UNIVERSITY of SOPRON

11th Hardwood Conference

30-31 May 2024
Sopron

11TH HARDWOOD CONFERENCE PROCEEDINGS

Róbert Németh, Christian Hansmann, Holger Militz, Miklós Bak, Mátyás Báder

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Sopron, Hungary, 30-31 May 2024

Editors: Róbert Németh, Christian Hansmann, Holger Militz,
Miklós Bak, Mátyás Báder

UNIVERSITY OF SOPRON PRESS

SOPRON, 2024

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ISBN 978-963-334-518-4 (pdf)
DOI https://doi.org/10.35511/978-963-334-518-4
ISSN 2631-004X (Hardwood Conference Proceedings)

Constant Serial Editors: Prof. Dr. Róbert Németh, Dr. Miklós Bak
Cover image based on the photograph of Dr. Miklós Bak, 2024

The manuscripts have been peer-reviewed by the editors and have not been subjected to linguistic revision.
In the articles, corresponding authors are marked with an asterisk (*) sign.

University of Sopron Press, 2024 (Bajcsy-Zsilinszky 4, 9400 Sopron, Hungary)
Responsible for publication: Prof. Dr. Attila Fábián, rector of the University of Sopron

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Content

Preface to the 11TH HARDWOOD CONFERENCE

Róbert Németh............ 9

Plenary Session - Keynotes of the 11TH HARDWOOD CONFERENCE

The role of black locust (*Robinia pseudoacacia*) in Czechia
Ivan Kuneš, Martin Baláš, Přemysl Šedivka, Vilém Podrázský............ 11

Engineered wood products for construction based on beech and poplar resources in Europe
Joris Van Acker, Liselotte De Ligne, Tobi Hallez, Jan Van den Bulcke............ 23

The situation in the hardwood sector in Europe
Maria Kiefer-Polz, Rainer Handl............ 60

Session I - Silvicultural aspects and forest management of hardwoods

Monitoring xylogenesis esis as tool to assess the impact of different management treatments on wood formation: A study case on *Vitis vinifera*
Angela Balzano, Maks Merela, Meta Pivk, Luka Krže, Veronica De Micco............ 62

The History of Forests - Climate Periods of the Middle Ages and Forestry
Emese Berzsenyi, Dóra Hegyesi, Rita Kattein-Pornói, Dávid Kazai............ 63

Climate change mitigation aspects of increasing industrial wood assortments of hardwood species in Hungary
Éva Király, Zoltán Börcsök, Attila Borovics............ 71

Uncovering genetic structures of natural Turkey oak populations to help develop effective climate change strategies for forestry
Botond B. Lados, László Nagy, Attila Benke, Csilla É. Molnár, Zoltán A. Köbölkuti, Attila Borovics, Klára Cseke............ 78

Ash dieback: infection biology and management
Nina E. Nagy, Volkmar Timmermann, Isabella Børja, Halvor Solheim, Ari M. Hietala............ 86

The Role of Industrial Hardwood Production Plantations and Long-Term Carbon Sequestration in a Circular Economy via the New Robinia pseudoacacia 'Turbo Obelisk' Varieties
Márton Németh, Kálmán Pogrányi, Rezső Solymos............ 95

Initial growth of native and introduced hardwoods at the afforested agricultural lands – preliminary results
Vilém Podrázský, Josef Gallo, Martin Baláš, Ivan Kuneš, Tama Abubakar Yahaya, Miroslav Šulitka............ 102

Poster Session

Light response curve analysis of juvenile Püspökladányi and Üllői black locust
Tamás Ábri, Zsolt Keserű, József Csajbók............ 111

Revealing the optimum configuration of heat-treated wood dowel joints by means of Artificial Neural Networks and Response Surface Methodology
Bogdan Bedelean, Cosmin Spîrchez............ 115

Artificial neural networks as a predictive tool for thrust force and torque during drilling of wood-based composites
Bogdan Bedelean, Mihai Ispas, Sergiu Răcășan............ 121

Research on the value retention of hardwood products in the spirit of sustainability
Daniel Bodorkós , József Zalavári , Péter György Horváth *126*

