

COST ACTION IE0601

Short Term Scientific Mission Report

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Applicant: Dr Paola Mazzanti, DISTAF University of Florence, Florence - ITALY

Title: Laboratory tests set up comparison and in-depth analysis of collected data on Compression Set Shrinkage in transverse direction of wood

Period: from 26 July 2009 to 2 August 2009

Host institute: School of Construction and Management Engineering, University of Reading, Reading (UK)

To MC Chair Prof. Luca Uzielli

DISTAF

University of Florence

Florence

Italy

To STSM Coordinator Prof. Joris Van Acker

GENT UNIVERSITY

Gent

Belgium

To STSM Coordinator Dr. Anastasia Pournou

Department of Conservation of Antiquities and Works of Art

Technological Educational Institute of Athens

Ag. Spyridonos, Aigaleo

Athens

Greece

To the Host: Prof. George Jeronimidis

School of Construction and Management Engineering

University of Reading

Reading

UK

To the COST Office

Brussels

Belgium

Purposes of the visit

The mission has been planned for two different research works, both related to the conservation of wooden cultural heritage:

- the mathematical modelling validation of the Medusa shield mock up deformation behaviour;
- the analysis of Compression Set Shrinkage (CSS is the acronym), the mechanism that origins permanent deformations of the painted panels.

At DISTAF (University of Florence, Italy) a replica of the Medusa shield by Caravaggio was manufactured using materials and techniques similar to the original ones as much as possible, in order to obtain information on its conservation. A deep research to characterize physical and mechanical properties of the utilized wood, that is Poplar wood (*Populus alba* L.), was carried out: shrinkage/swelling coefficients and elastic properties were measured. Moreover many data were collected on the deformations of the replica due to the environmental condition variations. One of the objectives of this work was the elaboration of a mathematical model able to interpret the deformative states of the shield and this part of the work has been carried out in cooperation with the School of Construction and Management Engineering, University of Reading. The main aim of the visit was to improve the mathematical model and validate by comparison with the experimental data.

Another common field of work is the study of Compression Set Shrinkage. This research has been carried out at the University of Florence from several years and it has been planned at the University of Reading, too. The CSS shows up when wood is subjected to climatic variations (especially the Relative Humidity of the air, RH) and restrained deformation at the same time. It induces compressive states in wood that are responsible of a loss of dimensions and, sometime, of cracks. that is why the CSS is considered the origin of permanent deformations of painted panels, the typical convexity of the front of the panel. The interest in analysing this phenomenon has developed the cooperation between the University of Florence and the University of Reading. The main purposes of the visit were to deepen the theory of the phenomenon, to compare the two experimental set-up and to test the measurement techniques.

Description of the work carried out during the visit

Shield modelling

The mathematical model has been already planned and realized, but it needed to be refined. The precise geometric characteristics were introduced in the model, to which the correct physical and mechanical properties, such as swelling/shrinkage coefficients and the modulus of elasticity, were added. The geometry of the shield was converted into a Finite Elements Model (Strand 7 Software) for the purpose of the analysis. The dimensional changes due to changes in moisture content of the wood were simulated using the analogy between thermal and hygro-expansion. The temperature change is replaced by a water content change and the thermal expansion coefficients by the hygro-expansion ones. The model was analysed using quadrilateral planar elements, describing the two-layers structure of the shield.

Compression Set Shrinkage set up tests

The set up was decided and the first test carried out was the swelling of a soaked specimen, in order to test the measurement techniques dipped in water and obtain some basic data.

Four specimens were cut by a new board of Poplar wood (*Populus alba* L.), and called Ta, Tb, Ra and Rb (the first letter indicates the main anatomical direction to measure and the second one the

number of the specimen itself). The approximate dimensions were 20x3x20 mm, Ra and Rb, and 20x20x3 mm, Ta and Tb, (LxRxT) and the initial moisture content was around 10%.

The use of the strain gages to measure the deformations of the wooden specimens was decided. This measurement techniques was chosen because of the:

- the high resolution of the measure;
- possibility to measure the behaviour of two opposite faces of the same specimen and to consider the measures as separate or as average;
- easy way of assembling;
- acquired know-how due to several years of utilization;
- immediate availability.

