Reference code: COST-STSM-IE0601-05235

STSM Scientific Report

after completion of the Short Term Scientific Mission (STSM)
in the frame of COST IE0601

STSM Title: Non-destructive analysis of archaeological wood

Period: September 07th – September 12th, 2009

Visitor: Dr. Magdalena Zborowska, University of Life Sciences in Poznan, Institute of Chemical Wood Technology, (PL)

Host: Dr. Jakub Sandak, Trees and Timber Institute, IVALSA/CNR, (IT)

1. PURPOSE OF THE VISIT

Estimation of the degree of wood degradation is one of the most important stages of conservatory process. Taking into consideration major value of archaeological objects destructive methods should be replaces by non-destructive ones.
The aim of this STSM was to study a possibility of application of selected non-destructive methods toward characterization of archaeological wood degradation. The other goal of the mission was to start scientific cooperation between the Institute of Chemical Wood Technology of Poznan in Poland and Trees and Timber Institute, IVALSA/CNR in Italy.

2. DESCRIPTION OF THE WORK CARRIED OUT DURING THE VISIT

A set of softwood and hardwood samples from different waterlogged archaeological sites located in Poland was analysed. Non-destructive investigations were carried out by using solid blocks, as presented in Figure 1. All samples were differing in terms of the degree of degradation. The degradation state has been stated on the basis of "standard" procedures of classical analysis, for example on the basis of density (Figure 2). The archaeological wood has been compared with similar (from the species, size, age, anatomical structure, etc. point of view) pieces of contemporary wood. Non-destructive characterization of archaeological and modern wood was carried out using x-ray densitometry, resistography as well as near-infrared spectroscopy. Results obtained with the above non-destructive methods were finally confronted to the reference data produced on the basis of "standard" procedures of classical analysis.

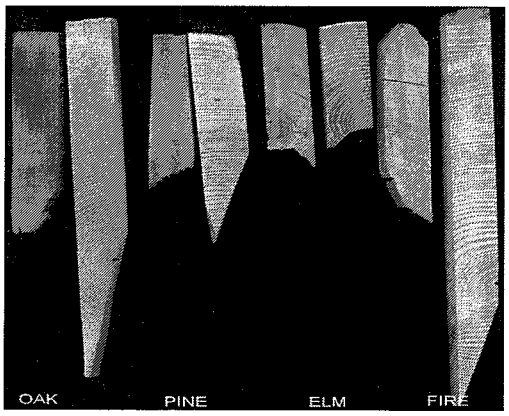

Figure 1 Samples of archaeological and modern wood (oak - *Quescus petrea.*, pine - *Pinus sylvestris*, elm – *Umlus* sp. fire – *Abies alba*).

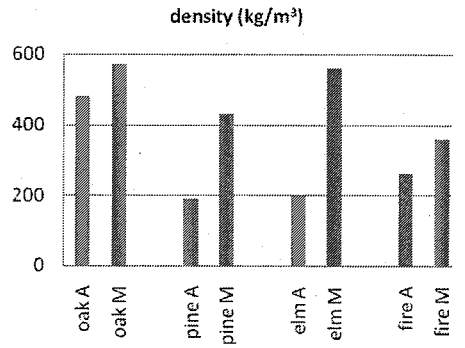

Figure 2 Density of investigated samples (a-archaeological wood, m-modern wood)

3. DESCRIPTION OF THE MAIN RESULTS OBTAINED

X ray densitometry was employed for mapping of the density distribution and detection of cracks and voids. Results of x-ray measurements are presented in Figures 3 and 4 for softwood (pine) and hardwood (elm) respectively. The variation of the density along the sample length is much higher in case of the archeological wood; it was observed significant drop of the density (A) or particular density

increase in the other areas. The higher absorbance of X-rays within the nucleus area (B), especially in pine is probably the consequence of the mineralization process.

