STSM SCIENTIFIC REPORT

Cost FP1101	Assessment, Reinforcement and Monitoring of Timber Structures
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STSM topic	Hyperspectral imaging of weathered wood samples
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STSM Scientific Report Contents:

1. Purpose of the STSM

2. Description of the work carried out during the STSM

3. Description of the main results obtained

4. Future collaboration with host institution (if applicable)

5. Foreseen publications/articles to result from the STSM (if applicable)

6. Confirmation by the host institution of the successful execution of the STSM

7. Other comments (if any)

8. Acknowledgments

1. Purpose of the STSM

Wood has been traditionally used for various kinds of load-bearing structures, as well as for complementary constructive components, such as cladding and decking. Wooden elements can undergo to alteration during their service life that can be caused by mechanical, environmental or biological agents. Surfaces are the most vulnerable parts of the structures, since these are the most exposed to altering factors, such as ageing, weathering or decay.

Weathering is the general term used to define the slow degradation of materials exposed to the weather condition. The rate of weathering varies within timber species, function of product, technical/design solution, finishing technology applied but most of all on the specific local conditions. In general, the process of wood weathering leads to a slow breaking down of surface fibers, their removal, and in consequence to a roughening of the surface and reduction of the glossiness. The formation of discontinuities on the wooden surface can cause penetration of the wood-decaying biological agents into the material structure and influencing mechanical performances of the load-bearing members. The other significantly changing parameter is colour, which changes rapidly when exposed to weathering. It is mostly caused by photodegradation of lignin and wood extractives in middle lamella.

The goal of this research is to investigate the kinetic of the degradation rate of wooden samples exposed for the short term weathering conditions. It is expected that using hyperspectral imaging technique for detection of colour alteration, changes to chemical composition and detection of decay at the early stage may provide new understanding for the weathering process. The experimental samples used for evaluation were weathered in 15 locations in Europe for a period of 1 month.

2. Description of the work carried out during the STSM

The research related to STSM was conducted in two institutions: IVALSA/CNR and Norwegian University of Life Sciences and includes following working packages:

WP1. Preparation of experimental samples after short term weathering (IVALSA/CNR)

WP2. Hyperspectral imaging of investigated samples (Norwegian University of Life Sciences)

WP3. Verification of applicability of hyperspectral imaging for evaluation of short term weathering of wood (Norwegian University of Life Sciences)

WP4. Data evaluation and comparison of weathering kinetic between investigated sites (Norwegian University of Life Sciences and IVALSA/CNR).

WP1.

Experimental samples were prepared from one piece of Norway spruce wood (*Picea abies.*) on the slicing planner (Marunaka). The thickness of samples was ~100µm and the efficient surface exposed to weathering was 30 x 30mm (width x length respectively). Sets of samples were exposed in 15 locations in Europe (Figure 1), and were collected before exposition and after 1, 2, 4, 7, 9, 11, 14, 17, 21, 24 and 28 days of weathering. Samples were exposed to south direction; however in some locations more then one set was tested (more exposure direction). Additionally one sample set was stored in dark climatic chamber during whole duration of the test and served as reference. Samples were conditioned after collection in the climatic chamber (20°C, 60%RH) to the equilibrium moisture content of ~12%. The image of the experimental samples after weathering campaign is presented in Figure 2.