The main characteristics of the chosen strain gages were monoaxiality, that is to say the capacity to measure only one direction; the gages have a resistance of 120 ohm and a gage factor of 2.19.

The strain gages were mounted as a part of a Wheatstone bridge and the other part was represented by the PS-3500 bridge, able to power the electric circuit too.

Each specimen was polished by hand in order to obtain a clear surface to glue the strain gage on and the gluing surface was coated by a varnish to help the adhesion.

After these starting steps, the specimen was equipped by the strain gage (see fig. 1). It was glued by a cyanoacrylate adhesive, that guaranteed an immediate bond. The electric circuit, strain gage and cables, were coated by silicone in order to be isolated when soaked.

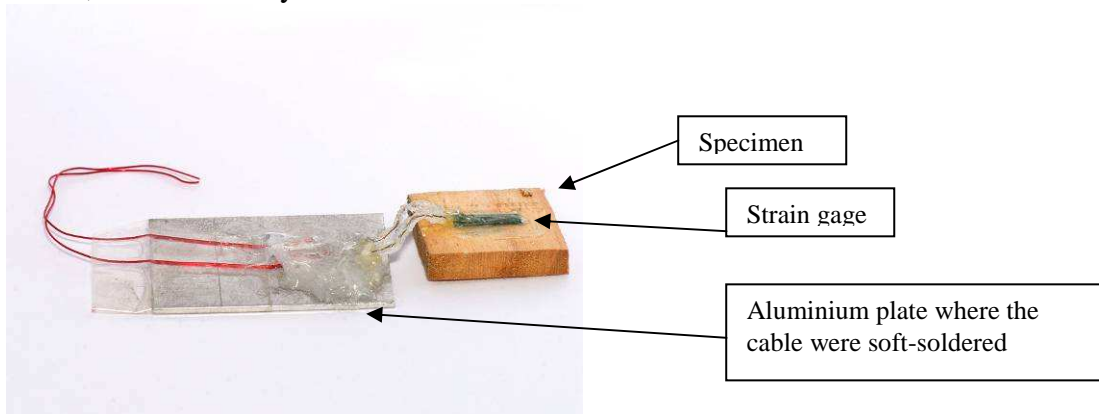


Figure 1: the specimen with the strain gage mounted on.

Two different specimens were equipped: one used to measure and one used as reference. The last one worked to balance the deformation of the strain gage resistance due to the temperature variations, it was necessary not to measure it as a wood deformation. Both the specimens were equipped by two strain gages mounted on the two opposite faces in order to balance the different ways of deforming of each one, such as cupping (see fig.2).

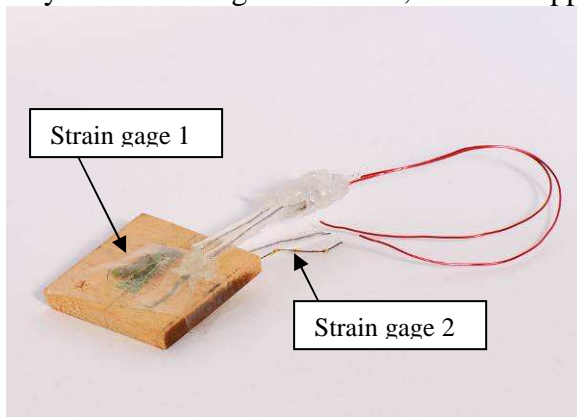


Figure 2: the specimen equipped by two different strain gages on the two opposite faces.

After equipped the specimens and tested the electric circuit, the specimens were soaked by distillate water. The swelling data were read on the display of the PS-3500 bridge and chosen according to a decreasing rate time (see table 1).

Time [min]	Collecting rate [point/min]
0->5	1
5->30	5
30->150	15
150->330	30

Table 1: collecting time rate.

Description of the main results obtained

Shield modelling

The improved mathematical model gave the results presented in fig.3 and fig. 4. The two graphs represented the trend of the two perpendicular maximum radius of the shield: the X direction represented the across the grain radius, while the Y direction represented the axial direction. The model interpreted the deformational states of the shield mock-up quite precisely except probably the borders that represented a discontinuous zone.

