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Original article

Moisture uptake and permeability of canvas paintings and their components

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ABSTRACT

Canvas paintings may show significant dimensional changes and experience internal stresses with fluctuating relative humidity. The relatively high and rapid absorption and drying of moisture within the different layers makes them more vulnerable than panel or wall paintings in comparable conditions. The dynamics of the moisture response is controlled by the water vapour permeability of the different layers. This paper presents a quantitative investigation of the vapour sorption and permeability of a selection of canvas painting components and of reconstructed paintings made of them. The selection of test samples was based on a survey of the materials used by Cuno Amiet in his early work and encompasses linen canvas, collagen glue sizing, chalk-glue ground and brown umber pigmented oil paint. Dynamic Vapour Sorption (DVS) tests were performed to obtain sorption isotherms. The vapour permeability was analysed in terms of the vapour resistance of layers and measured by means of wet cup and dry cup tests as well as in double chamber tests. The principle of incremental resistances was used to discriminate between the properties of the different layers. Whereas glue and canvas are comparable in being strongly absorbent, it appears that their vapour resistance is very different: a continuous glue film has a much higher vapour resistance than a canvas. In this context, we found that the method of applying glue sizing on a canvas influences the permeability of the resulting sized canvas: a gel size forms a more continuous glue film and hence leads to higher vapour resistance of the system, as opposed to a liquid size. Chalk-glue grounds have low moisture sorption, when compared to the high absorption of the proteinaceous glue, because they consist largely of chalk particles, which are not hygroscopic. The umber oil paint stands out for its low sorption and its high resistance to vapour transfer. These results characterise the highly heterogeneous nature of the multi-layered system of a painting in a quantitative way, enabling to better interpret damage phenomena and to make computational predictions of the influence of changing boundary conditions.

1. Introduction

Paintings on canvas are very sensitive to moisture: fluctuations in the surrounding environment, the use of liquid water or water vapour in conservation treatments, contact with liquid water due to hazards or condensation on the surface can lead to irreversible damage. The importance of museum climate for conservation has received a lot of attention over the past decades [1–3] and the response of canvas paintings in terms of deformation has been studied by several authors [4–6]. The differential behaviour of textile support, ground layers and paint layers, is thought to be a primary cause of damage. At very high relative humidity, a canvas may shrink while all other layers tend to swell; the stresses

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arising from this differential dilatation can lead to cupping [7,8]. The behaviour of a linen or cotton canvas on itself is already highly complex, the warp direction usually being more prone to deformation than the weft direction. Multiple factors such as weave density, yarn twist, crimp and warp and weft tension during weaving have an important influence [9–12].

While considerable research has been dedicated to the stress-strain behaviour and the chemistry of damage processes [5,13,14], comparative quantitative data on the moisture response of each of the layers of a canvas painting are rare. Worch (2007) carried out wet cup tests for an approximate determination of the vapour resistance of different layers used in traditional oil paintings. His results show the large relative difference between the more vapour-open canvas and preparation layers on the one hand, and the more vapour-tight oil paint and varnish on the other hand [15]. Detailed quantitative data is essential to understand the response of the complex multilayer system as a whole. This paper presents such a study, focused on a specific layered build-up which is typical for the early work of the Swiss painter Cuno Amiet (1868–1961). His oeuvre has been the subject of an in-depth art technological and art historical study in the recent past at the Swiss Institute for Art Research [16]. Amiet's choice of materials and his working methods during the investigated time span (from 1883 until 1914) were in many aspects typical for the international scene of that period. The materials are: flax linen canvas, proteinaceous glue sizing, chalk-glue ground and oil paint with umber pigment. The use of ground with a purely aqueous binder was popular among painters in Europe in the late 19th and early 20th centuries because its absorbent nature was believed to give a matte quality to the surface and long-term preservation of the luminous colours in the paint which was applied on top of it [16,17].

