STSM Scientific Report

Purpose of the STSM

During my Bachelor thesis from January to the end of March, it was investigated how different volume fractions of the main components of the varnish would change the vibro-mechanical properties of wood. My main objective was to quantify the trend of changes in vibro-mechanical properties of wood after coating with different varnishes.

The aim of STSM was a complimentary study for evaluation of the three-dimensional extent of penetration of the laboratory cooked and master varnishes into the wood structure, at microscale, using a micro-tomography and microscopy setup. Understanding the structure-property relationship in varnished wood is an extremely important topic which contributes to a platform for engineering of a generation of high quality varnishes for string instruments. Furthermore it was interesting to see how properties change after drying of the varnish in the UV drying box for longer times.

Description of the work carried out during STSM

To get a better understanding I will give a brief overview of the experiment.

We prepared 60 wood specimens: 20 sapwood, 20 heartwood (Fig.2) and 20 radial samples (Fig.1). These numbers were calculated out of five samples per varnish (four different varnishes) and per direction of wood. Each longitudinal specimen had the same dimensions of 12 (R) mm x 2.5 (T) mm x 150 (L) mm. The dimension of radial specimens was 12 (R) mm x 2.5 (T) mm x 120 (L) mm. Also the conditions of the room were fixed at 20°C and 35% relative humidity, where the wood had to stay for a few weeks to reach the equilibrium moisture content.

Figure 1: 20 radial wood specimens of Norway spruce

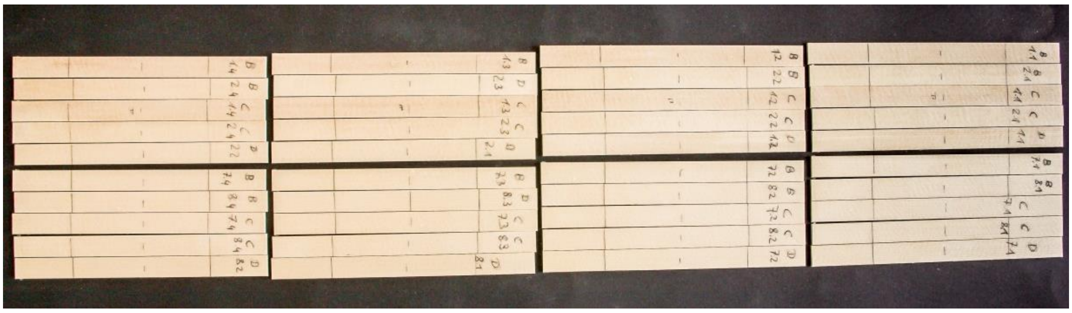

Figure 2: row of 60 longitudinal wood specimens of Norway spruce

After cooking the varnish, I measured all 60 raw wood samples to get a comparison between certain time periods. I applied the primer and after drying spread the four varnishes (two self-cooked varnishes and two varnishes of master craftsmen) on the samples. Due to the short time of our project we had to construct a varnish box with UV light to speed up the drying process of the varnished wood samples. This allowed us to imitate 24 hours of sunshine with flexibility in choice of drying time.