Abrasive Water Jet Cutting vs. Laser Jet Cutting of Oak Wood Panels
Camelia Cosereanu, Gheorghe Cosmin Spirchez, Antonela Lungu, Sergiu-Valeriu Georgescu, Alexandru Catalin Filip, Sergiu Racasan *131*

Polyphenol content of underutilized wood species from Hungary
Tamás Hofmann, Haruna Seidu, Kibet Tito Kipkoror *136*

Wood quality evaluation of 32 grafted clone linages of Keyaki (*Zelkova serrata*) plus trees 12 years after planting
Kiyohiko Ikeda, Shigehiro Yamamoto *141*

Influence of the number of belts over vibrations of the cutting mechanism in woodworking shaper
Georgi Kovatchev, Valentin Atanasov *146*

The impact of litter forest fires on the internal structure of wood from stem of beech trees
Elena-Camelia Musat, Costin-Ovidiu Vantoiu, Emilia-Adela Salca *153*

Analysing innovative wood joints crafted by laser cut spline curves
László Németh, József Garab, Péter György Horváth *158*

Dynamic fatigue tests of hardwoods
Gábor Orbán, Antal Kánnár *163*

Restoration of an old painted oak boardsign - A case study
Gabriel Calin Canalas, Emilia-Adela Salca, Elena-Camelia Musat *168*

Some physical properties of native and thermo-treated *Fraxinus excelsior* timber
Cosmin Spîrchez, Aurel Lunguleasa, Alin Olărescu, Camelia Coșereanu, Bogdan Bedelean *173*

The surface morphology of sanded curly maple in comparison with straight grain maple selected for musical instruments
Mariana Domnica Stanciu, Lidia Gurau, Florin Dinulica, Catalin Constantin Roibu, Cristian Hiciu, Andrei Mursa, Marian Stirbu *178*

Analysis of changes in the composition of beech as an important industrial raw material in Hungary
Katalin Szakálosné Mátyás, Attila László Horváth *183*

Investigation of old hardwood structure element
Fanni Szőke, Antal Kánnár *187*

An investigation of the influence of coating film thickness on the light induced colour changes of clear coated maple (*Acer pseudoplatanus*) wood surfaces with natural aspect
Mihai-Junior Torcătoru, Maria Cristina Timar *192*

Composite Material Manufacturing from Plantation Paulownia Wood with Using Microwave Technology: Technical and Cost Analyses
Grigory Torgovnikov , Peter Vinden, Alexandra Leshchinskaia *198*

Thermal modification of wood as a tool for changing the colour of hardwoods
Vidholdová Zuzana *203*

High termite resistance of kempas (*Koompassia malaccensis*) hardwood protected with a novel vegetal extracts-cypermethrin wood preservative under outdoor aboveground tropical environment
Messaoudi Daouia, Wong Andrew H.H. *209*

Comparison of wood properties of pedunculate oak and non-native northern red oak from an anthropogenic site
Aleš Zeidler, Vlastimil Borůvka *214*

Acoustic Parameters of Pioneer Wood Species
Petr Horák, Vlastimil Borůvka *219*

Determination of Elastic Parameters of Birch and Oak Wood Using Optical Method
David Novák, Vlastimil Borůvka, Petr Horák, Tomáš Kytka *224*

Preliminary study on climate change impacts on annual wood growth development in Hungary
Péter Farkas, Zsolt György Tóth, Huba Komán *230*

Combustion characteristics of Russian olive (*Elaeagnus angustifolia* L.)
Szabolcs Komán, Krisztián Töröcsi *236*

Withdrawal capacity of Green ash (*Fraxinus pennsylvanica* Marsh.) and Box elder (*Acer negundo* L.)
Szabolcs Komán, Boldizsár Déri *241*

Formaldehyde emission from wood and wood-based products
Szabolcs Komán, Csilla Czók, Tamás Hofmann *246*

Finite element analysis of heat transfer of Turkey oak (*Quercus cerris*)
Sándor Borza, Gergely Csiszár, József Garab, Szabolcs Komán *250*

