Using DIC to develop an Experimental Methodology for Measuring Moisture Induced Fatigue in Panel Paintings.

Dr Christina Young and Alice Aurand, Conservation & Technology Dept. Courtauld Institute of Art, Somerset House, Strand, London, WC2R 0RN. christina.young@courtauld.ac.uk

This research was aimed at developing an experimental methodology for measuring moisture induced fatigue in panel paintings. The testing included environmental cycling, four point bend fatigue testing and digital image correlation (DIC) to study the strain fields induced in historically accurate reconstructions of the underlying layers of fourteenth century panel paintings.

In the last five years there has been a re-evaluation of the environmental guidelines for the care of museums' collections [1, 2]. Panel paintings, alongside a wide range of works of art, are composed of hygroscopic materials, reacting to changes in ambient moisture. Thus there is a need for a better understanding of moisture induced damage mechanisms, in order to establish safe and sustainable environmental standards. Panels consist of wooden boards on which the preparatory layers have been applied to receive the painted image. Repeated fluctuations in relative humidity have been associated with the cracking of preparatory layers in panel paintings, this can in turn lead to delamination of the layers and loss of the image. The focus of this research was on panels produced in Italy in the 14th century. Preparatory layers at that time included a size of animal glue and a gesso, composed of animal glue bound in gypsum. Rabbit skin glue (RSG) was chosen as the representative material during this research. Material choices were aimed at establishing comparisons with the existing body of research.

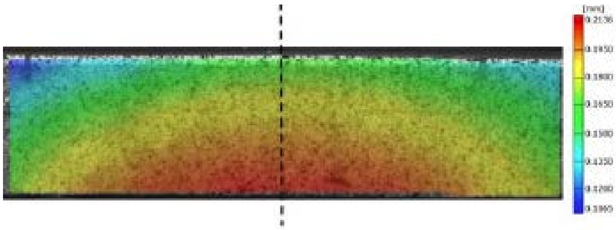
Delamination between preparatory layers and wood induced by repeated movements of the structure may produce mix-mode fracture I and II. Crack propagation in coatings usually follows a through-thickness pattern [3] and evidence of this has been found in composite structures of artist's materials, as well as interfacial cracks [4]. Recent research into panel painting deterioration has focused on moisture induced fatigue damage. The results and recommendations from this research have wide ranging implications. In particular, yield strains of the preparatory layers have been suggested as the failure criterion for panels, based on the lowest yield strain of their constituent materials. However, replicating fatigue caused by deformations induced by cyclic environmental fluctuations, equivalent to the age of the painting, is not feasible in a realistic timescale. An alternative is to use mechanically induced deformations for fatigue testing. Researchers have used uniaxial tensile fatigue to replicate the behaviour of panels, assuming in-plane contraction and expansion. The validity of this approach and whether four point bending produces strain fields that are more representative of naturally occurring warping was investigated with DIC. Digital image correlation has been developed over the past thirty years for the study of a wide variety of polymeric and hygroscopic materials [5], the technique has been applied in the field of conservation science, to measure strain fields in tapestries and panel paintings [6-8].

Forty six samples of wood were cut (100 x 40 x 10 mm and mean density 0.46 g/cm^3) from a single radial board of seasoned white poplar from the region of Florence. The uncoated samples were divided into seven homogeneous groups with regards to swelling rate and equilibrium moisture content. Different formulations of gesso, thicknesses and layer structure were applied in order to establish comparisons. The typical coating thickness was 2mm [9].

DIC 2D analysis was used for comparison of mechanically induced strain distribution, to moisture induced strain distribution. The strain distribution and central deflection induced by a single desorption from 55%RH to 40%RH of the most moisture responsive coated samples were measured. The deflection data was then used to reproduce the naturally occurring warping by static three-point and four-point bending, as well as dynamic fatigue four point bend. All quantitative and qualitative results were extracted using GOM-5M Aramis software. The DIC 100mm focal length camera lens was zoomed in on the central part of the sample in order to achieve a higher resolution across the gesso/wood interface (170pixels mm^{-1}). The gesso (2mm thick) was included in the correlation zone up to two thirds of its thickness.

The most significant DIC results were as follows:

To the authors' knowledge, this is the first time the strains across the wood/gesso interface have been measured.Curved vertical displacement fields were characteristic of an increased asymmetrical response of the composite samples depending on the type of coating (see Figure 1). This contrasts with the uniform displacement field of the uncoated samples with decreasing relative humidity (RH).