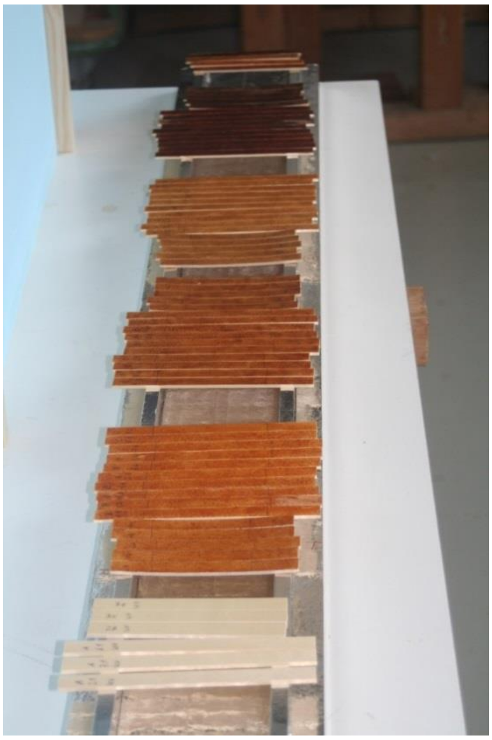

Figure 3: varnished wood specimens

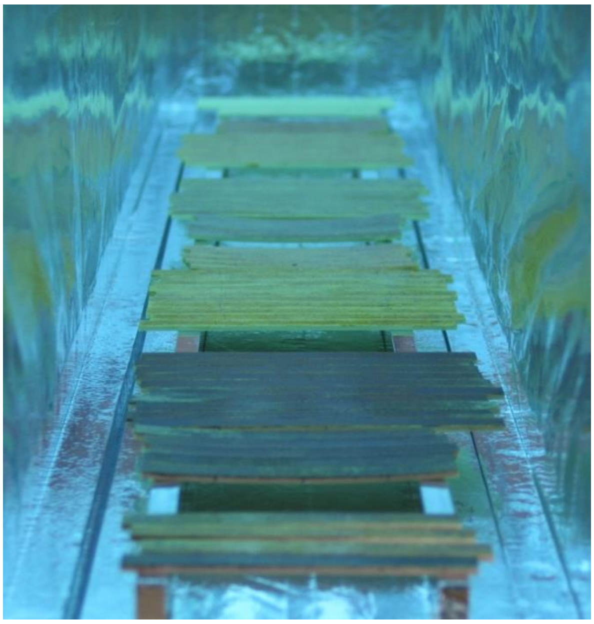

Figure 4: varnished wood specimens in the UV box

Due to the technical problems that occurred during the period of STSM at EMPA X-ray micro-tomography facilities, it was not possible to use the new setup, so there was no chance to do any analysis this way. Therefore I made some studies with the microscope. I took one sample of each varnish and viewed how deep the four varnishes penetrated into the wood. Furthermore I used the free-free resonance flexural vibration test to determine the damping (tan δ) and the resonance frequency (f_R) of the samples after eleven hours drying.

Description of the main results obtained

Varnish penetration into wood

For all four varnishes I could obtain a different penetration into the wood. Oil is getting more sucked into the porous structure of wood than resin. I could not manage to get the same viscosity for all varnishes. It might play a role for the deepness of penetration into wood. Still they have similar viscosities so we can see that varnish lab_2 with the highest amount has the deepest penetration (Fig.5). Varnish B. and H. are penetrating least (Fig.6, Fig.8) and varnish lab_1 was the most liquid one that might be one of the reasons for deep penetration of the one with the highest amount of resin (Fig.7).

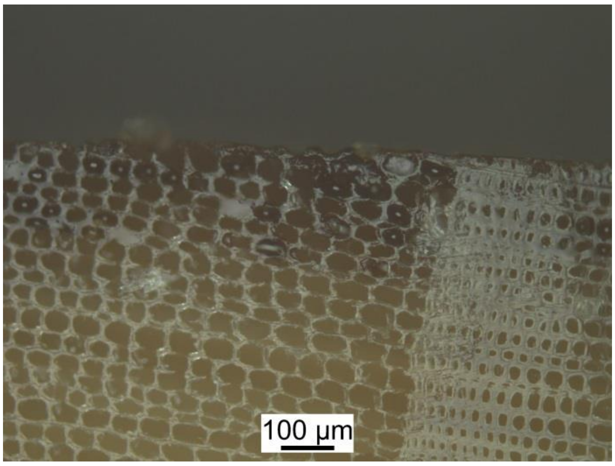

Figure 5: varnish lab_2; 50% resin 50% oil

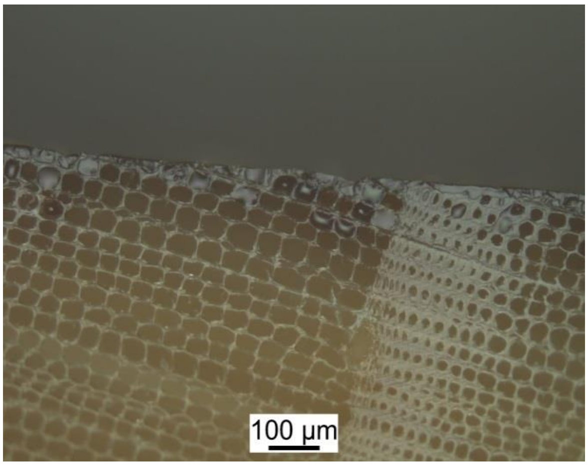

Figure 6: varnish B.; 60% resin 40% oil

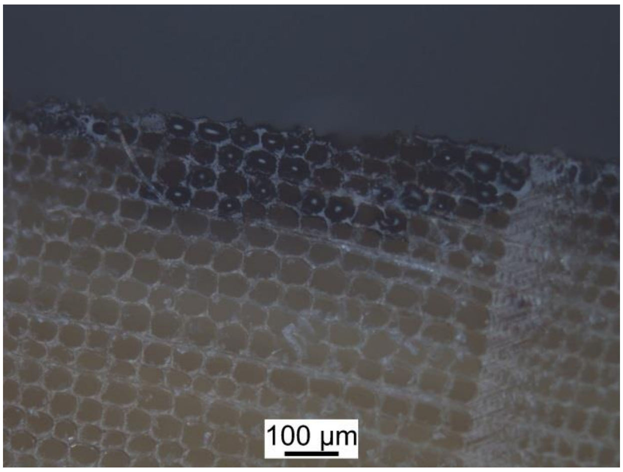

Figure 7: varnish lab_1; 73% resin 27% oil

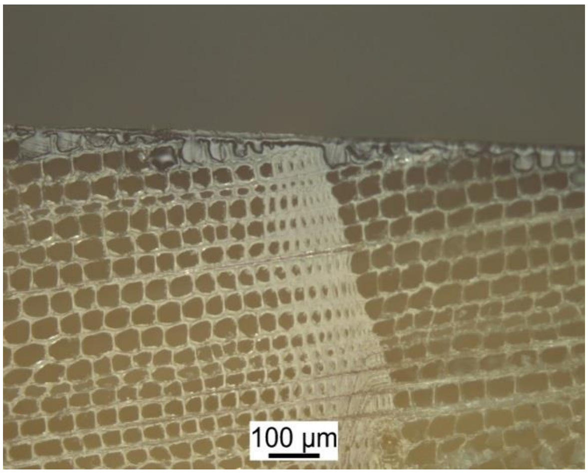

Figure 8: varnish H. 62% resin 38% oil

Influence of different varnishes to several vibro-mechanical properties:

