REPORT FOR SHORT TERM SCIENTIFIC MISSION (STSM)
The Short-Term Wood Creep Test by Means of DMA

May 31, 2017

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Beneficiary:	Roman Shchupakivskyy (UA) Ukrainian National Forestry University Gen. Tchuprynka, 103 str., Lviv, Ukraine Email: roman.shchupakivskyy@nltu.edu.ua
Host:	Prof. Alexander Pfriem University of Applied Sciences in Eberswalde Schicklerstraße 5, 16225 Eberswalde, Germany Email: alexander.pfriem@hnee.de
Co-authors	Dr. Nadine Herold University of Applied Sciences Eberswalde Email: nadine.herold@hnee.de Ms. Lothar Clauder University of Applied Sciences Eberswalde Email: lothar.clauder@hnee.de
Approved by	Chair of the Action: Dr. Philipp Dietsch (DE) Email: Dietsch@tum.de STSM manager: Dr. Thierry Descamps (BE) Email: Thierry.descamps@umons.ac.be

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Introduction

Physical, mechanical and rheological properties of wood are among the constitutive properties while using it as a building material. They have decisive importance to the manufacture of wooden building constructions and elements including CLT panels, etc. as directly effect on performance of the product. Moreover, one of the better-known aspects of designing with wood or wood-based products is that the strength of these products is dependent on time under stress.

The best characterizes mentioned above wood properties its creep performance. Creep is not only an important phenomenon in viscoelasticity, but is also of great significance in the design of wood based products for load-carrying applications. Consequently, creep in wood and wood structures can lead to serviceability problems due to excessive deformations or to safety problems due to strength reduction. Evaluating creep behaviour of a product, however, takes a great deal of time and cost. For example, to evaluate the long-term performance of some timber material, ASTM D 6815 requires the applied load for the long-term (min 90-day) specimens to be based on 55% of the 5th percentile parametric point estimate of the short-term bending load using matched specimens. Furthermore, in such conditions seems almost impossible to investigate wood creep behaviour under variable temperature and stress level.

Purpose of the STSM

As a structural material, solid wood may perform differently under various conditions over a long period of time. However, evaluation of the long-term performances of a product takes a great deal of time. Therefore, in order to reduce the expense and time, as well as to generate the long-term information for constructing purposes, alternative methods for long-term prediction with shorter-term experimental data are needed. In addition, whereas various structural and environmental parameters influence creep behaviour: temperature, moisture content and different stress level might be the most important variables in long-term performance. For this reason, the effects of stress and temperature need to be carefully studied and considered in the application. In our opinion such a method could be a DMA (Dynamic mechanical analysis) analysis, which has not been widely used before in wood research, what is confirmed by the absence of any standards, but often used in the study of biopolymers, and the like.

Thereby, the main aim of this study within the framework of short-term scientific mission was verify possibility of Dynamic mechanical analysis using to investigate short-term creep behaviour of beech wood. Other main objectives of activity due to STSM are summarized as follows:

- study the effects of stress level and temperatures on the creep behaviour of wood by means of dynamic mechanical analysis;
- generate the master curves for beech wood under various stresses and temperatures for the prediction of long-term wood performance;
- compare the results obtained from short-term DMA tests and long-term creep experiments, as well as to study the relationship between DMA results and long-term test results.

Material and methods (Experiment Setup)

The commercial device, a Gabo Eplexor 25N Dynamic Mechanical Analyser (DMA), was used to study the viscoelastic response of a specimen under constant loads in creep tests between 20 and 75°C (Fig. 1). The DMA has the advantage of quickly giving results, and, it does allow for control of the relative humidity in the measuring chamber.

