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Cover art: Mount Fuji from the mountains of Tōtōmi, (遠江山中 Tōtōmi sanchū) from Thirty-six Views of Mount Fuji (富嶽三十六景 Fugaku Sanjūrokkei) by Hokusai Katsushika (葛飾北斎)

Changes in Color and Vibrational Properties of Wood Due to Accelerated Ageing

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ABSTRACT: Long term ageing affects the vibrational properties and color of wood, important factors for the quality of wooden musical instruments. In general, the rate of chemical reaction in wood during ageing does not only depend on the temperature but also on the humidity. Therefore, the effects of humidity should be clarified when we need to appropriately conserve and restore old musical instruments. Although it is difficult to obtain aged wood samples whose humidity history is clearly recorded, the effects of humidity during ageing can be reproduced by hydrothermal treatment under precise control of temperature and humidity. Thus, we investigated the effects of hydrothermal treatment at 120°C and various humidities on the vibrational properties and color parameters of Sitka spruce wood. Dynamic Young's modulus was reduced remarkably and mechanical loss tangent increased drastically when the wood was heated at high heating humidity (>88%). Such a particular effect of high humidity heating (steaming) was explained by the plasticization effects of depolymerized hemicelluloses remaining in the wood cell wall. It is considered that the vibrational properties and color of wood change in different manners during ageing, depending on the environmental humidity.

KEYWORDS: *Musical instrument, Ageing, Vibrational properties, Color, Hydrothermal treatment,*

1 INTRODUCTION

For musicians and artisans making wooden musical instruments, ageing is an efficient process to improve the acoustic quality and stability of wood. According to Noguchi et al., aged pine wood shows a higher sound velocity and lower loss tangent (tanδ) than newly cut one, while the rigidity ratios (Young's modulus divided by shear modulus, *E'/G'*) of woods of different ages are nearly equal [1]. Those changes with long-term ageing suggest that wooden soundboards become more resonant while maintaining their tone quality. Moreover, long-term ageing slightly reduces the hygroscopicity of wood probably due to the decomposition of hemicelluloses which are the most hygroscopic component of wood [2-5]. The reduced hygroscopicity is responsible for improved dimensional stability, and it indirectly stabilizes the mechanical and acoustic quality strongly depending on the moisture content. Those effects of ageing are similar to those induced by hydrothermal treatment, i.e., accelerated ageing at higher temperatures [6].

The effects of ageing have been explained as results of irreversible changes in wood polymers. However, recent investigations have suggested that the effects of natural and accelerated ageing can be partly reversed by moistening or rewetting the wood [7, 8]. Such a reversible change is explained by the physical ageing of wood polymers, and also, it can be related to the effects of seasoning and playing.

In this paper, the reversible and irreversible effects of hydrothermal treatments, i.e., artificially accelerated ageing on the hygroscopicity and vibrational properties of wood are reviewed to suggest the importance of humidity control for the conservation of old wooden instruments. In addition, the changes in vibrational properties and color of wood due to extraction in water are detailed to suggest the effects of water soluble decomposition residues on those properties relevant to the practical quality of wooden musical instruments.

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2 THE REVERSIBLE AND IRREVERSIBLE EFFECTS OF ACCELERATED AGEING [8]

In Figure 1, the equilibrium moisture contents (EMC) at 25°C and 60% relative humidity (RH) of artificially aged wood are plotted against the relative humidity during heating (HRH). The EMC is reduced by the artificial ageing, and is minimized by heating at 40-80% HRH. However, after the wood specimens are moistened in highly humid condition, the EMC significantly recovers and monotonically decreases with increasing HRH. That is, the reduced hygroscopicity of artificially aged wood is partly recoverable by moistening.

