Understanding the moisture induced fatigue damage in panel paintings: a methodological approach for quantifying the role of preparatory layers in the overall response

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This paper presents the development of an experimental methodology for quantifying the moisture related response of preparatory layers in the overall behaviour of panel paintings.

This research to date has focused on 14th century Southern European panels. Those consist of wooden boards on which preparatory layers, including size, canvas and gesso, have been applied to receive the painted image. The main layers in terms of thickness are the wooden board and the gesso, both of which are hygroscopic and drive the overall mechanics of the panel structure. Past research has looked into characterising theses layers and constituent materials in order to identify some of their properties [1]. Since then it has been shown that repeated fluctuations in relative humidity are associated with the cracking of preparatory layers [2]. Small repeated RH changes cause stresses within the structure, leading to deformation, cracking, delamination, flaking and eventually paint loss. Known as the fatigue damage, this may cause eventually a loss of the image. The importance of damage mechanisms in relation to the loss of legibility and original intent of a work has been acknowledged in the literature [3].

When subjected to fluctuating RH, the gradient of expansion and contraction occurring between gesso and wood have been held responsible for the fracturing of the gesso. However, the fatigue damage induced by moisture changes are caused by complex interactions between the wood and the preparatory layers of a panel. Not only is the wooden board subjected to a coupled effect such as mechanosorption, but a panel is also a multi-layer composite composed of several types of preparatory layers.

As complex composites, a methodology is required to identify the hygro-mechanical parameters causing the damage. To access the variables of such a model, it was first necessary to study the contribution of preparatory layers in the overall mechanics of a composite panel. To do so it was decided to use small replicas of 14th century panels. A survey of the existing literature pointed to the need of using historically based replicas as starting point of the analysis. This was key in trying to relate this research more closely to real panels.

The specificity of each painting and subsequent difficulty in identifying the exact mechanism responsible for the damage have been pointed out [4]. Specificities can be explained by regional differences in the making of traditionally constructed panel paintings, workshop practices and varying properties of the materials used according to their source and implementation. Technical examinations and study of contemporary treatises have supported existing differences and singularities in the course of the period studied. Furthermore, the physical history of each panel, including past interventions, has contributed to the difficulty in pinpointing factors and sources of degradation.

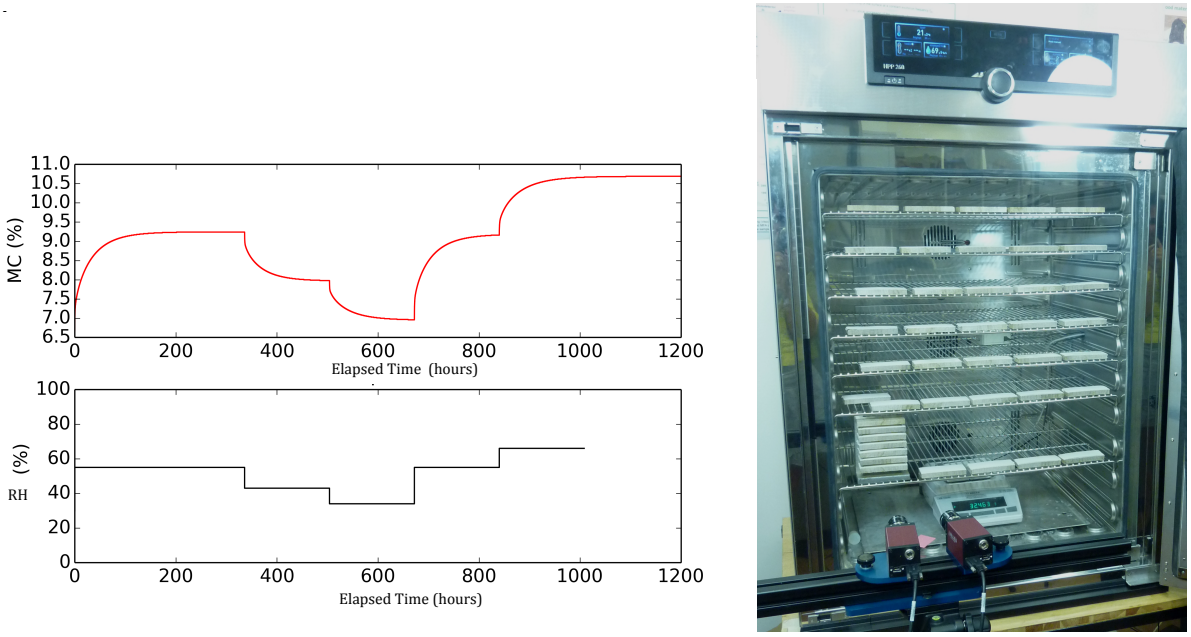
In facing such multiplicity, some factors had to be standardised and others were diversified. Quarter-sawn samples were cut from a seasoned board of white poplar (Populus alba L.) from the region of Florence, Italy. Technical examination, historical sources, and practical knowledge provided by workshops on replica making of early Italian paintings were used to select different formulations of gesso, thicknesses and layer structure [5] [6]. The materials chosen aimed at establishing comparisons with the existing body of research. Replicas were divided into groups according to their homogeneity in term of physical properties (same mean and standard deviation). This was done to limit the effect of the natural variability of materials such as the wood component in the analysis of the results.