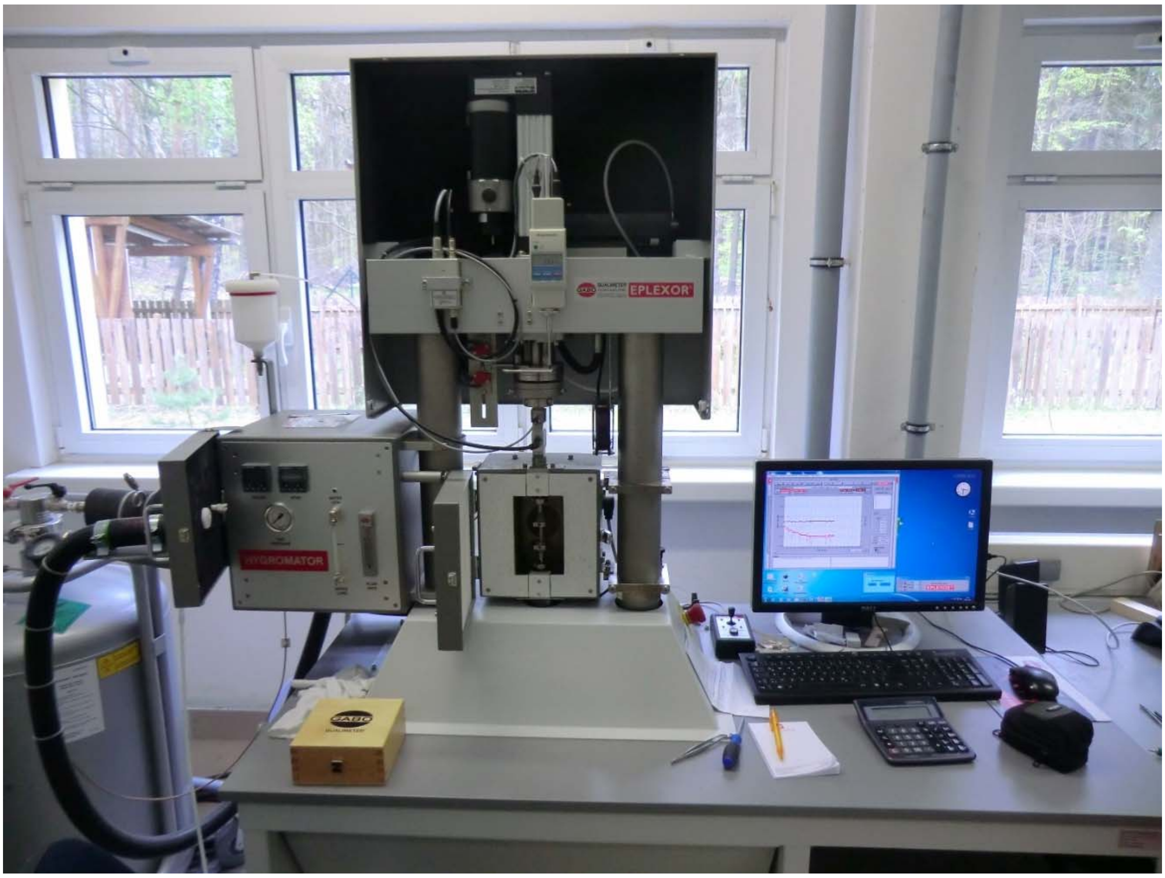

Figure 1. Overall view of the DMA Gabo Eplexor

Creep experiments for tension on the DMA were done using GABO software. The sample is mounted in the clamps and the clamps are tightened using screws with adjustable torque (Fig. 2). Full load was rapidly and smoothly applied to the specimen, mainly in 1 to 5s, soak time before starting the measurement under the static load was 300s. A constant load was applied to a specimen in selected loading configurations (tension) at constant temperature and the deformation was measured as a function of time. The sample creeps for 3 hours than recovers for 6 hours. The data is read and manipulated by the on-line computer system and the results were displayed as the experiment progresses. Experiments were performed at Time Sweep and Temperature Sweep module with the fixed constant frequency (close to 0 -0.001Hz). In order to construct master curves for the prediction of long-term behaviours, a series of 180-minute isothermal creep tests were conducted at various temperatures and stresses, and the corresponding creep strains were measured. The range of selected temperatures was from +25°C to +75°C with a 25°C increment. Time to equilibrate the temperature rate was calculated based on range of heating, which was near 5°C / min. To insure that behaviour of test specimens remains within the linear range, loads in the 20% to 25% range of the short-term ultimate strength were from 5 to max. 20N with ∆5N. Tolerance of static load were between 0.1-0.2N. No load was applied during temperature ramp, and the temperature-equilibrating time was 5 minutes for each temperature. All these parameters are entered using the “CREEP 25N©” template available in the GABO software.

The investigations were carried out on wood samples taken from a single beech tree obtained from a forest in the north-west part of Germany. The rectangular beech wood samples, cut from oven dried blanks, were conditioned for at least 2 weeks before measurements at constant climate room with a temperature 20±2°C and relative humidity of approx. 60%. Have been used few different types with different dimensions of DMA specimens: 1 - geometry measured approximately 60 mm in length, 12 mm in width and 0.6 mm in thickness, and the span of the test is 35 mm; 2 – 50mm length, 5 mm width and approx. 0.16mm thickness, span of the test 35 mm (Fig. 6). Specimen dimension is a compromise between the load magnitude that can be applied (25N using tension clamps) and the size that would be representative of the species. For this study, 22 samples of each dimension were tested.