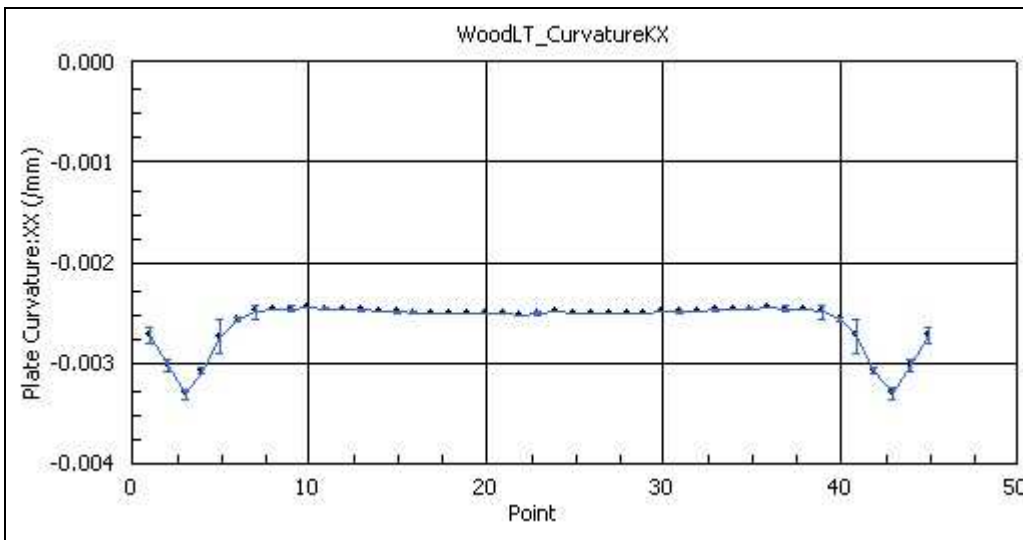


Figure 3: the X profile of the shield according to the mathematical model interpretation.

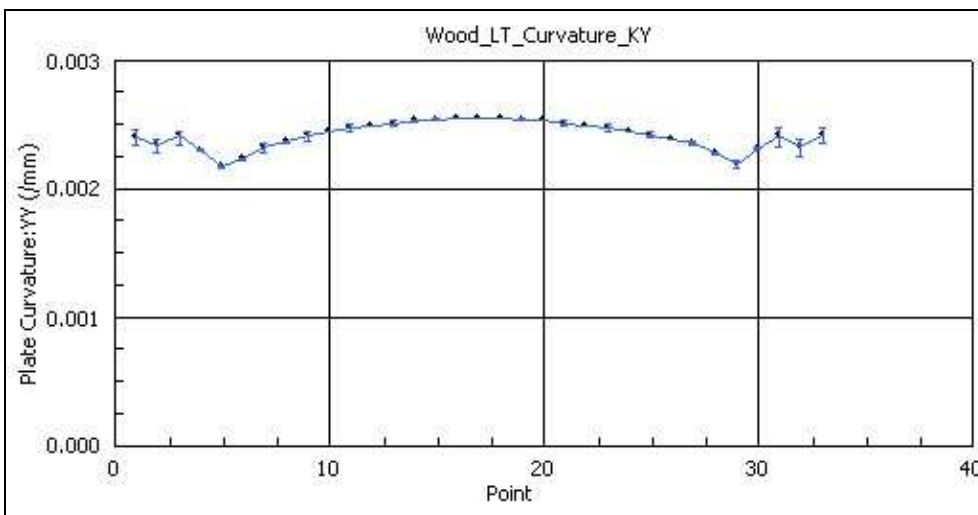


Figure 4: the Y profile of the shield according to the mathematical model interpretation.

Compression Set Shrinkage set up tests

Three tests were performed and the result of one is shown in figure 5.

The graph represented the swelling behaviour of specimen Ta: it was evident that during the first 150 min the trend was a typical wooden swelling curve, while during the successive time the curve started growing up too fast.

Each performed test showed the above described behaviour.

