time, the acetate groups occupy space in the cell wall and swell it to almost its green volume after drying. The acetate groups are mainly reacted to lignin and hemicellolose polymers (11). The wood is not quite back to its original living volume, since the acetate group is larger than the water molecule. Only one acetate group can react with one hydroxyl group and no polymerization can take place. The result is a modified wood with greatly reduced fiber saturation

The ancient Egyptians took advantage of wood's swelling pressure to quarry large stones by drilling holes for the desired size stone, driving dry wooden stakes into these holes, then adding water. The wood expanded and the swelling pressure of the wood split the rock from the face of the mountain.

point and equilibrium moisture content, which shows that the hydroscopicity of the wood has been reduced.

The acetylation of wood slightly reduces both sound velocity and sound absorption when compared to unreacted wood (18). Acetylation greatly reduces variability in the moisture content of the cell-wall polymers, thereby stabilizing both the physical dimensions of wood and its acoustical properties. A violin, guitar, and piano soundboard have been made in Japan from such wood, along with a thin wooden diaphragm speaker system (4). A violin has also been made in Sweden from acetylated wood. The actual changes in sound quality of all of these instruments are presently being investigated.

In a second step, the acetylated wood can then be treated with a polymerizing monomer and using a chemical catalyst, polymerized in the lumen structure. The most common and easiest to work with is using methyl methacrylate (2). Using a cross-linking agent, a very hard cross-linked polymer is formed (Plexiglas) that almost completely fills the voids in the wood.

The result of this treatment is a filled structure that greatly reduces the rate at which water can enter the wood and act as a plasticizer to reduce acoustical properties (1). There is an increase in specific gravity as a result of the polymer, which has a slight negative effect on acoustical properties. The main advantage of this treatment, other than water exclusion, is that the polymethyl methacrylate polymer acts as a finish for the wood, so the finish is not only on the outside but throughout the entire wood structure.

A recorder was made by Thomas Boehm using hard maple that was first acetylated and then treated with methacrylate. Its acoustical properties are sustained through a wide range of moisture changes, and it has retained its tuning and tone quality without modification since it was made. It is presently being played and tested in Madison, Wisconsin. Trumpet and trombone mouthpieces are also being produced in Sweden using this dual process.

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