specific modulus of elasticity

For specific modulus of elasticity we experienced a decrease in the longitudinal direction throughout all varnishes although we can see an increase during the drying process in the UV box for sapwood and heartwood compared to the raw material.

E’ of heartwood was slightly higher than sapwood before applying the varnish, but changes were almost identical as sapwood, after varnishing and after 11 hours UV treatment (Fig. 9). All varnishes have a positive effect in radial direction after UV, varnish H. showed the highest increase.

Varnish H. is one with the most amount of resin. Linseedoil remains a lot more flexible after drying than resin, which might be the reason for the higher stiffness.

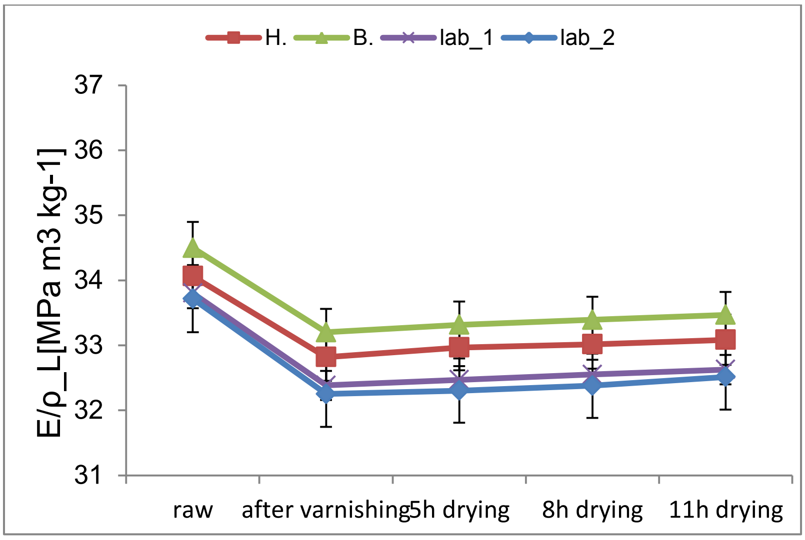

Figure 9: sapwood; specific modulus of elasticity (Mpa m^3 kg^{-1})

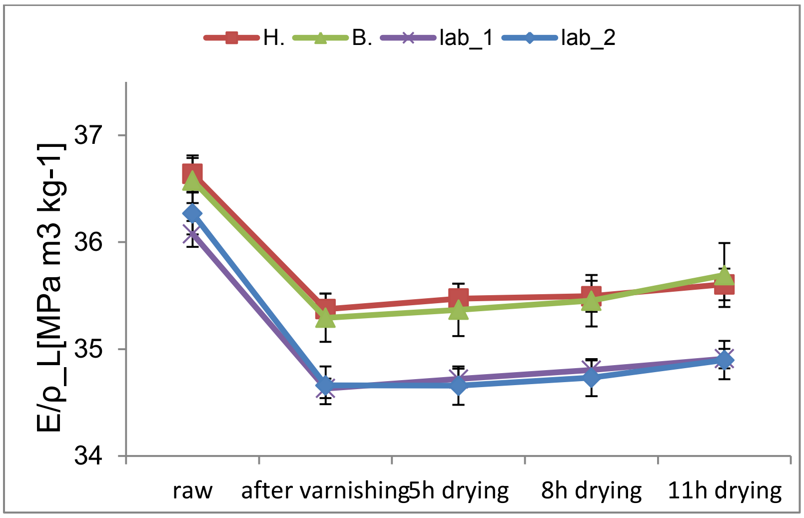

Figure 10: heartwood; specific modulus of elasticity (Mpa m^3 kg^{-1})

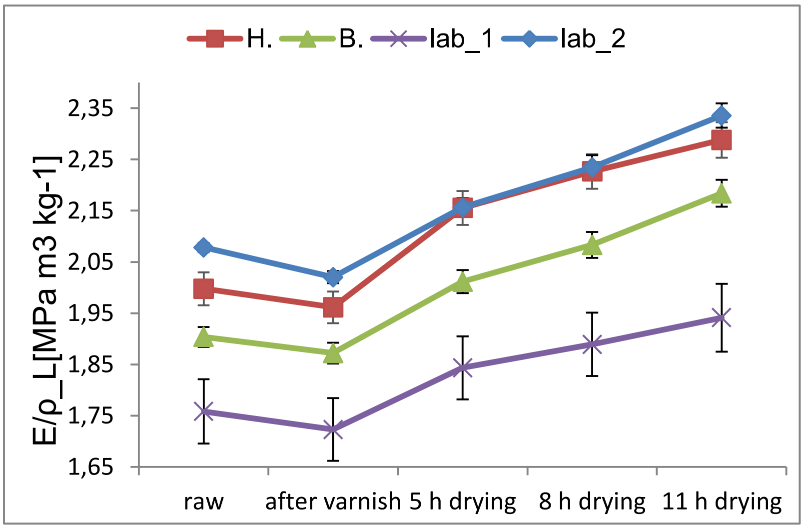

Figure 11: radial; specific modulus of elasticity (Mpa m^3 kg^{-1})