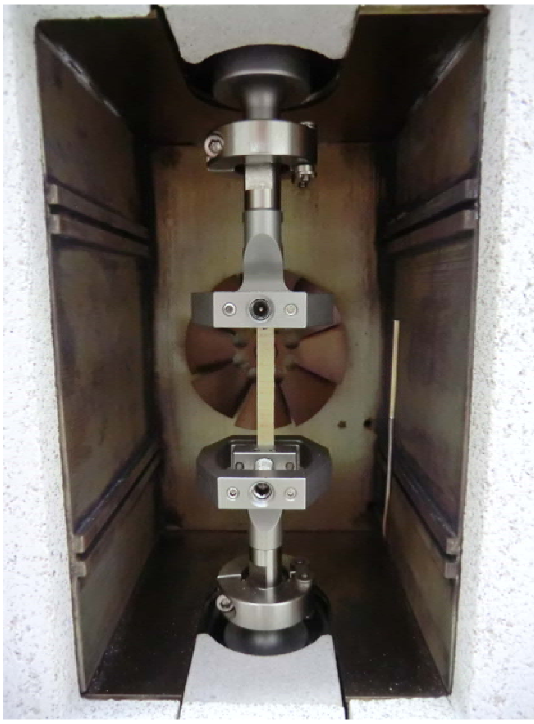

Figure 2. DMA tension clamps

Description of the main obtained results

- The short-term creep test using DMA

As a result of short term creep test, have been obtained Tensile-Creep curves as well as Creep-Modulus curves at different load values and temperatures. Figure 3 shows a representative plot of the creep strain from a 180-minute creep tests at 22°C and 20N.

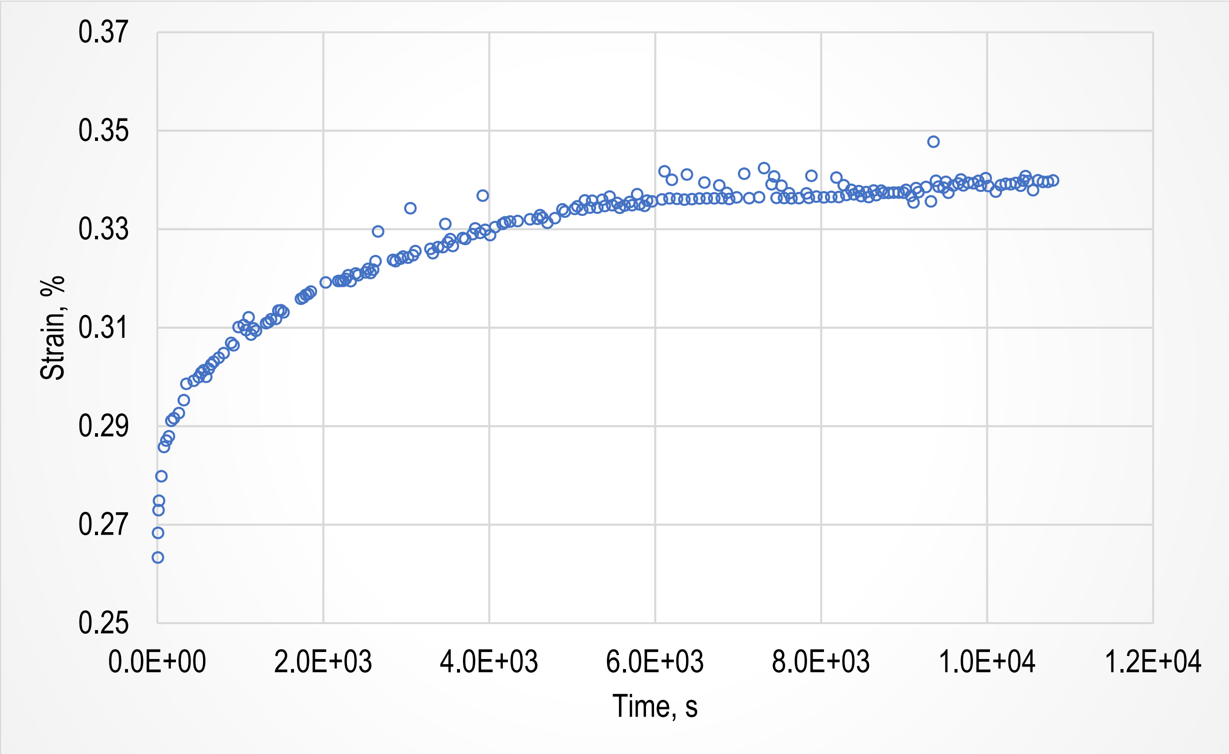

Figure 3. Tensile-creep curve of beech at 20N and 22°C. Creep strain versus time.