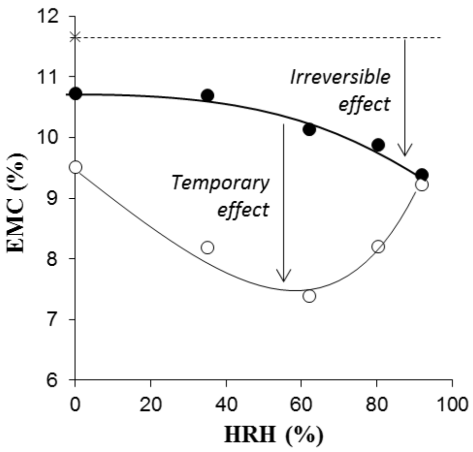

Figure 1: *Effects of HRH on the EMC at 25°C and 60% RH of artificially aged wood.*
Open circles, artificially aged at 120°C for 2 days; *filled circles*, artificially aged and moistened at 25°C and 100% RH; *cross and dashed line*, EMC value of unmodified wood

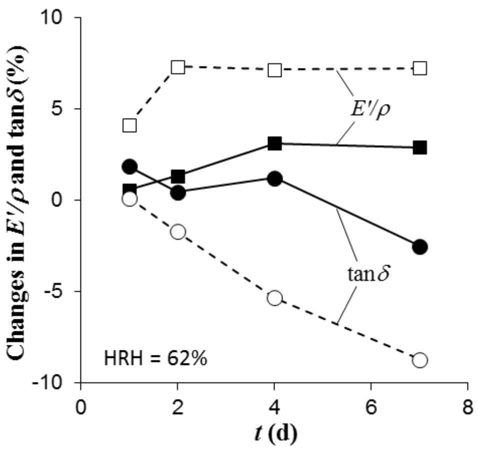

Figure 2: *Changes in E'/ρ and tanδ due to artificial ageing at 120°C and 62% HRH with the elapse of heating time (t).*
Squares, changes in *E'/ρ*; *circles*, changes in tan*δ*; *dashed lines*, artificially aged; *solid lines*, artificially aged and moistened

Figure 2 shows the changes in the *E'/ρ* and tan*δ* values due to artificial ageing at 62% HRH for over 7 days. The artificial ageing increases the *E'/ρ* and reduces the tan*δ*. These changes are fascinating for the efficient sound radiation from wooden soundboard. By moistening, however, the *E'/ρ* decreases and the tan*δ* increases. That is, the improved acoustic quality of artificially aged wood is fairly recovered when it experiences highly humid condition. Such recoverable or temporary effects of artificial ageing should be considered when we use the artificially aged wood for the repair or reproduction of old wooden instruments. To maintain the reduced hygroscopicity and improved acoustic quality of artificially aged wood, it needs to be kept in air-dry condition.

3 THE EFFECT OF DECOMPOSITION RESIDEUS ON THE VIBRATIONAL PROPERTIES OF ARTIFICIALLY AGED WOOD

Even after moistening treatment, the physical properties of artificially aged wood are more or less different from those of untreated wood. Such differences reflect the irreversible effects of the artificial ageing. In Figure 3, the relative values of tan*δ* and *E'/ρ* are plotted against the loss in weight due to artificial ageing (WL_h). By heating at low HRH, the tan*δ* remains unchanged or slightly decreases, and the *E'/ρ* slightly increases with increasing WL_h. On the other hand, when a wood is heated at 100% HRH, the tan*δ* remarkably increases and the *E'/ρ* significantly decreases. These facts suggest that the irreversible effects depend strongly on the HRH. The particular effects of high humidity heating (steaming) are presumably due to the effects of decomposition residue remaining in the wood cell wall.