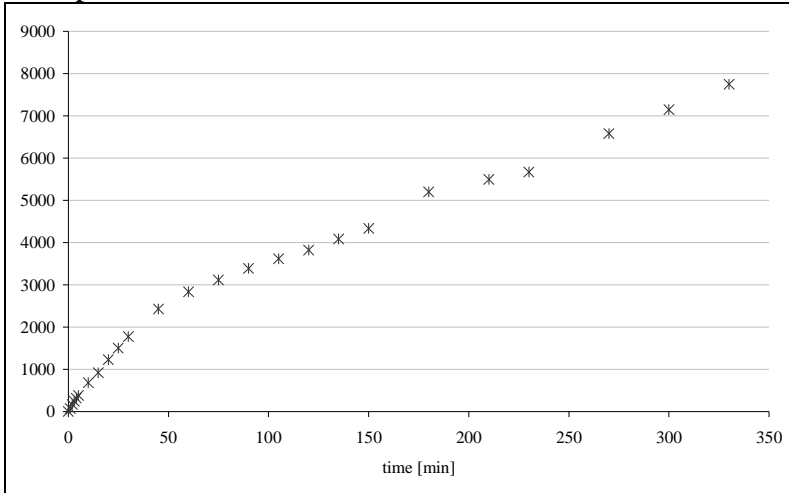


Figure 5: the swelling trend of the specimen Ta.

At the end of the test the specimens were put out the water and examined. The simply observation showed that the electric circuit did not resist the water dipping: the worst case showed a detachment of the strain gage resistance from the rest sheet, that is to say the strain gage was split in two parts (see fig. 6). The measure of the circuit resistance gave 90 ohm, instead of the 120 ohm measured before the tests started. It was obvious that the silicone, utilized as waterproof coating, did not work well.

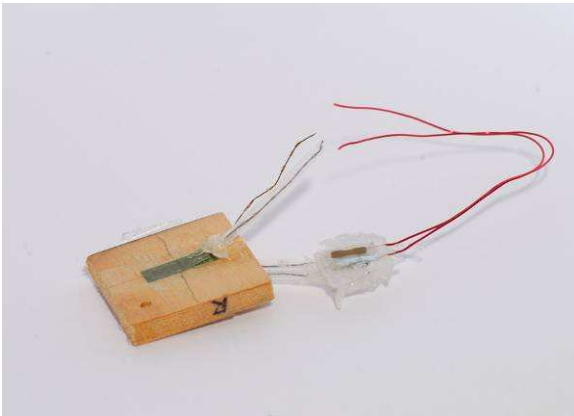


Figure 6: the rising of the strain gage resistance.

Conclusions

Shield modelling

The mathematical model worked fine in interpreting the qualitative deformation state of the mock-up shield. The next step will be to continue collecting experimentally deformation data to improve the model and to compare the quantitative results obtained by the model with the real shape of the shield. The model can be refined to take into account the precise dimensions and orientation of the strips of Poplar wood used to make the two layers. To verify the accuracy of the model, it will be necessary to compare predicted and measured deformations for given changes in moisture content.

Compression Set Shrinkage set up tests

The preliminary tests of swelling on Poplar wood (*Populus alba* L.) specimens were necessary to test the measurement techniques. The first results put in evidence the necessity to improve the system. Indeed the electric circuit needed a better waterproof coating than the one used (silicone). A chance to solve the problem could be covering the strain gage thanks to a very thin aluminium sheet, to be itself glued on the wooden surface.

If the proposed system solves the problems in measuring, it will be necessary to test the stiffness of the adhesive, used to glue the strain gage on the wood, in order to be sure that it does not affect the measure.

Future collaboration

Each one of the two research fields gives the opportunity to continue the started collaboration. The improvement of the mathematical model and its comparison with the experimental data need to deepen the cooperation, maybe trough out a future mission at the University of Florence working to achieve the publication of a paper on the conservation of the shield. Moreover the CSS tests planned at the University of Reading will be a source of discussion and comparison with the results obtained at the University of Florence. The differences in the set-up tests could give information on the good quality of the experimentally collected data.