Figure 5 shows a representative plot of the creep strain from a series of 180 minute creep tests at various temperatures from +22 to +75°C with an increment of apporx. 25°C.

The effect of temperature can be observed in that the creep strain increased with elevating temperatures, and the strain increment also increased nonlinearly with respect to temperature. This may imply that, at a lower temperature, the effect of temperature was linear.

At a lower temperature, the creep strain did not increase considerably; whereas, the strain increased more and more significantly with elevating temperature.

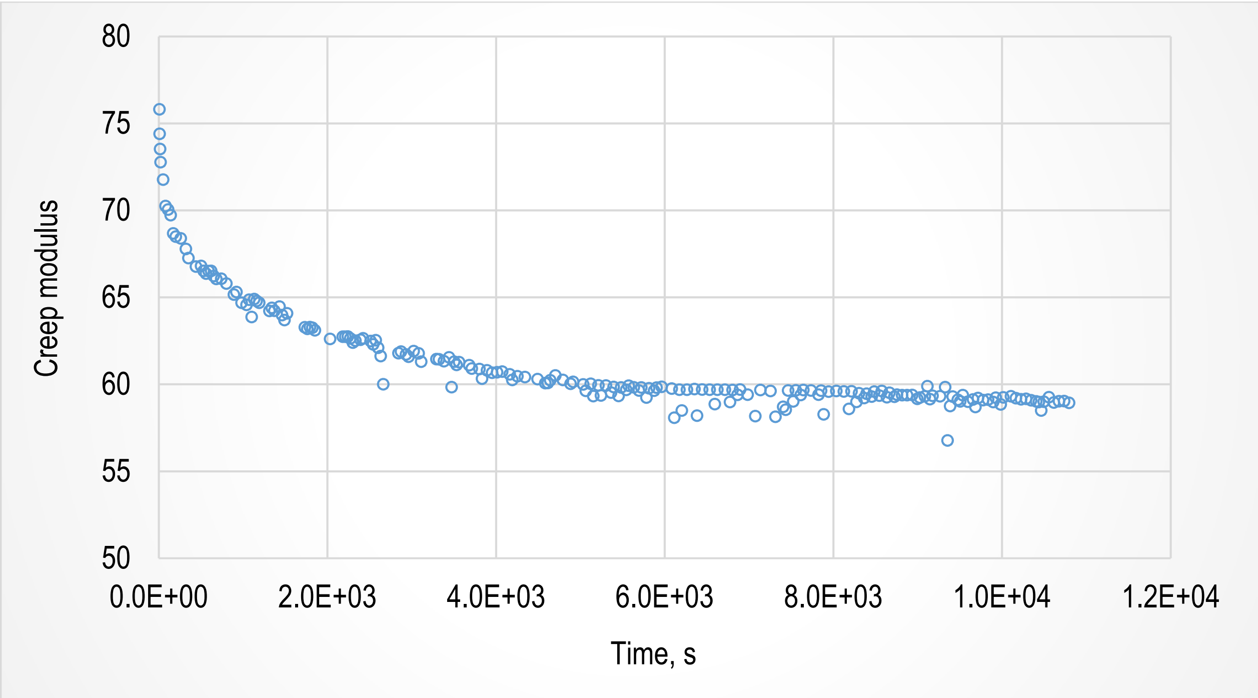

Figure 4. Creep modulus of beech at 20N and 22°C. Creep modulus versus time.