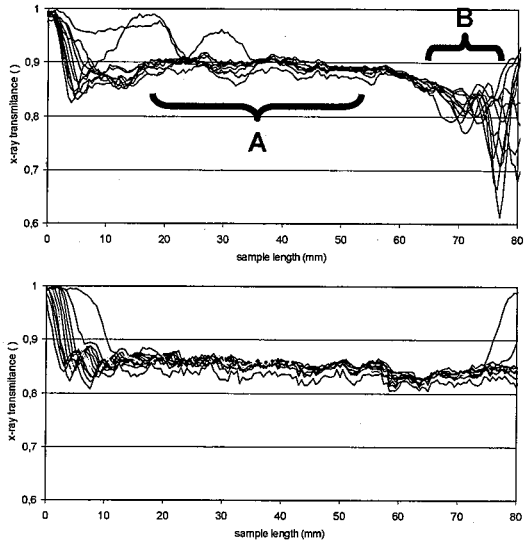

Figure 3 X-ray absorbance of the archaeological (top) and modern pine (bottom)

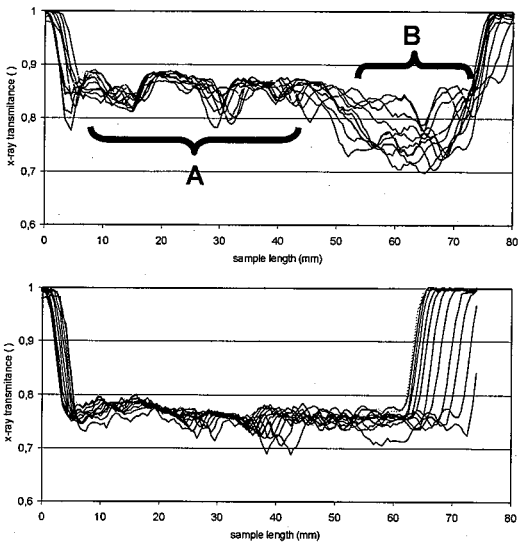

Figure 4 X-ray absorbance of the archaeological (top) and modern elm (bottom)

Resistography has been exploited toward generation of the density profiles along the radius for each wooden disk and estimation of the weaknesses of the wood strength. Example results of such measurements can be presented in the form of charts, as shown in Figure 5. Resistography confirmed two-zone degradation of the object (part A and B on the left drawing on Figure 5) and a presence of mechanical defects such as voids and cracks (arrows are pointing internal defects). It was in correspondence to the x-ray results.

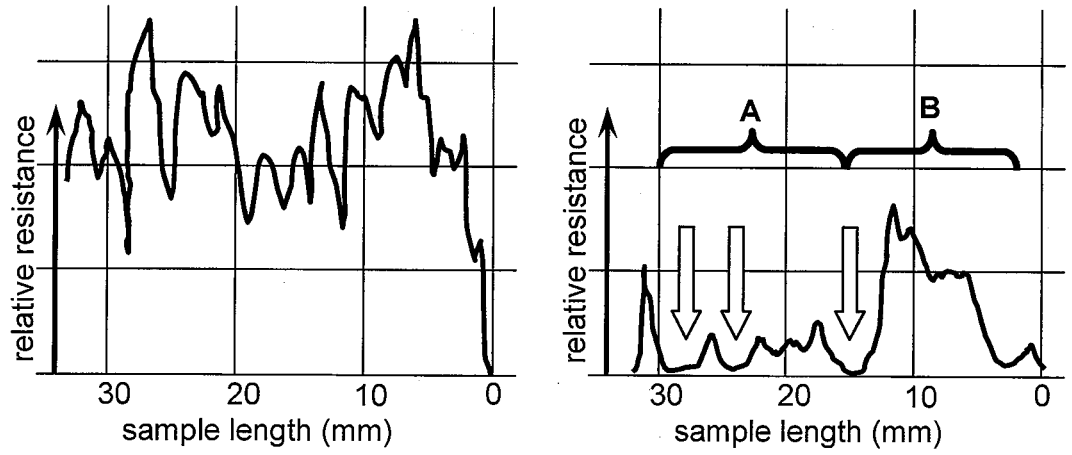

Figure 5. Resistography of archaeological (left) and modern (right) elm. Archaeological sample with two zones of degradation (A high degree of degradation and, B low degree of degradation).