Possible alternative to creosote treated railway sleepers, Fürstenberg-System Sleeper (FSS)
Szabolcs Komán, Balogh Mátyás Zalán, Sándor Fehér, ... *255*

Investigation of bendability characteristics of wood-based polymer composites
S. Behnam Hosseini, Milan Gaff *260*

Comparing the blossoming and wood producing properties of selected black locust clones
Alexandra Porcsin, Katalin Szakálosné Mátyás, Zsolt Keserű *266*

The influence of two different adhesives on structural reinforcement of oak-wood elements by carbon and glass fibres
Andrija Novosel, Vjekoslav Živković *271*

Investigating Kerf Topology and Morphology Variation in Native Species After CO2 Laser Cutting
Lukáš Štefančin, Rastislav Igaz, Ivan Kubovský, Richard Kminiak *272*

Comparison of fluted-growth and cylindrical hornbeam logs from Hungarian forests
Mátyás Báder, Maximilián Cziczer *279*

Thermal modification affects the dynamic vapor sorption of tree of heaven wood (*Ailanthus altissima, Mill.*)
Fanni Fodor, Lukas Emmerich, Norbert Horváth, Róbert Németh *285*

How conditions after application affect the depth of penetration of gel wood preservative in oak
Jan Baar, Štěpán Bartoš, Anna Oberle, Zuzana Paschová *290*

The weathering of the beech wood impregnated by pigmented linseed oil
Jakub Dömény, Jan Baar *294*

Examination of the durability of beeswax-impregnated wood
Miklós Bak, Ádám Bedők, Róbert Németh *299*

Preparation of pleated oak samples and their bending tests at different moisture contents
Pál Péter Gecseg, Mátyás Báder *304*

Bending test results of small-sized glued laminated oak timber consisting of 2, 3 and 5 layers
Dénes Horváth, Sándor Fehér *308*

Homogenized dynamic Modulus of Elasticity of structural strip-like laminations made from low-grade sawn hardwood
Simon Lux, Johannes Konnerth, Andreas Neumüller *314*

Impact of varnishing on the acoustic properties of sycamore maple (*Acer pseudoplatanus*) panels
Aleš Straže, Jure Žigon, Matjaž Pavlič *319*

The effect of wood and solution temperatures on the preservative uptake of Pannonia poplar and common spruce – preliminary research
Luca Buga-Kovács, Norbert Horváth *325*

Session II - Hardwood resources, product approaches, and timber trade

Birch tar – historic material, innovative approach
Jakub Brózdowski, Monika Bartkowiak, Grzegorz Cofta, Grażyna Dąbrowska, Ahmet Erdem Yazici, Zbigniew Katolik, Szymon Rosołowski, Magdalena Zborowska 330

Beech Wood Steaming – Chemical Profile of Condensate for Sustainable Applications
Goran Milić, Nebojša Todorović, Dejan Orčić, Nemanja Živanović, Nataša Simin 336

Towards a complete technological profile of hardwood branches for structural use: Case study on Poisson's ratio
Tobias Nenning, Michael Grabner, Christian Hansmann, Wolfgang Gindl-Altmutter, Johannes Konnerth, Maximilian Pramreiter 342

Low-value wood from non-native tree species as a potential source of bioactive extractives for bio-based preservation
Viljem Vek, Ida Poljanšek, Urša Osolnik, Angela Balzano, Miha Humar, Primož Oven 349

Hardwood Processing - do we apply appropriate technologies?
Alfred Teischinger 357

Session III - Surface coating and bonding characteristics of hardwoods

Influence of pretreatments with essential oils on the colour and light resistance of maple (*Acer pseudoplatanus*) wood surfaces coated with shellac and beeswax
Emanuela Carmen Beldean, Maria Cristina Timar, Dana Mihaela Pop 365

Oak timber cross-cutting based on fiber orientation scanning and mechanical modelling to ensure finger-joints strength
Soh Mbou Delin, Besseau Benoit, Pot Guillaume, Viguier Joffrey, Marcon Bertrand, Milhe Louis, Lanvin Jean-Denis, Reuling Didier 376

From Phenol-Lignin Blends towards birch plywood board production
Wilfried Sailer-Kronlachner, Peter Bliem, Hendrikus van Herwijnen 386