Recently there have been important advances in the understanding of moisture transport in textile, especially in advanced measuring techniques and numerical modelling [18]. Flax as a raw material, including its moisture sorption, has received renewed attention because of its potential use in new composites [19]. Moisture in proteins has been an important topic in the research on protein films in foodstuffs and coatings in pharmaceutics [20,21]. The moisture response of animal glue was studied in the context of its use with wood [22]. Literature on moisture sorption and permeability of oil paints goes back mostly to earlier research [23–25] (see [26] for a comprehensive review up till the date of publication). More recent work has concentrated on the possibilities of new or improved experimental techniques and numerical models [27–29].

The deformation of paintings is not the primary focus of this paper and is not taken into consideration when not essential to explain the observed moisture phenomena. The experimental results are only valid for the limited selection of materials, based on the criteria as mentioned above and specified below, even though many other materials have been widely used and could be equally relevant. A third important limitation is that we have studied young materials, which were naturally aged for a limited time ranging from 7 days to 3 months. It is known, but to our knowledge not studied quantitatively, that the aging of oil paints leads to an increased polarity and hence higher affinity to moisture [30]. Changes in the cross-linked structure and long-term degradation probably have an influence on permeability for solvents, including water.

The aim of this study is to perform a full experimental characterisation of the equilibrium sorption as well as of the vapour resistance of a selected set of materials, which form the layers of a reconstructed painting. The tests are carried out in such a way that we gain insight in the relative importance of these materials in the response of the full-layered system. The dependence of these properties on relative humidity is also taken into account. The final goal is to provide data that will first help improve existing preventive conservation strategies, and second allow a better selection of operational parameters in conservation treatments involving moisture exposure. Because of the complexity of the phenomena, the use of numerical simulations will be very useful to complement empirical and experience-based knowledge. We intend here to provide an adequate set of moisture-related material parameters to enable such simulations in future studies.

2. Materials and methods

2.1. Sample preparation

All materials were selected for being representative of those found on the early work of the Swiss painter Cuno Amiet (1883–1914) [16]. The particular interest for Amiet had arisen from the observation that this painter often prepared his own canvases by hand and that, in his paintings, damage related to water as a reagent or material transport vehicle was observed.

2.1.1. Canvas

The selected canvas is a medium coarse plain linen weave produced by Libeco-Lagae (Belgium) and distributed in loom state by Kremer Pigmente (Germany) under the name L515. It has a light sizing of a water-soluble wax on the warp yarns, which was washed out in cold water. The clean canvases were dried in ambient air and steam ironed. The yarn count after this preparative procedure was 16 counts per cm in warp direction and 15 counts per cm in weft direction, and the surface mass density was 372 g/m^2.

2.1.2. Glue sizing and glue film

Glue was prepared out of dried cow hide glue granules (Kremer Pigmente) and deionised water mixed in a ratio of 7 g of glue to 100 g of water. After overnight soaking at lab temperature, the mixture was heated to 40 °C and gently stirred until the mixed solution was homogeneous. The obtained glue was applied to the canvas in 3 different ways:

- as a warm liquid of 35–40 °C with a brush;
- as a room-temperature gel with a rubber spatula;
- as a cooled-down, stiffer gel at 15 °C, also using a spatula.

The aim was to study the differences in behaviour between canvases prepared in different ways. We do not have clear evidence as to which of these methods was favoured by Amiet.

Samples of separate glue film (i.e. not applied on canvas) were prepared using a calibrated film applicator (Erichsen) on siliconised polyester foil. For reasons of practical feasibility the glue mix for this particular purpose was richer in glue with respect to the glue used for sizing: 25 g of dried glue in 75 g of deinoised water. The glue was allowed to cool to about 25 °C and applied to the foil in wet thicknesses of 100, 150 and 200 micron. When dry, the glue film could be separated easily from the polyester foil.

2.1.3. Chalk-glue ground

A chalk-glue ground was prepared by mixing 1 part of white chalk powder (Champagne chalk, Kremer Pigmente) in 1 part of glue solution by mass. Contrary to known recipes [31], the ground was stirred by hand, instead of being left to soak, and then applied in 2 layers to the sized canvas using a brush. This practice leads to the formation of air bubbles, which is assumed to be realistic as such bubbles have been observed in hand-made painting grounds [32]. Samples of pure ground, i.e. not applied on a canvas, were produced by putting blobs of ground material on siliconised polyester foil, allowing them to dry in lab conditions and then removing them from the foil.