Fourier Transform Near – Infrared Spectroscopy (FT-NIR) has been applied for chemical changes detection of archaeological samples, determination of wood species and estimation of the degradation degree. Results of FT-NIR analysis for all investigated species are presented in Figures 6, 7, 8 and 9. The spectral bands corresponding to crystalline or semi-crystalline zones in cellulose (seen in the spectra in peak 6287 cm^{-1}, 6450 cm^{-1} and 5464 cm^{-1}) seem to have very similar shape for all analyzed samples. These results are might be correlated with crystallity index measured with wide angle x-ray diffractometry (reference, but destructive testing methodology). Significant differences can be noticed however in wavenumbers 7000 cm^{-1} and 5800 cm^{-1} related to the amorphous regions of cellulose and hemicelluloses respectively. This kind of carbohydrates in wood is potentially much more degradable compare to the cellulose's crystalline regions. Significant changes have been also noticed in the spectral regions related to lignin (5980 cm^{-1}), especially in the cases of elm and pine archaeological samples (the most degraded objects). All the above discoveries are closely related to the observations derived by analysis of the data produced on a basis of "standard" procedures of classical analysis.

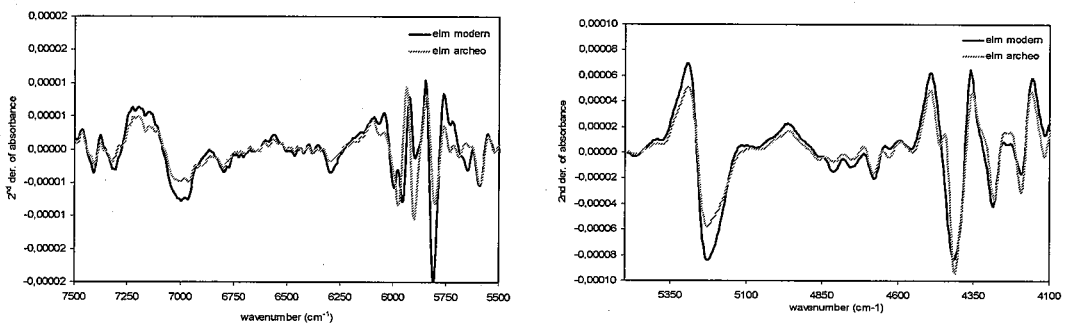

Figure 6 FT-NIR second derivative spectra of solid samples of archaeological and modern elm

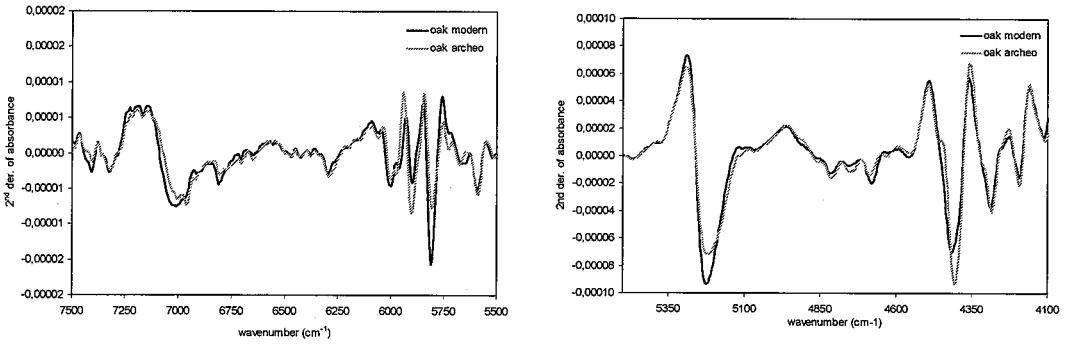

Figure7 FT-NIR second derivative spectra of solid samples of archaeological and modern oak