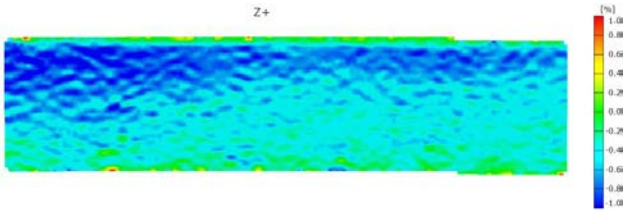


Figure. 1 Vertical displacement field at 40% RH equilibrium. Figure 2. Ey distribution at 55% to 40% RH.

At 40% RH, Ey strain concentrations were identified at 0.006, higher than the suggested criterion for failure of gesso of 0.002. For panels, it has been suggested that the upper layers will crack or delaminate induced by deformation of the wood if the strain induced goes beyond a critical strain. This critical level for panels has been defined as the lowest yield strain out of each of the materials present in the panel. Mecklenburg and Rachwal [10,11] who have suggested the yield strain of gessoes at 0.002.

The upper part of the gesso was mostly in tension with decreasing RH, whilst the wood immediately underneath was in compression, a gradient of decreasing compression occurred from the middle to the bottom of the wood (Fig.2). Published research (testing and modelling) on panels has assumed that all the wood is simply undergoes linear compression or tension with changing RH.

Increasing compressive Ex strains indicated strain fields driven by growth ring orientations, whilst decreasing compressive strains occurred from bottom to top of the substrate.

Static three-point bend and four-point bend did not reproduce the asymmetrical deflection occurring between the gesso and bottom of the wood when subjected to RH steps. The strain distribution induced showed some correlation with environmental induced deformation.

Cyclic loading during dynamic four point bending produced deformations similar to those occurring through moisture. Notably the gesso and wood showed distinct strain fields, exhibiting the interaction between the two layers seen during the RH steps. The difference between static and dynamic testing may relate to mechano-sorptive behaviour and creep. This requires further investigation.

This research has demonstrated the applicability of DIC to measurement of complex multi-layer structures. It has shown that a development in the failure criterion of the preparatory layers needs to take into account local strain distribution. The continuing research is focused on monitoring the samples during fatigue testing with different bending configurations and RH to more accurately replicate moisture induced fatigue.

[1] Kirby Atkinson, J. Environmental Conditions: Background to The Current Debate. Studies in Conservation. 59(4), 2014, 205-213.

[2] Michalski, S. Crack Mechanisms In Gilding. In: Gilded Wood: Conservation and History, Madison: Sound View Press, 1991. p171-181.

[3] Kim, S. and Nairn, J.A., Fracture mechanics of coating/substrate systems Part I: Analysis of tensile and bending experiments. Engineering Fracture Mechanics. 65(5), 2000, p573-593.

[4] Tantideeravit, S et al.,. Prediction of delamination in multilayer artist paints under low amplitude fatigue loading. Engineering fracture mechanics. 112-113, 2013, p.41-57.

[5] Muszynski, L et al,. Optical measurements of wood deformations under changing climate. In: Proceedings of 2002 SEM IX International Congress on Experimental Mechanics. Milwaukee, 2002, p 298-301.

[6] Lennard, F. and Dulieu-Barton, J. Quantifying and visualizing change: Strain monitoring of tapestries with digital image correlation. Studies in Conservation. 59(4), 2014. p.241-255

[7] Gauvin, C. et al, Image Correlation to Evaluate the Influence of Hygrothermal Loading on Wood. Strain, An international journal for experimental mechanics. 50(5), 2014. p.428–435.

[8] Dureisseix, D. et al., Follow-up of a panel restoration procedure through image correlation and finite element modelling. International Journal of Solids and Structures. 48, 2011. p1024-1033.

[9] Young C., Aurand A., Gauvin, C. et al. Paper in preparation For Studies In Conservation. 2015.

[10] Mecklenburg, M.F. et al. Structural response of painted wood surfaces to changes in ambient relative humidity. In: V. Dorge, (ed). Painted Wood: History and Conservation, Los Angeles: The Getty Conservation Institute. 1998.

[11] Rachwał, B., Bratasz, L.K. et al.. Fatigue Damage Of The Gesso Layer In Panel Paintings Subjected To Changing Climate Conditions. Strain: An International Journal For Experimental Mechanics. 48(6), 2012, p474-481.