Figure 1. Locations of sites where Round Robin tests was performed

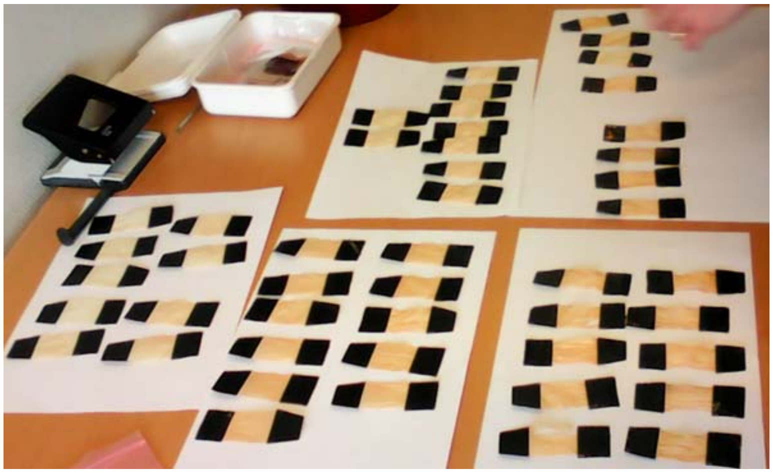

Figure 2. Experimental samples after weathering campaign

WP2

Hyperspectral imaging of the wood samples was carried out by using an MCT camera, covering the NIR wavelength region 900 – 2500nm distributed on 256 channels (Specim, Oulu Finland). The experimental set-up is presented in Figure 3.

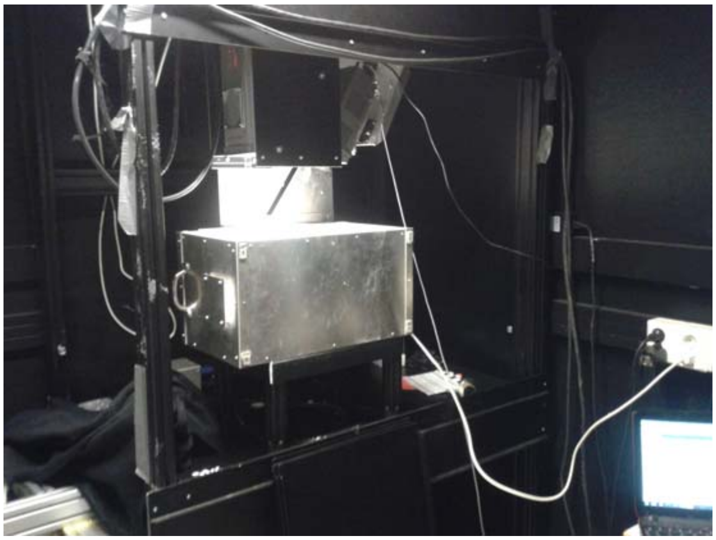

Figure 3. Experimental set-up used for hyperspectral imaging

One dimension of the detector is used for the spectral separation and the other for imaging one of the two spatial directions so that one line is recorded each time with a spectrum in each pixel. The second spatial dimension is obtained by moving the camera over the sample using a translation stage. In average it takes 5 seconds to scan the sample. The spatial resolution of the setup was approximately 150µm. Figure 4 presents print-screen of software used for the acquisition of images.

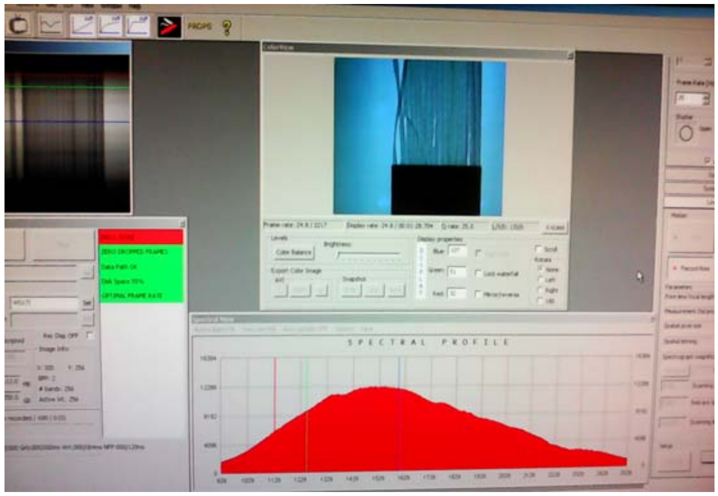

Figure 4. Print-screen of software used for the acquisition of images

WP3.