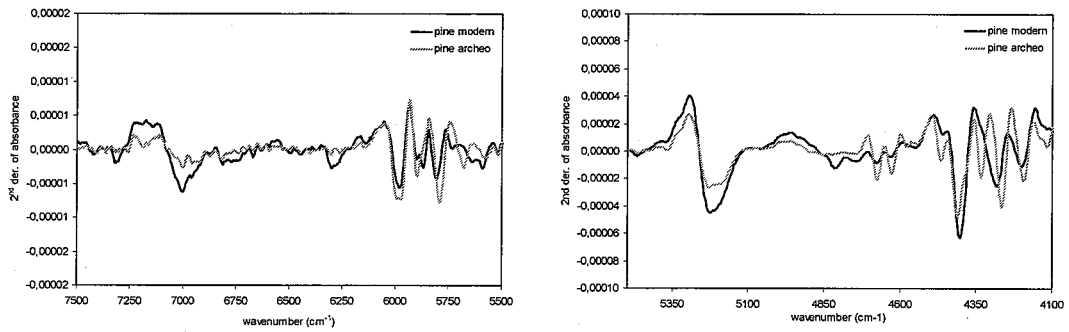

Figure 8 FT-NIR second derivative spectra of solid samples of archaeological and modern pine

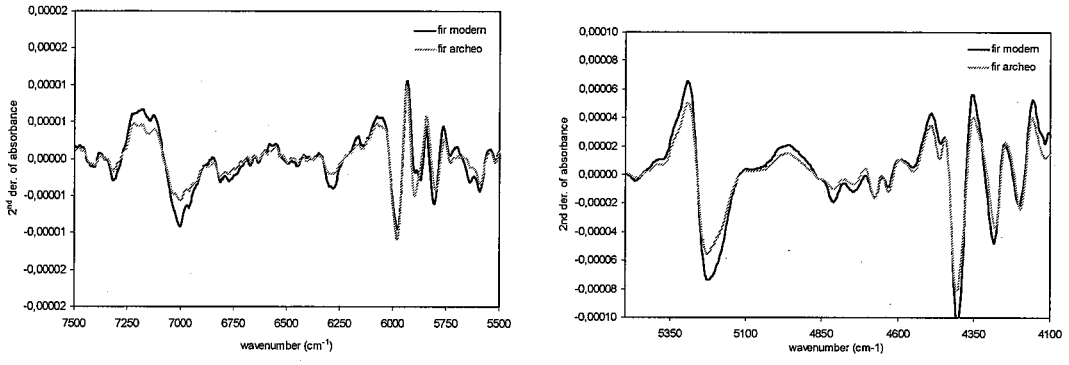

Figure 9 FT-NIR second derivative spectra of solid samples of archaeological and modern fir

An example of further utilization of the FT-NIR spectroscopy into evaluation of the archaeological wood is presented in Figure 10. Some dedicated mathematical algorithms, such as principle component analysis (PCA) can be used for data mining of the spectra. Discrimination of the wood species and degradation state can be accurately achieved with the help of such methods. The three-dimensional separation of the experimental samples researched is presented in Figure 10. It is clear that the FT-NIR is capable to correctly distinguish all the samples investigated.

