Conservation of the Mazarin Chest: structural response of Japanese lacquer to variations in relative humidity

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Abstract

Moisture absorption and diffusion, dimensional response, as well as the related stress field in materials constituting lacquer furniture were investigated to support the conservation treatment of the Mazarin Chest, renowned as one of the finest pieces of Japanese export lacquer from around 1640 preserved at the Victoria and Albert Museum in London. The measurements demonstrated that both the wood support and the lacquer adsorb considerable amounts of moisture and undergo dimensional changes which, when restrained, lead to mechanical damage. The domains of tolerable fluctuations of relative humidity (RH) are quite considerable in the mid-RH region: variations in RH in the current display environment of the chest at V&A are much smaller. The domains become, however, narrower at high RH levels. The lacquer layer, though retarding the water vapour diffusion into the wood, cannot mitigate the stress development in the object if the variations in RH become significant.
**Introduction**

The Mazarin Chest, renowned as one of the finest pieces of Japanese export lacquer to have survived from around 1640, is a star item in the V&A’s internationally acclaimed collection of Japanese art (Figure 1). A collaborative project was launched in 2004 to develop an integrated approach to the conservation of urushi (lacquer) objects that respects both western conservation ethics, in which concern with the treatability of objects is paramount, and Japanese conservation values, which seek to preserve the cultural continuity of objects by employing, as far as possible, materials and techniques similar to those used at the time of manufacture (Rivers 2005).

The choice of conservation treatment is being informed by scientific research (Mazarin Chest project 2007). Fluctuations in ambient relative humidity (RH) are considered to be one of the main factors that contributed to the past deterioration of the chest. They have caused cracks in the lid as well as damage and loss to the lacquer (Figure 2). Whilst losses are most dramatic on the exterior of the lid, it is a smaller crack on the interior that is causing most concern, as it has encroached onto an otherwise pristine surface. The damage has occurred in the areas where the wooden elements of the chest have a cross-grained construction. The damage mechanism is discussed in detail below.

Though instability of the indoor climate is indicated as a major cause of the deterioration of the lacquer objects (Miura 2000, Lambooy 2005), little systematic research to determine the response of the multilayered structure of the lacquer to RH variations has been undertaken (Ogawa and Kamei 2000).

This paper reports on moisture absorption and transport, dimensional response, as well as the related stress field in materials constituting lacquer furniture: wood of *hinoki* – Japanese cypress (*Chamaecyparis obtusa*) originally used for manufacturing the chest, ground layers and lacquer surface coatings. The primary aim has been to establish the principal damage mechanisms and to predict the RH conditions that are needed for the future in order to minimise further deterioration. In addition, we wish to understand whether sealing the edges of structural cracks with fresh lacquer, as would often occur in a Japanese conservation treatment, will act as an effective barrier against water vapour penetration into the adjacent wood.
Materials and methods

The following materials were investigated in this study: a defect-free, long-seasoned hinoki – Japanese cypress, a shitaji ground layer being a mixture of urushi and clay, and a surface lacquer layer. The dimensions of the wood specimen coincided with its principal anatomical directions – radial 2.5 cm x tangential 2.5 cm x longitudinal 0.3 cm. The dimensions of the specimens of the ground layer were 5 cm x 1 cm x 0.1 cm. The urushi finish layer was a ribbon 5 cm x 1 cm and 0.01 mm thick. All specimens were produced by Yoshihiko Yamashita, freelance lacquer conservator based in Tokyo.

Further, two samples of a historic lacquer layer, delaminating from a nineteenth century screen in the collection of the Victoria and Albert Museum, were investigated. One sample was taken from a surface exposed to light and the other from a surface sheltered from light. The different exposition was reflected in a marked difference in the gloss of the samples: the surface of the exposed sample was photo-degraded and therefore more matte than the unexposed one.