<u>Damping</u>

Musically the dynamic of the instrument is increasing with lower damping (Schleske 1998). The damping properties are negatively influenced for all varnishes in both directions.

For the sapwood they are increasing and approaching one certain value, except of varnish "H.", which does not take the usual run but is decreasing the damping after varnishing. Lab_2 stands out with its high damping.

Heartwood is supposed to be less permeable than sapwood. That means that varnish may remain on top of the wood surface not penetrating intracellular so much. Lab_1 has higher values for heartwood than for sapwood, varnish H. is not decreasing like at the sapwood samples. In our experiment raw sapwood has a higher density than heartwood. Wegst is quoting Sell in her paper: "In general, the speed of moisture sorption decreases with increasing density" (Wegst 2006). We can transfer this fact to the sorption of oil and assume that sapwood absorbs more oil. If wood soaks more oil, the curing process might take shorter because there is less varnish remaining on the wood surface. This again could explain why varnish B. (with a higher fraction of oil than varnish H.) has a lower damping increase for heartwood than for sapwood and vice versa for varnish H.

For radial samples treated with varnish H. and lab_1 are evolving in parallel in the second drying process. This can be related to the same percent friction of resin.

All in all varnish lab_1 is sticking out positively for radial samples. Oil is getting more sucked into the porous structure of wood than resin and this is why varnish lab_2, with the highest part of oil, might have the most negative effect on damping for all samples after 8 hours drying. After 11 hours curing process we can observe a decreas of damping except of varnish lab_1. Particularly striking is the decreas for varnish lab_2. Reason for this development is the total drying after 11 hours. Varnish H. shows the best results for sapwood .