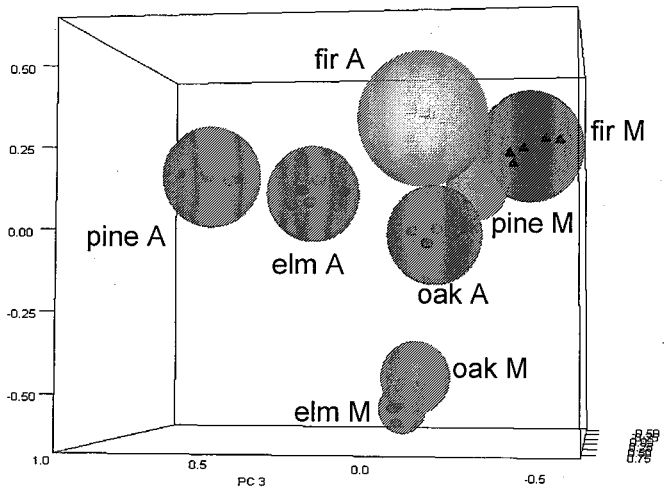

Fig. 10. PCA performed on eight wood solid samples on different species and degradation stage. Note: Preprocessing: 2nd derivative, 13 smoothing points, Region 7990-5300, 4980-4100cm-1, method: factorization, 4 factors

Summarizing, all the results presented above shows a great potential of the non-destructive testing methods in to application toward evaluation of the archeological wood. X-ray densitometry can be applied for accurate estimation of the density distribution of the samples in the laboratory. The resistograph however can be applied for the in-filled measurement of the degradation degree of the archaeological wood as well as for detection of the defects, such as cracks, voids and/or decay.
FT-NIR spectroscopy has a great potential to replace the standard "wet chemistry" methods of the chemical composition estimation. It can also be applied for rapid ranking of the degradation degree, species recognition or sample origin determination.

4. FUTURE COLLABORATION WITH THE HOST INSTITUTION

The STSM conducted is a starting point for extension of bi-lateral cooperation between IVALSA/CNR, Italy and Institute of Chemical Wood Technology University of Life Sciences in Poznan, Poland. Several common interests have been stated and preliminary steps are conducted in order to continue collaboration. The mutual exchange of results and samples is the first, already performed activity. The future joint researches will be focused not only on the non-destructive analysis of archaeological wood but also extended to other aspects of cultural heritage and wood science in general.

5. PROJECT OF PUBLICATIONS/ARTICLES AS RESULTS OF THE STSM

Some of the STSM results will be presented on the oncoming conferences:

1. M. Zborowska, A.Sandak, J.Sandak, S. Borysia, L. Babiński, W. Prądzyński: *Characterization of archaeological wood degradation with selected nondestructive methods*; to be presented on International Conference on Wooden Cultural Heritage: Evaluation of Deterioration and Management of Change (Hamburg/Germany; October 7-10, 2009)
2. A. Sandak, J. Sandak, M .Zborowska, W. Prądzyński, M. Negri *Characterization of archaeological oak (Quercus sp.) with mid and near infrared spectroscopy*; to be presented on International Conference on Wooden Cultural Heritage: Evaluation of Deterioration and Management of Change (Hamburg/Germany; October 7-10, 2009)
3. J. Sandak, A. Sandak, M. Zborowska, A. Spek-Dźwigała: *Archaeological waterlogged oak wood characterization with NIR*; to be presented on 14th International Conference on Near Infrared Spectroscopy (Bangkok, Thailand 9-13 November 2009)

It is also intended to publish soon the STSM results in the referred international journal related to wood science and/or cultural heritage.

6. CONFORMATION BY HOST INSTITUTE OF THE SUCCESSFUL EXECUTION OF THE MISSION

See annex

7. ACKNOWLEDGEMENTS

I am grateful to the Management Committee of the COST Action IE 0601, especially to Chairman Professor Luca Uzielli for granting the funding for this Short Term Scientific Mission.
I would like to thank Professor Ario Ceccotti; Director of the Trees and Timber Institute, IVALSA/CNR in San Michele for allowing me to work in his Institute.
I would like to thank Dr. Jakub Sandak as well as Anna Sandak for their warm welcome, great support and help during my stay in Italy.
Finally, thanks for Agnieszka Spek-Dźwigała, MSc for continuous support.

Magdalena Zborowska

Institute of Chemical Wood Technology
Poznań University of Life Science, Poland
30.09.2009