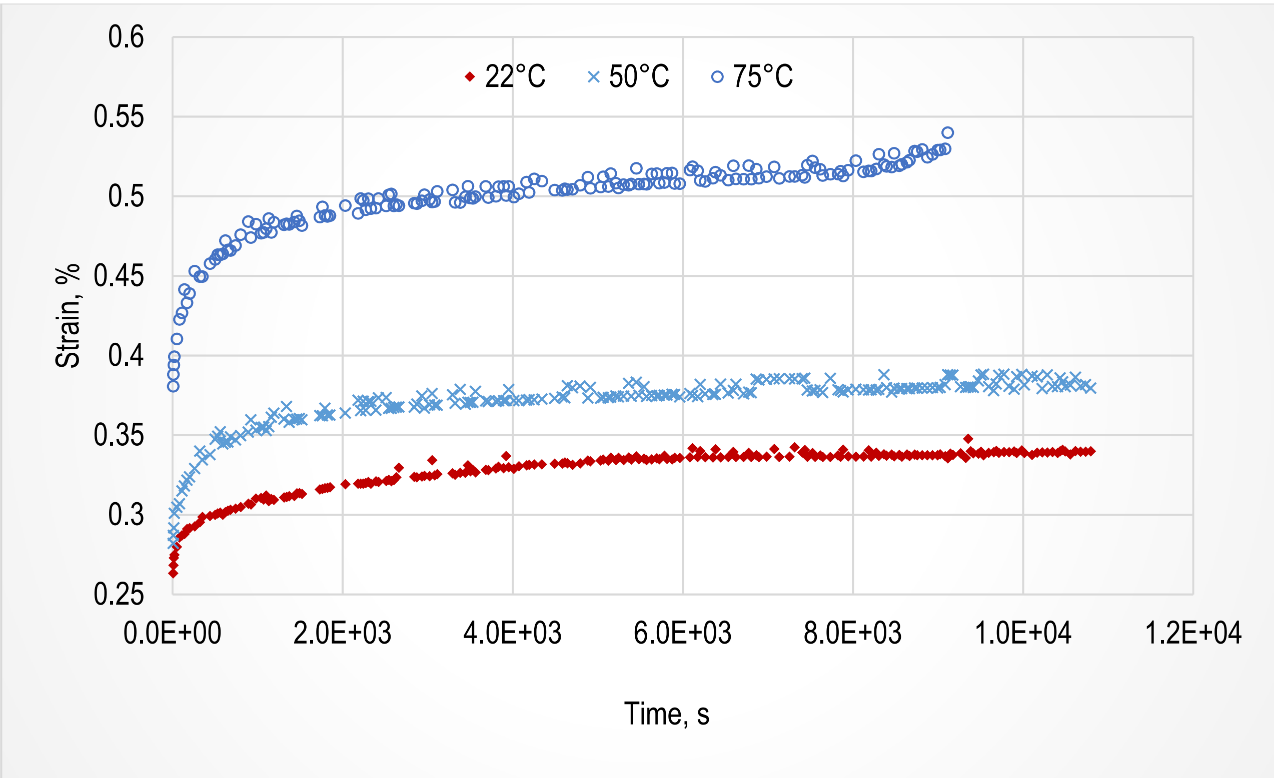

Figure 5. Tensile-creep curve of beech at 20N and 22°C, 50°C and 75°C respectively. Creep strain versus time.

- **Time-Temperature Superposition**

To estimate the long-term behavior of solid wood, one can either conduct experiments for an extended period of time or use the principle of time-temperature superposition (TTSP) to construct a master curve from a number of short-term creep tests at different temperatures. The experimental procedure has been arranged using Macknight[1] methods. A reference temperature T_0 (T_0=50°C) has chosen, the compliance and time curves for temperatures different than the reference temperature are horizontally shifted in such a manner that they join to form a smooth curve – master curve. To determine the horizontal and vertical shift factor Williamson[2] analytical approach was used. The shift factor was independent of the strain for horizontal shifts in time–temperature superposition, as well as the temperature- and strain-shift factors used to construct master curves were well fitted with the Williams–Landel–Ferry (WLF) relation[3]:

$$\log a_t = \frac{-C_1 \cdot (T - T_1)}{C_2 + (T - T_0)}$$

a_t – shift factor, C_i – constants, T_0 – reference temperature, T- sample temperature, °C.

If the shift factors, follow the WLF relation then the temperature shift factor is given by:

$$\Delta T = \frac{C_2 \cdot \log(T/T_0)}{C_1 - \log(T/T_0)}$$

Table 1. Shift Factors for the Master Curves

F stat.	T, °C	a_t (horizontal shift)	a_t (vertical shift)
20N	22	-0.83	+2.15
	50	+0.117	0
	75	+2.34	-2.074

A series of short-term creep tests were conducted at various temperatures, and the was successfully applied in the construction of master curves for the prediction of long-term creep strain of beech wood. The master curve was fitted to the power law equation using a nonlinear fitting procedure. Figure 6 and 7 shows a representative plot of the master curves for beech wood creep at 12% moisture content in tension.

[1] MacKnight, W. J. etl., Introduction to Polimers Viscoelasticity John Wiley and Sons, 1983.
[2] Williams, J. G., Accelerated Characterization of Creep Response of an Off-Axis Composite Material, Composites Science and Technology, Vol. 38, 1990, pp. 103-118.
[3] Jacem Tissaoui. Effects of Long-Term Creep on the Integrity of Modern Wood Structures. Blacksburg, Virginia, 1996, pp 10-11.