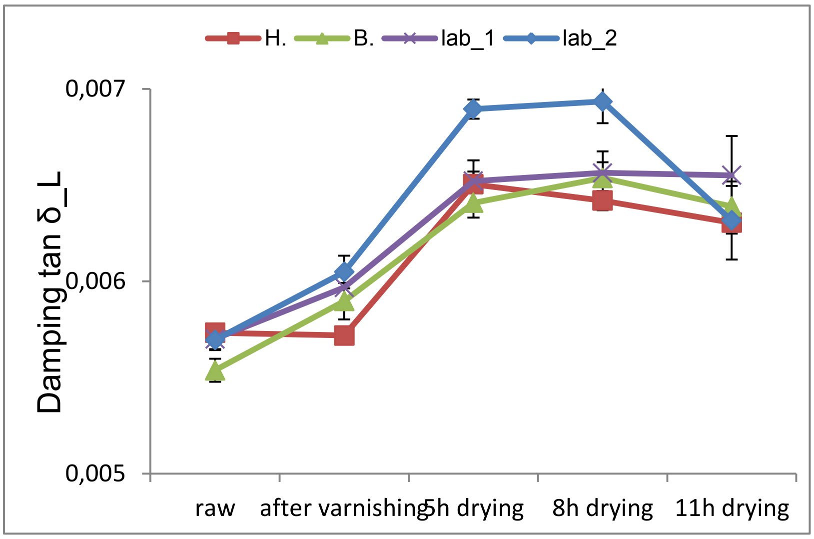

Figure 12: sapwood; damping

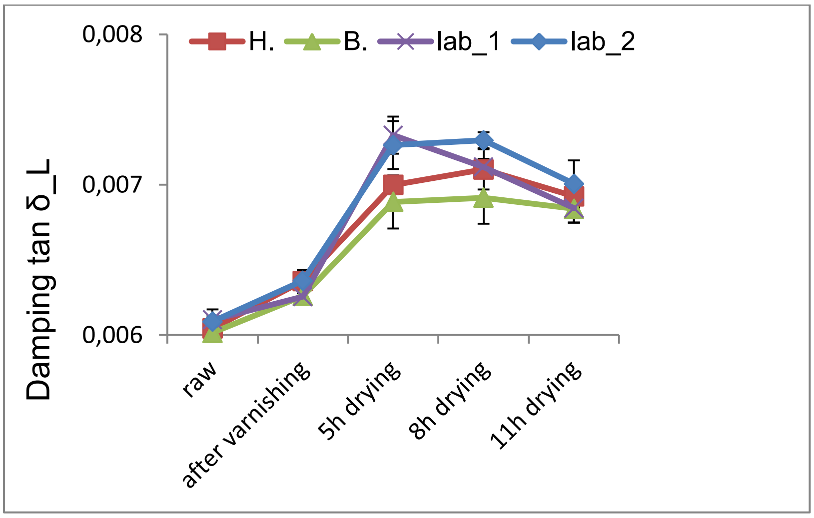

Figure 13: heartwood; damping

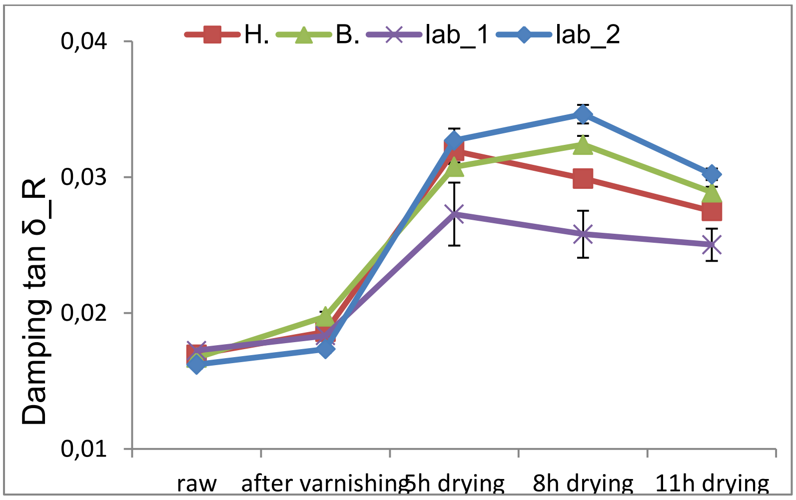

Figure 14: radial; damping

Sound velocity

Sound velocity is calculated by the root of the specific modulus of elasticity. Therefore the behavior is exactly the same. With an increase of both frequency and vibrational amplitude speed of sound would decrease (Wegst 2006). This creates a correlation with the quality factor Q and therefore with damping.

We have to wonder why E' and thereby c is increasing in the radial direction and not longitudinally. Young's modulus elasticity in the radial direction is only 1/20 to 1/10 of that in the longitudinal direction. We do not know the stiffness of varnish but it can be assumed that varnish in a dry state has a higher stiffness than transversal wood and thus transversal stiffness is increased after varnishing. The same approach is valid longitudinally, i.e. only with a decrease instead of an increase.

Again we can see a very positive development for lab_2 expecially for radial wood during the last curing process.

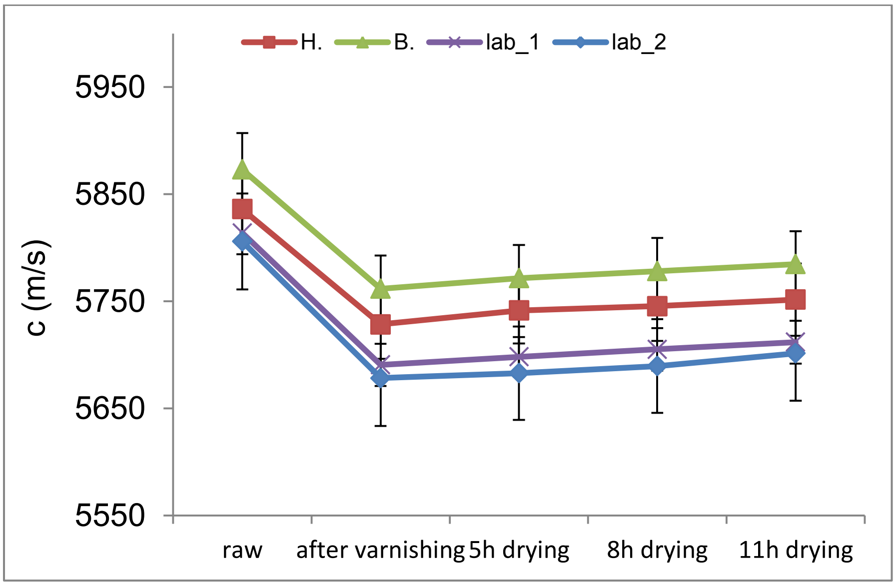

Figure 15: sapwood; sound velocity c (m/s)

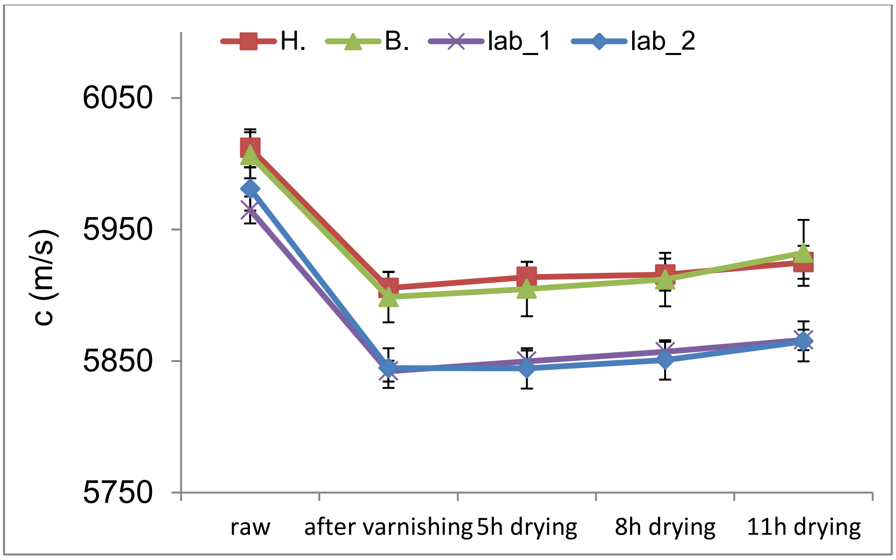

Figure 16: heartwood; sound velocity c (m/s)