Having produced a range of replicas both as free films and layered composite, their mechanical properties were evaluated. Testing included Beam Identification by Non-destructive Grading, four-point bending and tensile testing and results evaluated in relation to the published data on gesso layers. The modulus of the composite samples as well the tensile yield strain of free films of gesso was investigated. For the latter the aim was to provide data for comparison with the failure criterion (ie yield strain) of the gesso at 0.002 stated in the literature.

However mechanical testing of free films only allows for a characterization of a coating to some extent. It has been shown that strain to failure of a free film and strain to failure of the same coating on a substrate can differ [7]. It seems that factors to be accounted for included the adhesion effect and the restrained deformation of the coating by the substrate. Thus it was necessary to characterise the interaction of preparatory layers and wood when subjected to fluctuating relative humidity. To do so, composite samples were subjected to relative humidity steps in controlled environments (Figure 1). Resulting central deflection and strain distribution across samples were measured in detail using digital image correlation. Comparisons were made between sample categories and analysed in relation to the existing and suggested model of interaction.

Recording strain fields induced in selected historical preparatory layers coated on wood was successful using digital image correlation under hygro-loading (Figure 2). It allowed for a characterisation of key parameters involved in the moisture-induced damage to some extent. In combining analytical testing it was possible to identify heterogeneous behaviours depending on the type of preparatory layers. According to the existing linear model the gesso follows the shrinking of the wood but to a lesser extent, resulting in the gesso experiencing compressive strains. This standard model of strain does not represent a panel which has a heterogeneous and anisotropic structure. Other phenomena occur, such as bending, when the panel cups at the interface between preparatory layers and wood.

Further understanding of the mechanisms involved and the long-term consequences will allow stakeholders of cultural heritage to anticipate deteriorating conditions and inform standards of environmental control.



(a) (b)

Figure 1: (a) Hygro-loading set to the quarter-sawn replicas and their response in average moisture content, calculated by a numerical model TransPore [8]. (b) The climatic chamber with the digital image correlation set-up.

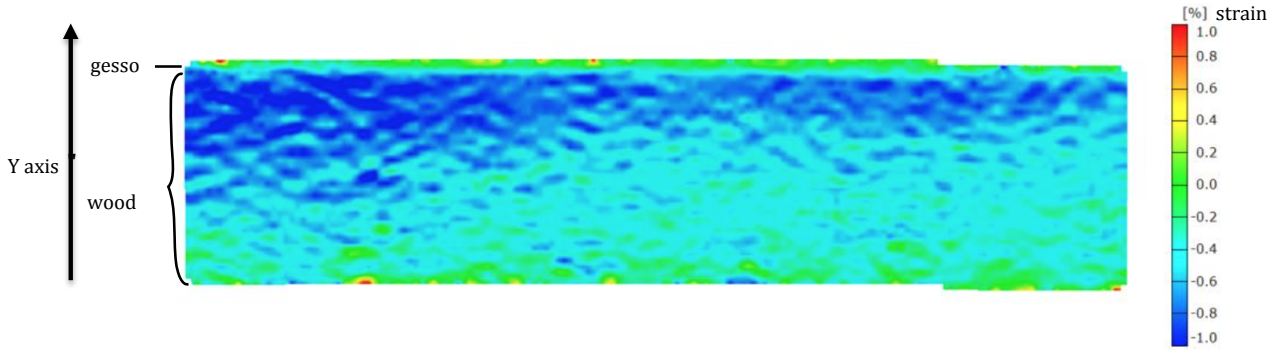


Figure 2: digital image correlation map showing strains along the y-axis for a sample coated with gesso.

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