Moisture adsorption and desorption isotherms were determined for all materials studied at 24 °C and for a full range of RH. The measurements were done gravimetrically with the use of a Sartorius vacuum microbalance. Typically, a 0.05 g piece of wood or lacquer material was weighed and out-gassed prior to a measurement under a vacuum of a residual pressure less than $10^{-3}$ mbar to eliminate most of the species sorbed during their storage, especially adsorbed water. When a constant weight was obtained, portions of water vapour were introduced, and the respective mass increases due to the sorption and the corresponding equilibrium pressures were recorded. The process was fully automated and rapid. The equilibrium moisture contents (EMC) were calculated on the basis of the initial weight of the out-gassed sample.

The dimensional change in radial and tangential directions in the wood specimen was measured at 24 °C using two inductive transducers of accuracy 2 μm. The dimensional change in the urushi-based materials was measured in one direction. The measurements were taken in specially built specimen holders placed in a vacuum vessel. The vessel was connected to the same out-gassing and water vapour dosing system which was used to determine water vapour
sorption isotherms; in fact the two measurements were taken simultaneously. Both absorption and desorption branches of the dimensional change isotherm were recorded.

To determine moisture diffusion characteristics, a modified ASTM E 96-80 permeance cup procedure was used. The water vapour transport was measured at 23 °C for hinoki wood specimens of thicknesses varying from 3 to 20 mm, and 35 mm in diameter and a hinoki wood specimen 3 mm thick coated with a lacquer layer. The RH difference applied across the specimens was around 32% controlled by saturated salt solutions of potassium carbonate (43%) and sodium chloride (75%) placed in the measuring vessels.

**Response of lacquered wood to variations in relative humidity**

Isotherms of adsorption-desorption of water vapour are shown in Figure 3 for the hinoki wood and specimens of new and historic lacquer. There is a characteristic evolution of the isotherms reflecting natural aging of the lacquer material. New lacquer adsorbs less moisture reaching EMC of 7% at saturation i.e. at the RH close to 100%. The aged lacquer adsorbs more moisture with EMC at the saturation reaching 17% for the photodegraded historic sample. Further, the shape of the adsorption isotherm changes with ageing. The sorption of water on new lacquer can be described by the type I II isotherm in the IUPAC classification (Sing et al. 1985). The isotherm shows a gradual curvature convex to RH axis over its entire range with a significant water vapour uptake only in the high RH region. The shape indicates weak water-solid interactions with adsorbed water molecules located on infrequent, unevenly distributed active surface sites. As the water vapour pressure is raised the molecules built multilayer clusters around these most favourable sites. The sorption of water vapour on aged lacquer can be described by a curve which is intermediate in character between type III and type II by the same IUPAC classification. The latter indicates the monolayer-multilayer physisorption in which an adsorbed surface layer progressively thickens as the vapour pressure is increased up to the saturation pressure. The growing moisture uptake by the aged lacquer surfaces can be accounted for by an increase in concentration of the oxygen ions resulting from the light-induced oxidation of the urushi polymer. Similar tendencies show adsorption isotherms of water vapour on active carbons (Rouquerol et al. 1999) where a shift from the cluster adsorption to a continuous adsorbed water film occurs on an increase of the surface oxygen containing structures.
The sorption of water on wood, shown in the same Figure 3, is described by the type II isotherm and a hysteresis effect is observed, i.e. higher moisture content after desorption when compared to that after adsorption at any given RH value. The described features of water sorption on wood are widely known and discussed in wood science, and the data for wood species contained in historic objects have been recently given by Bratasz et al (2007). The amounts absorbed by wood and aged lacquer are quite similar especially at high RH levels. Wood is regarded as a highly hygroscopic material and aged lacquer has to be similarly regarded. More studies of various historic lacquer samples should further elucidate its hygroscopic characteristics.