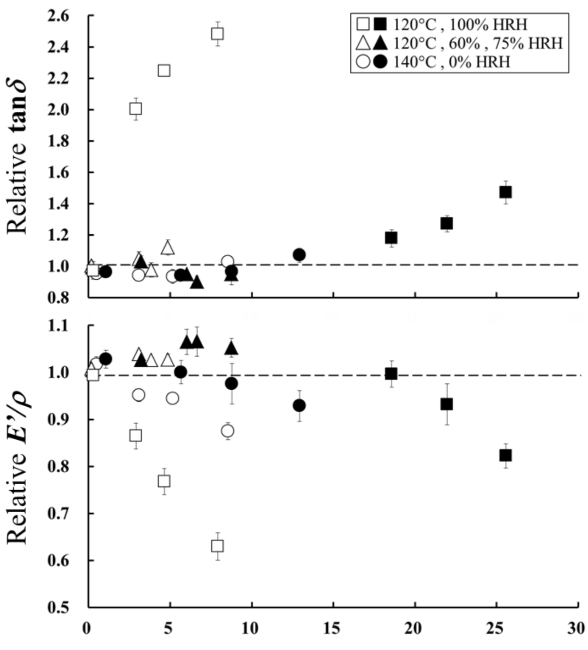

Figure 3: *Relative tanδ and E'/ρ values of artificially aged wood as a function of WL_h or WL_{h+e}.*
Dashed lines, relative value of unmodified wood; *error bars,* standard deviations; *open symbols*, artificially aged; *closed symbols*, artificially aged and extracted in water

According to Higashihara et al., steaming involves rapid depolymerization of hemicelluloses [9]. In addition, large amount of sugars in a reed (*Arundo donax*) is responsible for its abnormally large tanδ value [10]. From these results, we have speculated that hemicelluloses are depolymerized into low molecular weight sugars by artificial ageing at high HRH, and that those sugars increase the tanδ remarkably. To confirm that speculation, the tanδ and E'/ρ values of artificially aged wood specimens were measured at 25°C and 60% RH before and after leaching them in water at room temperature to remove the water soluble decomposition residues. In parallel, the extracted water soluble compounds (extractives) were analysed by using ion-chromatography.

In Figure 3, the tanδ and E'/ρ values of water-extracted specimens are plotted against the loss in weight due to heating and the following extraction in water (WL_{h+e}). After the removal of extractives, the tanδ of steamed (HRH=100%) wood decreased and its E'/ρ increased with additional loss in weight. In contrast, the water extraction affected little the tanδ and E'/ρ when the wood was treated at 75% HRH or less. Those results prove that the water soluble extractives remaining in the steamed wood are responsible for its extremely large tanδ and low E'/ρ values. In this case, the extractives act as a plasticizer in the wood cell wall.

Table 1: *The yields of monosaccharides in the water soluble extractives remaining in artificially aged wood.*

HRH (%)	Heating time (day)	WL_h (%)	Total Yields of extractives (%)	Yield (%)				
				Arabinose	Galactose	Glucose	Xylose	Mannose
0	12	3.2	3.7	0.1	0.1	0.0	0.0	0.1
60	10	3.9	4.7	0.0	0.5	0.5	0.4	1.4
100	2	3.2	12	0.4	1.5	1.5	1.3	4.6

Table 1 shows the yields of monosaccharides in the water soluble extractives isolated from the artificially aged wood. A large amount of sugars was detected only when the wood was heated at high HRH, whereas the WL_h was almost the same (3-4%). In the steamed wood, the dominant monosaccharide was identified to be mannose while the yield of glucose was less than 1/3 of that of mannose. Therefore, the water soluble compounds in the steamed wood are attributed to the decomposition residue of hemicelluloses.

4 THE EFFECT OF ARTIFICIAL AGEING ON THE COLOR OF WOOD

Here we describe the effects of artificial ageing on the color of wood. The color is an important factor determining the value of wooden crafts, and antique aged-like color is sometimes preferred for making string instruments such as violin. Heat treatment is a promising option to artificially modify the color of wood. Matsuo et al. clarified that time-temperature superposition can be applied to the change in color of wood due to dry heating [11]. In addition, Endo et al. has hypothesized that the time-humidity superposition is also applicable to the color of wood heated at different HRH [8]. However, little information is available for the influence of water soluble compounds remaining in the artificially aged wood. Thus, we have measured the color of wood specimens by using the CIELAB color parameters (L^*, a^* and b^*) before and after the extraction in water. In this color measurement, we have tested wood specimens employed in Endo's experiments [8].