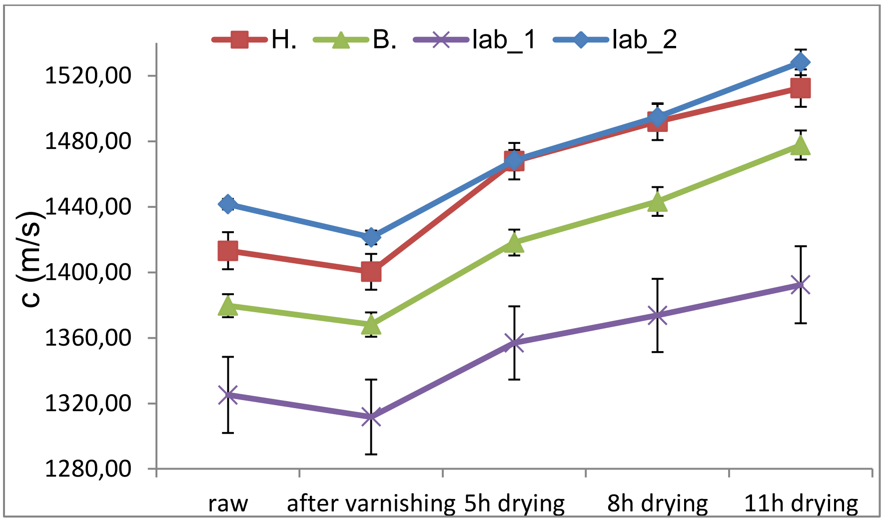

Figure 17: radial; sound velocity c (m/s)

Sound radiation

The sound radiation is linked very closely to the specific modulus of elasticity. It decreased after applying the varnish and increased again slightly after the curing process along the grain. In transversal direction we can notice a positive development for varnish H. and for varnish B. with. Lab_1 and lab_2 are not far from their raw value with a small decrease.

Sound radiation is correlated to the loudness of an instrument. By maximizing the amplitude of vibrational response of an instrument, R is increasing as well (Wegst 2006).

Small mass correlates with small density ($\frac{m}{V} = \rho$) and high sound radiation ($R = \frac{c}{\rho}$). If we want to enlarge R of the violin, the only way to reduce mass compared to the raw material, is to rework the wood thickness of the top plate. By explaining why the sound radiation for the wood in the radial direction is increased by drying we can argue with stiffness again. As seen before, stiffness in the transversal direction of the wood is increases after applying and drying varnish, so sound radiation increases as well, due to the following equation $\frac{\sqrt{E}}{\rho^3} = z$. The higher E and lower ρ, the higher the sound radiation.

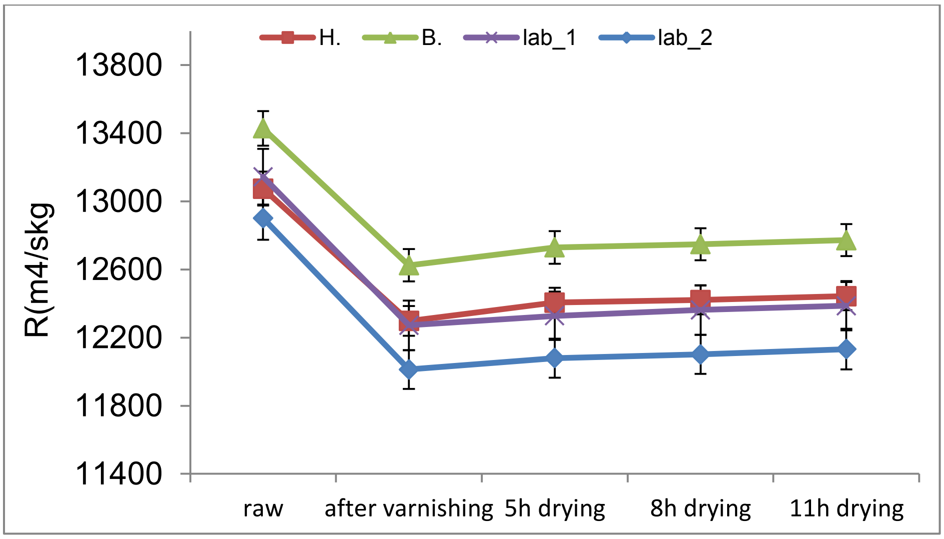

Figure 18: sapwood; sound radiation R (m⁴/kgs)