Dimensional change is the most important consequence of moisture sorption by the wood support and lacquer in the lacquerware. The materials shrink as they lose moisture and swell when they gain moisture. Wood is anisotropic and its moisture-related dimensional changes vary in its three principal anatomical axes – longitudinal, or parallel to grain, radial, or perpendicular to the concentric rings of wood, and tangential, or tangent to these rings. The most pronounced moisture response is in the tangential direction, where wood swells approximately twice than in its radial direction; the dimensional response in the longitudinal direction is negligible. The relative dimensional change of the materials, or strain, is illustrated by their swelling isotherms. The tangential and radial dimensional changes for the hinoki wood are compared with those for various lacquer materials in Figure 4. An important observation from this comparison reveals that lacquer undergoes a considerable dimensional response on the adsorption of moisture which is nearly identical to that of the hinoki wood in the radial direction. As already mentioned above, the wooden planks used to construct the chest were cut in the radial directions as the Japanese urushi masters knew, as did their European colleagues preparing panels for paintings, that wood cut in the most responsive tangential direction is to be avoided. Therefore, both the wood of the chest and the lacquer move in nearly the same way in the direction perpendicular to the grain with moisture change.

The restraint of the dimensional change leads to stresses within a material, which can cause significant damage (Mecklenburg et al. 1998). If a relatively dry material is restrained from swelling in high RH, it can experience plastic deformation in compression with resulting crushing of the internal structure and buckling, or cleavage from the substrate in the case of a
surface design layer. In turn, if a wet material is restrained from natural shrinkage on a return to low RH, it will experience tension leading to irreversible stretching and eventual cracking.

There are two areas of restraint in the Mazarin Chest. One corresponds to assemblies of cross grained wooden elements. A particular adverse condition is created by the cleated (hashibami) construction of the lid (http://www.vam.ac.uk/images/image/40056-popup.html). The cleats have acted as a restraint to the planks, which is the underlying cause of cracks in the wood and lacquer layers illustrated in Figure 2. Further, the lacquer layer itself is fully restrained from dimensional change in the direction parallel to the grain. Upon desiccation, the lacquer layer shrinks and is high in tension whereas it swells and is high in compression upon increases in RH. If the uncontrolled changes in the dimensional change go beyond a critical level, the lacquer can crack or delaminate.

A crucial question arises at this point: at which restrained dimensional change are wood or lacquer at risk? The criterion selected for further discussion is that the strain of the materials considered should not exceed their yield points either in tension or compression. The yield point defines the upper limit of the elastic (reversible) region of a material’s performance. Loading the material above the yield point induces plastic (permanent) deformation. It is further conservatively estimated that the yield point for the polymeric materials such as wood, hide glue, ground layers in panel paintings is 0.4%. A similar value can be applied to lacquer. A discussion of the yield point criterion in assessing the allowable RH variations is provided by Mecklenburg et al. (1998). It should be noted here that the yield dimensional change is much lower than the breaking dimensional change which ranges from 1 – 2%.

Figure 5 shows examples of the allowable decrease in RH in two different RH ranges. It is evident that the risk of damage appears already for the RH decrease of 13% for the lacquer and 16% for the wood if the change occurs from high initial RH level of 90%. The variation starting from 50% RH can be as high as 41% for the lacquer and 25% for the wood, confirming the established observation of the conservation practice that the mid-RH level is the safest and that a transfer of sensitive objects from high- to low-humidity conditions can result in a climatic shock leading to damage, even though the new conditions may be considered closer to the museum standards for optimum preservation. The reason for that is the least slope of the dependence between RH and EMC in the mid-region of the water vapour.
adsorption isotherm. The domains of tolerable fluctuations of RH for the wood and the lacquer are shown in Figure 6.

**Diffusion of water vapour through the lacquer layer**

So far equilibrium moisture contents in the hinoki wood and individual layers building up the lacquer structure were analysed i.e. constant levels of moisture contents attained when materials are exposed to a given temperature and RH. However, moisture diffusion is not instantaneous and the lacquer layer can act as an additional barrier preventing the change in the moisture content of the wood beneath. For how long depends on the lacquer moisture diffusion characteristics illustrated in Figure 7. It shows the water-vapour transfer resistance of wood as a function of the specimen thickness, and the same parameter for a wood sample 3 mm thick coated with a lacquer layer. The layer slows down considerably the diffusion as it provides a resistance corresponding to an extra thickness of 52 mm of wood.