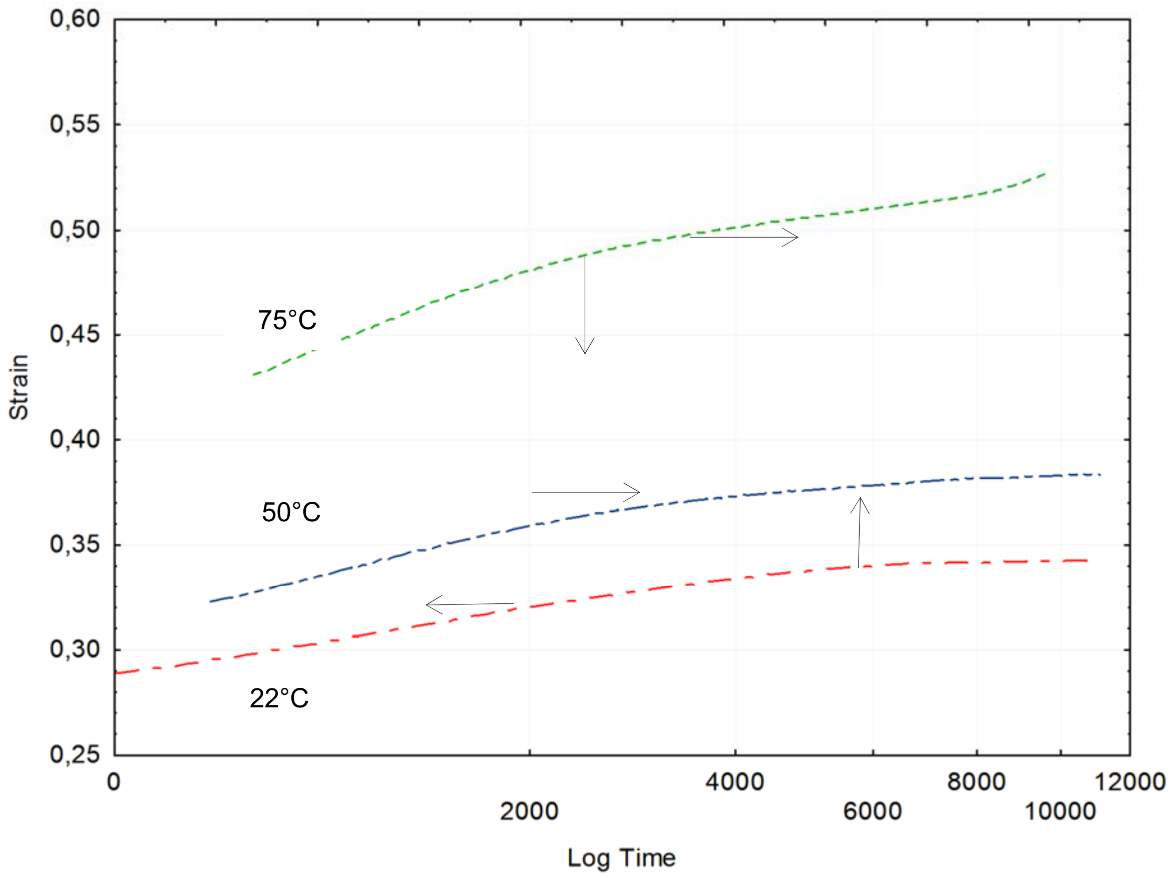

Figure 6. Master curve constructed with different temperature ranges (F stat. = 20N)