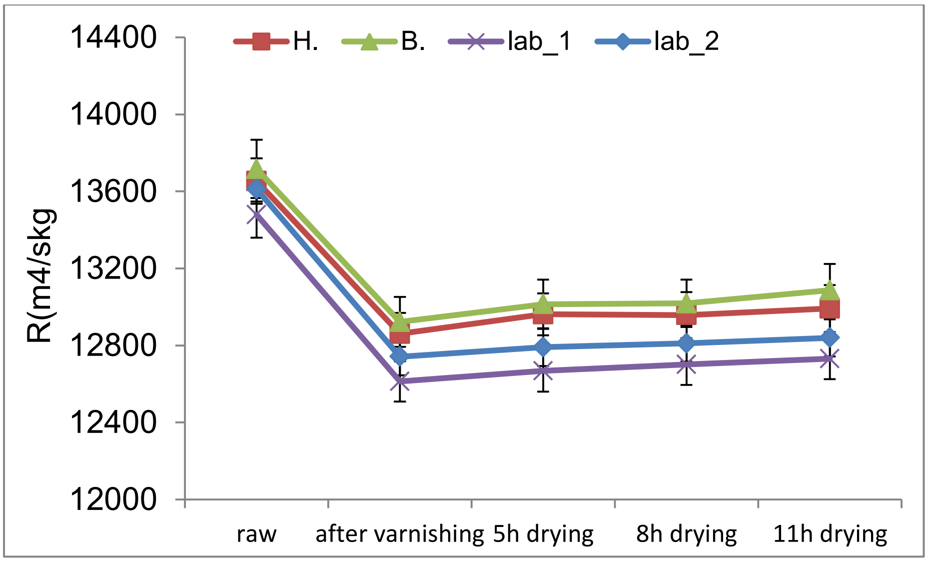

Figure 19: heartwood; sound radiation R (m^4/kgs)

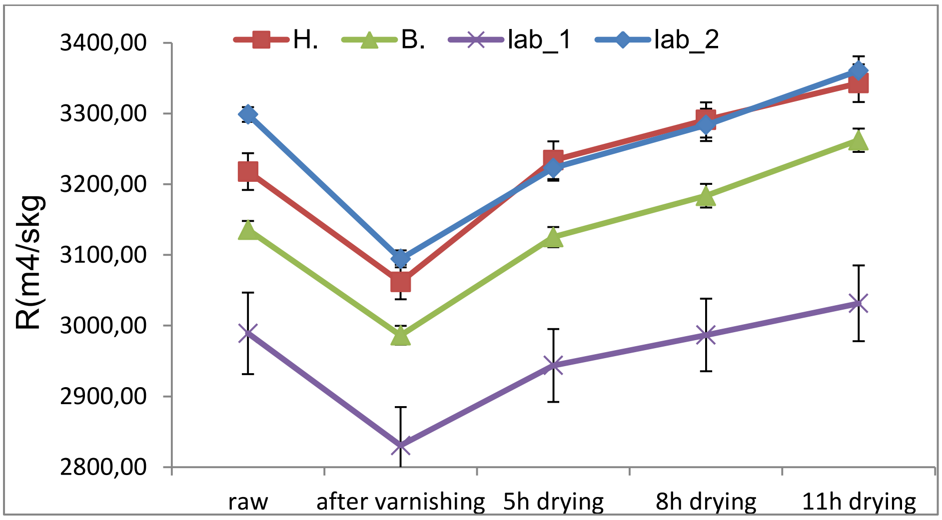

Figure 20: radial; sound radiation R (m⁴/kgs)

Characteristic impedance

The characteristic impedance is reversed to the properties formerly mentioned. Instead of a total decrease in longitudinal direction we can recognize an increase. In transverse direction we see a steady increase of impedance.

Wegst describes, that low impedance is important for transmission of energy from the string to the sound board by sending out the vibrational energy to another medium. The vibration would die straight away for high impedance. So the impedance of the sound board should be low for easily transmitting the vibration to the next medium and make the sound audible. However, impedance is increased by applying all varnishes in the beginning, decreased for longitudinal specimens after the first drying process and increased a little bit after 8 and 11 hours drying. The characteristic impedance for Radial specimens is climping up after each step.