It should be stressed however that the delay in the response of wood to the environment change brought about by the presence of the lacquer layer reduces the risk of damage induced only by short-term variations of RH; in spite of the diffusion barrier provided by the lacquer wood equilibrates to the slow variations of RH, for example the yearly seasonal cycles.

**RH variations at the Victoria and Albert Museum**

Figure 8 shows plots of indoor RH in the lacquer storage area at the V&A. The RH data were sampled every fifteen minutes for one year and 0 on the time scale marks the beginning of the calendar year. The sampled data were smoothed by calculating the running average in the two adjacent one month periods to obtain the seasonal variability. The yearly average is 37%, a decrease to 32% in the cold period when heating is operating and an increase in the warm period up to 42% are observed. The short-term RH fluctuations, superimposed on the seasonal variations, stay within 5% throughout the year.

As one can see in Figure 6, the tolerable RH variations centred around 40% (yearly average in V&A) are fairly large and hugely exceed the variations recorded both seasonal and short-term. This means that both the wood and the lacquer are behaving in a fully elastic and reversible manner in its current storage environment: the change in RH would have to be much greater to endanger the chest.
Conclusions
The measurements reported in this paper have provided a useful insight about the behaviour of the lacquer objects in general, and the Mazarin Chest in particular:

• lacquer was proved to adsorb considerable amounts of moisture especially at high humidity regions, the adsorbed amount increasing for historic, naturally-aged material due to the formation of an increased amount of polar oxygen-containing adsorption sites

• lacquer undergoes a considerable dimensional change on the water adsorption which compares with the dimensional change of the hinoki wood substrate in the radial direction in which planks used in the chest construction were cut

• two areas of restraint have been identified in the Mazarin Chest. One corresponds to assemblies of cross grained wood elements; the other is the restraint of the lacquer layer by the wood support in the direction parallel to the grain. As the result, the object can suffer from mechanical damage if subjected to large, uncontrolled changes in ambient RH.

• the domain of tolerable fluctuations of RH is quite considerable in the mid-RH region and becomes narrower only at high RH levels

• both the wood and the lacquer is behaving in a fully elastic and reversible manner in their current display environment: the change in RH would have to be much greater to endanger the chest.

The main conclusion from the presented study is that the dimensional response of the wooden elements restrained by the cleated (hashibami) construction of the chest, as well as of the lacquer layer restrained by the wood support beneath are the principal factors bringing risk of mechanical damage. The lacquer layer, though retarding the water vapour diffusion into the wood, cannot mitigate the stress development in the object. Therefore, on physical grounds, no clear arguments could support the application of the urushi lacquer into structural cracks to prevent uneven uptake of moisture and thereby reduce future damage. Thus the selection of
materials for sealing, infilling or retouching should be guided by aesthetic or ethical considerations.

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**References**


**Fig. 1.** The Mazarin Chest (412 – 1882). Courtesy of V & A Images

**Fig. 2.** Damage areas in the lid of the Mazarin Chest. Courtesy of V & A Images
Fig. 3. Adsorption isotherms of water vapour for hinoki wood as well as new and aged lacquer at 24°C.
Fig. 4. Dimensional change of new and aged lacquer materials as well as the hinodki wood in the radial and tangential directions plotted as a function of the equilibrium moisture content (EMC).
Fig. 5. Examples of tolerable decreases in RH in the environment of a lacquer object for two RH ranges
Fig. 6. Domains of tolerable variations producing safe, reversible response of the wood and lacquer
Fig. 7. Water-vapour transfer resistance by wood (square) or wood coated with lacquer (star) plotted as a function of the specimen thickness.
Fig. 8. Indoor RH at the V&A during one year measured at fifteen minute intervals and a general seasonal RH tendency obtained by calculating the two-month running average of the readings. The yearly average is marked by a horizontal line.