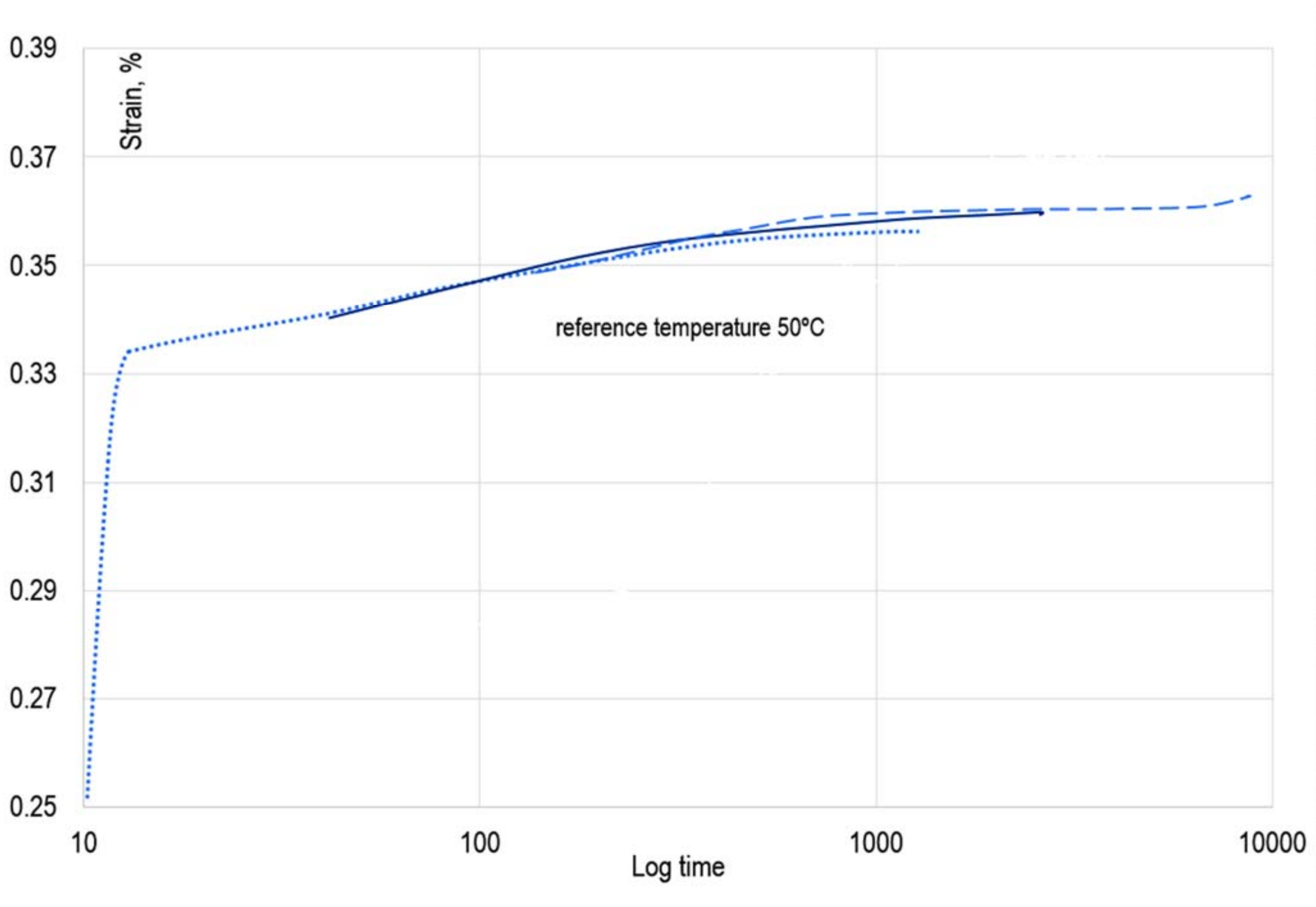

Figure 7. Master curve for beech wood creep behaivor (F stat. = 20N)

Conclusions

This STSM was devoted to verify possibility of Dynamic mechanical analysis using to investigate short-term creep behavior of beech wood. Short-term creep tests in tension have been conducted to obtain creep compliance curves at different temperatures and load level while maintaining a constant moisture content. The corresponding graphical dependencies characterizing the creep behavior of beech wood have been obtained. It should be noted, currently there is no standard testing method to properly evaluate the creep behaviour of wood using DMA, nevertheless the obtained results are in good agreement with the results obtained by other standard methods.

It was found that master curves constructed using DMA and TTSSP tended to overestimate a bit the creep strain of beech wood. The accuracy of the master curve may be improved by conducting more experiments with a smaller measurement step. Another important factor affecting the results of the experiments is the geometry of samples and the wood species. To conduct experiments using DMA and wood in the future has been decided to use wood species with a more "homogeneous" structure. Since the microscopic features of beech wood significantly influence to reproducibility of the results and the implementation of the comparative analysis as a whole.

According to the fitting results, the newly obtained master curves can smoothly predict creep strain under various stresses (Fstat. = 5-20N) and temperatures (T = 20-75°C). However, selected stresses were relatively small (F stat. = 20Nmax) for modelling creep behavior of wooden building elements. The study of creep with static loads up to 1000N is the task of the following experimental studies. The temperature range was chosen based on the practical environment condition. Employing the model for higher load/stress levels and wider temperature ranges would be an important task in the extension of the application of the model. Only the effect of increasing temperatures was considered, therefore, the effect of decreasing temperatures could be a topic for future research.

Based on the results obtained, we can summarize DMA can be quite acceptable for predicting the short-term creep behavior of wood materials. For a better quantitative assessment, it is necessary to carry out more thorough experimental studies taking into account all the factors described above.

Future collaboration with host institution

During this short-term scientific missions have been also discussed many issues regarding potential areas of cooperation between our institutions. We hope to continue and strengthen already existing cooperation between us and Prof. Pfriem scientific group. Both sides also planned new joint publications in scientific journals, organization of bilateral meetings between scientists from our universities, including through existing projects, applying new applications for joint project activities.