Flatwise bending strength and stiffness of finger jointed beech lamellas (*Fagus sylvatica*, L.) using different adhesive systems and effect of finger joint gap size
Hannes Stolze, Adefemi Adebisi Alade, Holger Militz 395

Mode I fracture behaviour of bonded beech wood analysed with acoustic emission
Martin Capuder, Aleš Straže, Boris Azinović, Ana Brunčič 402

Session IV - Hardwood structure and properties

Compression strength perpendicular to grain in hardwoods depending on test method
Marlene Cramer 410

Compensatory Anatomical Studies on *Robinia*, *Sclerocarya* and *Ulmus*
Fath Alrhman A. A. Younis, Róbert Németh, Mátyás Báder 420

The influence of the type of varnish on the viscous-elastic properties of maple wood used for musical instruments
Roxana Gall, Adriana Savin, Mariana Domnica Stanciu, Mihaela Campean, Vasile Ghiorghe Gliga 426

XRF investigation of subfossil oak (*Quercus* spp) wood revealing colour - iron content correlation
Nedelcu Ruxandra, Timar Maria Cristina, Beldean Emanuela Carmen 435

Investigating the Development of Heartwood in *Quercus robur* in Denmark
Andrea Ponzecchi, Albin Lobo, Jill Katarina Olofsson, Jon Kehlet Hansen, Erik Dahl Kjær, Lisbeth Garbrecht Thygesen 445

Modelling tensile mechanical properties of oak timber from fibre orientation scanning for strength grading purpose
Guillaume Pot, Joffrey Viguier, Benoit Besseau, Jean-Denis Lanvin, Didier Reuling *452*

Green oak building – small diameter logs for construction
Martin Huber, Franka Brüchert, Nicolas Hofmann, Kay-Uwe Schober, Beate Hörnel-Metzger, Maximilian Müller, Udo H. Sauter *461*

An evaluative examination of oak wood defect detection employing deep learning (DL) software systems.
Branimir Jambreković, Filip Veselčić, Iva Ištok, Tomislav Sinković, Vjekoslav Živković, Tomislav Sedlar *466*

Comparison of surface roughness of milled surface of false heartwood, mature wood, and sapwood within beech wood
Lukáš Adamčík, Richard Kminiak, Adrián Banski *467*

Session V - Hardwoods in composites and engineered materials

Developing Laminated Strand Lumber (LSL) based on underutilized Hungarian wood species
László Bejó, Tibor Alpár, Ahmed Altaher Omer Ahmed *475*

Feasibility study on manufacturing finger-jointed structural timber using *Eucalyptus grandis* wood
Adefemi Adebisi Alade, Hannes Stolze, Coenraad Brand Wessels, Holger Militz *481*

A novel approach for the design of flame-retardant plywood
Christian Hansmann, Georg Baumgartner, Christoph Preimesberger *486*

The use of beech particles in the production of particleboards based on recycled wood
Ján Iždinský, Emilia Adela Salca, Pavlo Bekhta *493*

Thermal properties of highly porous wood-based insulation material
Kryštof Kubista, Přemysl Šedivka *501*

Session VI - Modification & functionalization

Quantitative and qualitative aspects of industrial drying of Turkey oak lumber
Iulia Deaconu, Bogdan Bedelean, Sergiu Georgescu, Octavia Zeleniuc, Mihaela Campean *508*

Changes in properties of maple by hygrothermally treatment for accelerated ageing at 135-142°C
Tobias Dietrich, Herwig Hackenberg, Mario Zauer, Holger Schiema, André Wagenführ *518*

Change of chemical composition and FTIR spectra of Turkey oak and Pannonia poplar wood after acetylation
Fanni Fodor, Tamás Hofmann *525*

Change of cellulose crystal structure in beech wood (*Fagus sylvatica* L.) due to gaseous ammonia treatment
Herwig Hackenberg, Tobias Dietrich, Mario Zauer, Martina Bremer, Steffen Fischer, André Wagenführ *535*