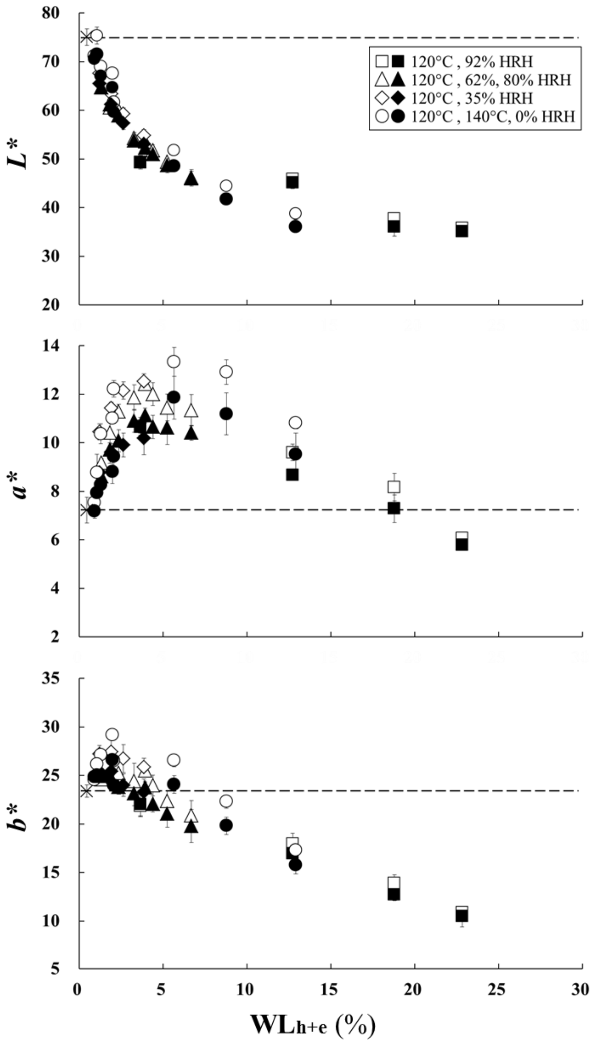

Figure 4: *Changes in L^*, a^* and b^* values due to artificial ageing and extraction in water plotted against WL_{h+e}.*
Crosses and dashed lines, the values of unmodified wood; *error bars,* standard deviations; *open symbols*, artificially aged; *closed symbols*, artificially aged and extracted in water

Figure 4 shows the color parameters of artificially aged wood plotted against WL_{h+e}. The L^* value decreased monotonically with increasing WL_{h+e} irrespective of HRH, and it remained almost unchanged by the extraction in water. On the other hand, the a^* value increased with increasing WL_{h+e} up to 5% above which it decreased. The b^* value also increased up to 2% WL_{h+e}, and then it turned to decrease. It should be noted that the a^* and b^* values were reduced by the extraction in water, and especially, the reductions were significant when the wood was heated dry (HRH = 0%). That is, the chroma of dry-heated wood decreases and it becomes grayish after the extraction in water, whereas the extractives content is very small. In contrast, the water extraction affects little the chroma of steamed wood in spite of large loss of extractives. These facts suggest that the water soluble extractives in the dry-heated and steamed wood are qualitatively different with respect to their effects on the color of wood.

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6 CONCLUSION

The reversible and irreversible effects of artificially accelerated ageing at different heating relative humidity (HRH) are reviewed. When a wood is heated at high HRH, its mechanical loss tangent (tanδ) steeply increases and its specific dynamic Young's modulus (E'/ρ) significantly decreases, because hemicelluloses are depolymerized into water soluble compounds acting as a plasticizer in the wood cell wall. After the removal of water soluble extractives the tanδ decreased and the E'/ρ increased. On the other hand, the water extraction affects little the color of steamed wood. The color change mainly depends on the loss in weight due to the artificial ageing and the following extraction in water, while slight decreases in a^* and b^* were recognized in dry-heated wood.

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