Foreseen publications/articles to result from the STSM

The results of STSM will be integrated, and planned to be presented at next COST1402 meeting. Also we think that it might be submitted as a pre-print in a scientific journal.

Other comments

I would like to thank the Managers of the Action FP1402 for agreeing this STSM which took me an opportunity to conduct this study at the University of Applied Sciences Eberswalde. I would also like to say that such kind of STSM is a great opportunity for young people to realize their scientific potential, as well as theoretical achievements in practical terms. Moreover, they contribute to democratization of relations and cooperation between the EU and its eastern neighbours (Eastern Neighbourhood countries), provides an opportunity and an incentive for further development of science at all. I also would like to express my personal thanks to Prof. Alexander Pfriem for agreeing to host me and all his colleagues for support during my short term staying there.

Confirmation by the host of the STSM

HNE Eberswalde
Hochschule für nachhaltige Entwicklung

Wood Chemistry, Wood Physics and Chemical Engineering
Prof. Dr.-Ing. Alexander Pfriem

Tel/Phone + 49 (0) 3334 657- 377 · Fax +49 (0)3334 657- 372
alexander.pfriem@hnee.de

April 30, 2017

Dear COST Action 1402 STSMs Manager,

I hereby confirm the successful execution of the short term scientific mission (The Short-Term Wood Creep Test by Means of DMA), in the framework of COST Action 1402 by Dr. Roman Shchupakivskyy from the Ukrainian National Forestry University, Faculty of Woodworking Technologies and Design, Lviv, Ukraine.

The STSM was performed during 14 days (17.04-30.04.2017) under the supervision of Prof. Dr.-Ing. Alexander Pfriem, Dr. Nadine Herold, M.Sc. Lothar Clauder in the Department of Wood Chemistry, Wood Physics and Chemical Engineering at the Eberswalde University for Sustainable Development, Eberswalde, Germany.

Above all this STSM was devoted to verify possibility of Dynamic mechanical analysis using to investigate short-term creep behaviour of beech wood. Short-term creep tests in tension have been conducted to obtain creep compliance curves at different temperatures while maintaining a constant moisture content. A series of data have been already obtained during the STSM, and the teamwork will continue at both universities.

Best Regards

Alexander Pfriem

HNE Eberswalde
Prof. Dr.-Ing. Alexander Pfriem

Hochschule für nachhaltige Entwicklung (F.
Fachbereich Holztechnik
Prof. Dr. -Ing. Alexander Pfriem
Schicklerstraße 5
16225 Eberswalde

EMAS

Hochschule für nachhaltige Entwicklung Eberswalde
Eberswalde University for Sustainable Development · *University of Applied Sciences*
Schicklerstraße 5 · D-16225 Eberswalde · Germany

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Appendices

Figure 8. Sampling preparation

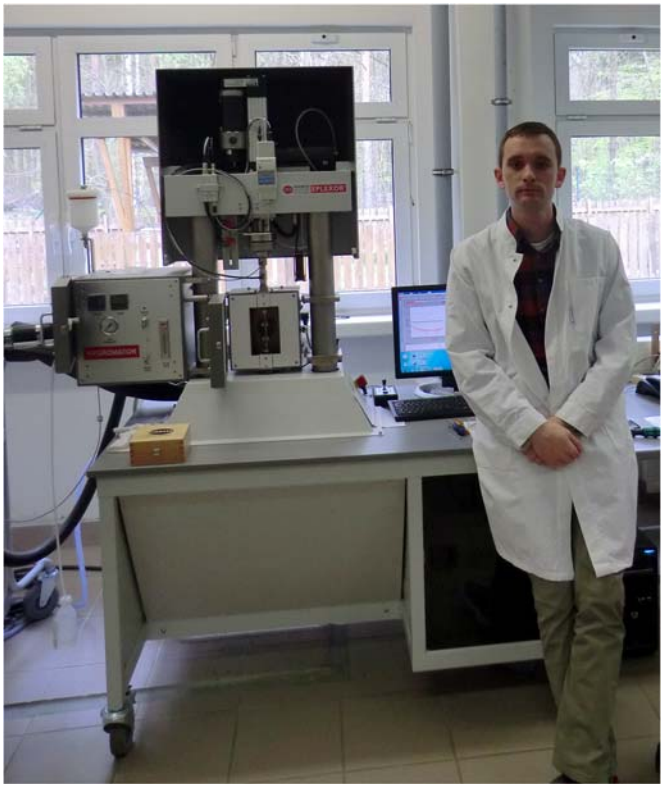

Figure 9. Working on wood creep performance on Gabo Eplexor 25 at HNE Eberswalde

Figure 10. With Prof. Alexander Pfriem scientific group at HNE Eberswalde