The samples were very thin, approximately 100 µm, and were observed in transmission mode, using halogen lamps as light source placed below a white demi-transparent glass plate. A transparent glass plate which is also transparent for NIR wavelengths was placed above the samples in order to obtain a flat surface for the imaging. Hyperspectral image files are composed of several spectrally resolved 2D-images of the sample, also called a hypercube. The structure of the hypercube X is (M x N x λ) where the M and N axes represent spatial information and the λ axis correspond to the spectral pattern. The quality of the raw measurements was affected by instrumental variations and varying light conditions, thus pre-processing of the data was required. Subtraction of dark frames was performed to correct for pixel to pixel variations in the detector, and a flat field division was conducted using an image of the white demi-transparent glass plate without samples on.

The new experimental set-up and measurement of thin wood samples in transmission mode provided satisfactory results; therefore acquired images were analyzed in the following WP.

WP4.

The samples were previously measured by means of FT-NIR spectroscopy at IVALSA/CNR. The partial Least Square (PLS) model was developed by regressing two points defining the border values for the weathering state:

• the initial stage (weathering index W_{ind}= 0), modelled on the base of the no-weathered samples

• final stage modelled with spectra collected from the most degraded samples after 28 days of exposure (weathering index W_{ind}= 1000).

The PLS model developed was used in the second phase for prediction of the W_{ind} values for all the intermediate samples (weathered between 1 and 24 days). Quant 2 Analysis tool pack, part of the OPUS software package (Bruker Optics GmbH) was used for both, PLS model development and for prediction of the intermediate indexes. The results of the degradation kinetics, as derived on a base of NIR spectra are presented on Figure 5.

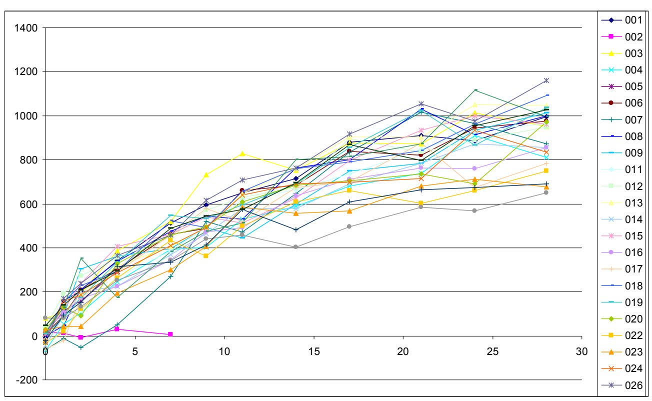

Figure 5. Weathering index rate W_{ind} predicted on the base PLS model of near infrared spectra

This step of analysis served for evaluation of severity of degradation rate among various locations. Locations placed above the W_{ind}= 1000 might be considered as more severe (e.g. #26, #18, #13, #19, #30), in contrary to the locations placed below that threshold, that seems to be less degraded (e.g. #27, #23, #28, #22, #17).

The second step was to perform the Principal Component Analysis (PCA) on the samples measured by hyperspectral imaging with various degradation rates. PCA searches for unique properties of spectra and separates set of input data into groups of peculiar similarities allowing visualization of natural clustering of the data. Preliminary results are presented in Figure 6.

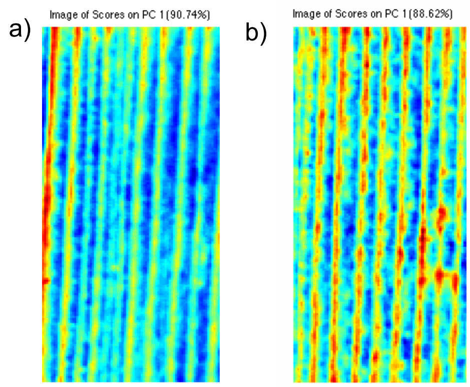

Figure 6. Example of PCA analysis performed on not weathered (a) and sample after 28 days of weathering (b).

Applicability of classification methods such as PLS-DA was also tested within this research. Partial Least Square Discriminant Analysis (PLS-DA) was performed in order to visualize the separation between groups of observations. PLS-DA allowed both: describing the set of explanatory variables and predicting the response ones. All measured variables play in this case the same role with respect to the class assignment. Examples of PLS-DA performed on whole set of samples considered as significantly weathered is presented in Figure 7.