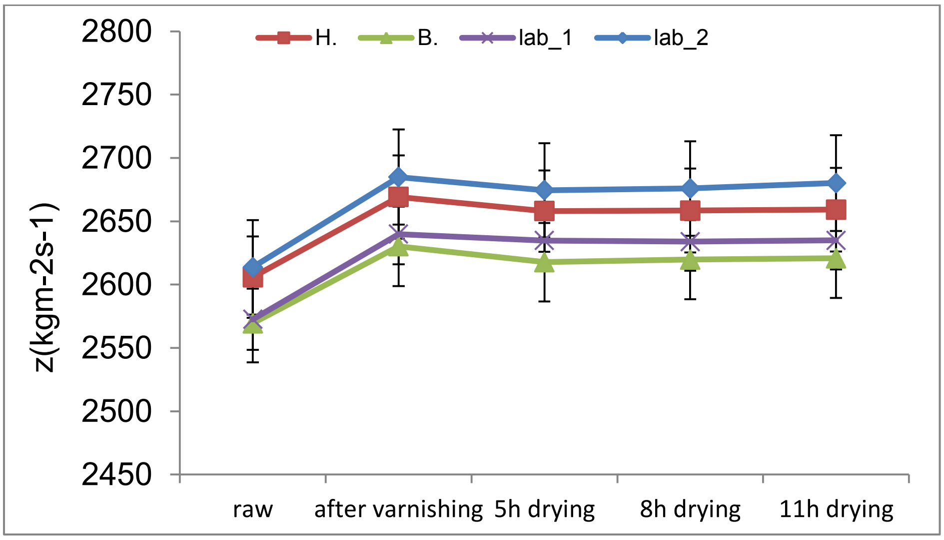

Figure 21: sapwood; characteristic impedance z (kgm^{-2}s^{-1})

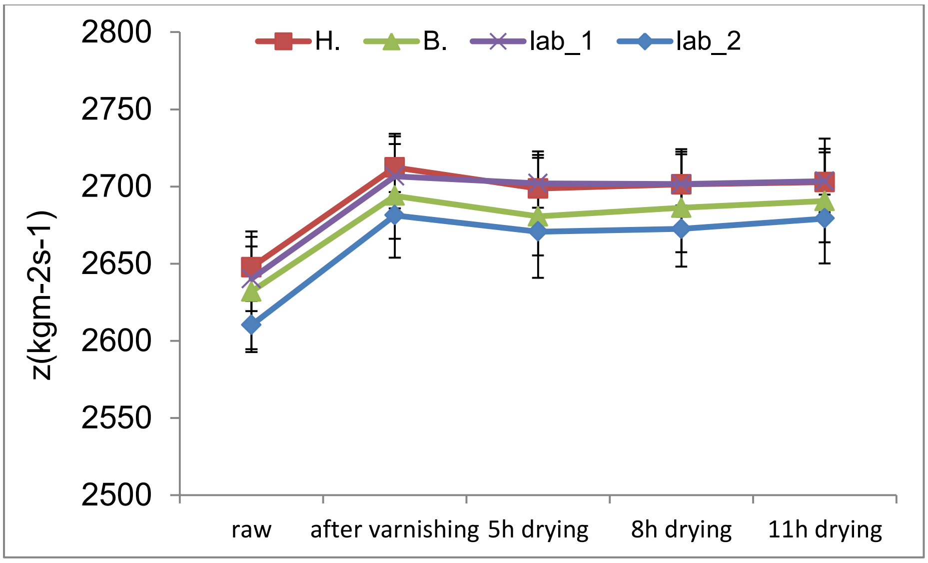

Figure 22: heartwood; characteristic impedance z (kgm^{-2}s^{-1})

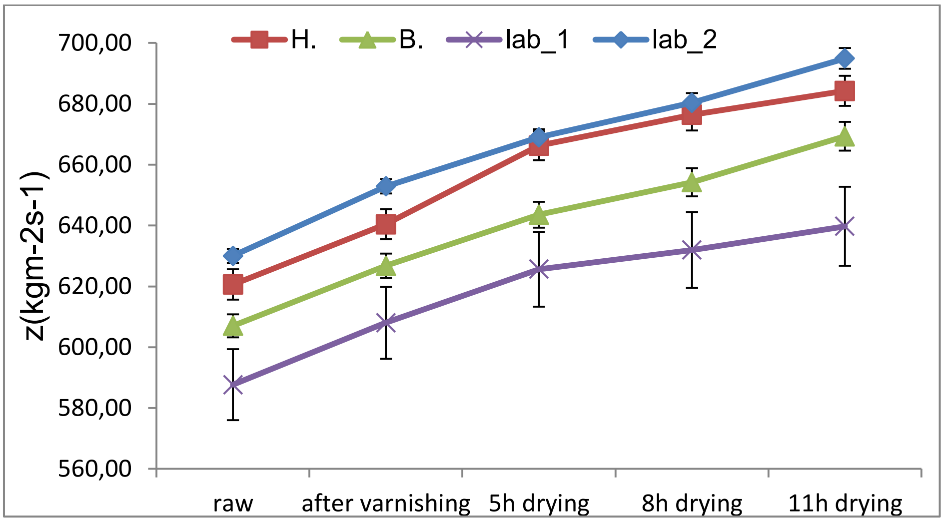

Figure 23: radial; characteristic impedance z (kgm^{-2}s^{-1})

All in all we can say that the development was keeping the direction it took before, except of the damping factor.

Future collaboration with host institute

It was a pleasure to continue the work of my bachelor thesis and thereby I could have an insight into scientific research.

I could imagine to collaborate with the host institution in the future like researching for the master thesis.

5. References

Schleske M. (1998): On the acoustical properties of violin varnish. Catgut Acoustical Society Journal 3, 15-24

Wegst UGK. (2006): Wood for sound. American Journal of Botany 93,1439-1448