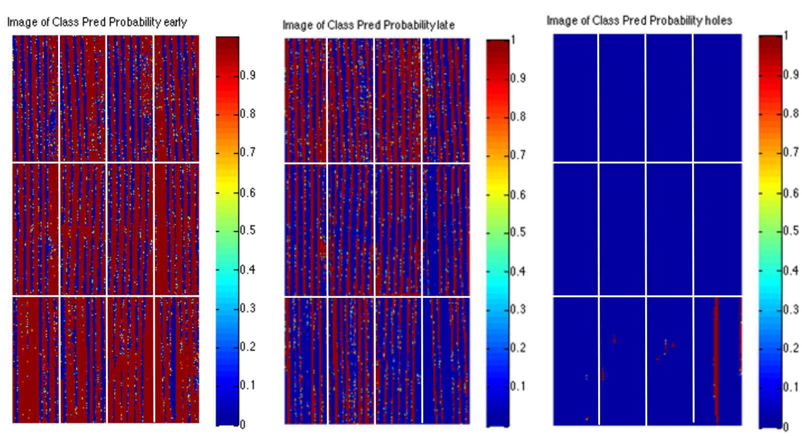

Figure 7. Results of PLS-DA on samples from location #13 used for discrimination of early and late wood and crack detection.

Firstly the PLS-DA was performed on sample “A” (not weathered) and then model was used for prediction early wood, late wood and crack in following samples. According to the literature the erosion rate caused by weathering is more evident in early wood. It can be seen however, that with the degradation time the quantity of late wood that can be recognized as model late wood diminished. It is perhaps due to the fact that late wood contain more lignin and this polymer is the most sensitive to weathering (photodegradation) in particular. This hypothesis will be verified with other set of samples and confront with data acquired with other analytical methods. Further investigation will also includes evaluation of the kinetic of the degradation of early and latewood zones.

Satisfactory performance of timber members may be achieved by combining proper design, careful assembly and maintenance, and, if applicable, chemical treatment and appropriate coating. Understanding the mechanisms of weathering and the role of the altering factors is fundamental to assess the actual conditions of timber structures. It is also essential to predict the future performance, and, possibly, to ensure a long-term preservation and maintenance.

4. Future collaboration with host institution

I am convinced that STSM strengthen my personal research network and the cooperation between my research group (Laboratory of Surface Characterization, IVALSA/CNR), and research group of prof. Ingunn Burud (Department of Mathematical Sciences and Technology, Norwegian University of Life Sciences) and dr Lone Ross Gobaken (Norwegian Forest and Landscape Institute). Based on good teamwork between mentioned institutions we agreed to continue with cooperation also in the future in the form of common projects or publications.

5. Foreseen publications/articles to result from the STSM

The results obtained during this mission will be presented in the Thessaloniki meeting within COST Action FP1006. Couple of articles in scientific journals are also foreseen as an output of this research.

6. Confirmation by the host institution of the successful execution of the STSM

The confirmation is attached as a separate file.

7. Other comments

During the period of my stay in Ås, I visited the laboratories of the Department of Mathematical Sciences and Technology and Norwegian Forest and Landscape Institute. I had the chance to present my research and to meet and discuss with researchers, professors and students. Together with prof. Ingunn Burud and dr Lone Ross Gobaken we performed visual assessment of degradation level of investigated samples. I also visited the field test site and saw examples of weathered wooden structures (Figure 8).

Figure 8. School in Ås as example of weathered structure

8. Acknowledgments

The samples investigated within this STSM were prepared within COST FP1006 and weathering tests were coordinated by dr Jakub Sandak. I am grateful for the opportunity to join this initiative. I would like to thank prof. Ingunn Burud for the constant help and great support during my STSM period. My acknowledgment to the research team: prof. Thomas Thiis and dr Andreas Flø as well as technician staff: Arne Svendsen and Tom Ringstad for their great help with experimental set-up and inspiring discussion. I also appreciate the time of dr Lone Ross Gobaken during visual assessment of the samples.

I would like in addition to express my thanks and appreciation to the MC of COST FP1101 and to the COST Administrative Secretariat for funding my trip, allowing me to carry out this Scientific Mission.