Evaluation of weathering performance of acetylated hardwood species
Rene Herrera Diaz, Jakub Sandak, Oihana Gordobil, Faksawat Poohphajai, Anna Sandak *539*

Unlocking a Potential Deacetylation of Acetylated Beech (*Fagus sylvatica* L.) LVL
Maik Slabohm, Holger Militz *544*

Fork and flying wood tests to improve prediction of board stress development during drying
Antoine Stéphan, Patrick Perré, Clément L'Hostis, Romain Rémond *549*

Modification of different European hardwood species with a bio-based thermosetting resin on a semi-industrial scale
Christoph Hötte, Holger Militz *557*

Finite element analysis of heat transfer of Turkey oak (*Quercus cerris*)

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Keywords: heat transfer, temperature measurement, finite element analysis, temperature distribution, Turkey oak (*Quercus cerris*)

ABSTRACT

Understanding the heat transfer in wood is essential when applying heat technological processes to it. In this study, the transient heat transfer characteristics during the heat treatment of Turkey oak (*Quercus cerris*) at 30 °C, 50 °C, and 70 °C were numerically investigated. The heat transfer model was compared to experimental results. The model aligns well with the experimental values in time, especially at the beginning and the middle phases, where the heat transfer is more dynamic than in later phase of the heat treatment process. The differences between the model and the actual temperatures varies up to 3.38 °C, indicating a maximum relative deviation of only 5.35%. This simulation of heat transfer within the hardwood samples offers valuable insights into the heat treatment processes.

INTRODUCTION

Before manufacturing wood products, special attention shall be paid to the proper preparation of the raw material. Ideally, this starts at the storage stage, where the raw material is stored at the right temperature and humidity to achieve or maintain the desired moisture content. Neglecting these parameters can cause significant problems before, during and after the technological process. The effect of changes in external temperature on the internal temperature of the wood is particularly important in certain technological processes. In the case of gluing, for example, a large temperature difference between the internal temperature of the wood and its surface causes problems because the colder layer inside can cool the adhesive below the minimum film-forming temperature. In such cases, it is important to know how long it takes for a material stored at a lower temperature than the production temperature to heat through its entire cross-section. Also important from an energy efficiency point of view is the reheating time of the wood in case of drying or heat treatment. In addition to considering the needs of manufacturing technology, knowledge of this property of wood is an important factor in the behaviour of structures and products in or in contact with the exterior environment under thermal fluctuations.

Due to the inhomogeneous, anisotropic properties, several factors influence the thermal conductivity of wood. The most important of these are the wood species, density, moisture content, anatomical orientation (longitudinal, radial, tangential), cross-sectional dimensions and the temperature. For European wood species, the coefficient of thermal conductivity perpendicular to the grain is about half that parallel to the grain. At low moisture content – between 0% and fibre saturation – wood is a good insulator. The more porous wood has a lower thermal conductivity (Rohsenow 1973), because the free water conducts more heat (Siau 1984). According to Parrot and Stuckes (1975), the heat conduction along the length of the microfibril is greater, so the thermal conductivity will be higher in the longitudinal direction than in the transverse direction. The difference between the radial and tangential anatomical directions might be affected by the rays. Since these cells are radially oriented, the conductivity will be higher in this direction. The thermal conductivity is determined by the amount of latewood for conifers (Steinhagen 1977).

Thermal properties of wood are available for the wood species in the literature. Among others Sitkei (1994) and Molnár (2004) published relevant findings, but dedicated information for Turkey oak

(*Quercus cerris*) is scarce. Therefore, the goal of this study was to create and validate a numerical model for the heat transfer process in Turkey oak when elevated temperature was applied.

MATERIALS AND METHODS

Materials and the experimental setup

The Turkey oak (*Quercus cerris*) cubic specimens had 45 mm edge length. Measurements were performed with an Ahlborn Almemo 2590 universal measuring device using NiCr-Ni thermowire with the sensor inserted in the centre of the samples through a 2 mm diameter hole (Figure 1). After conditioning the samples in normal climate (t=20°C; RH=65%), the 3 samples were put into the climate chamber with temperatures of 30°C, 50°C and 70°C. The temperature was recorded in 5 minutes incremental until 60 minutes.

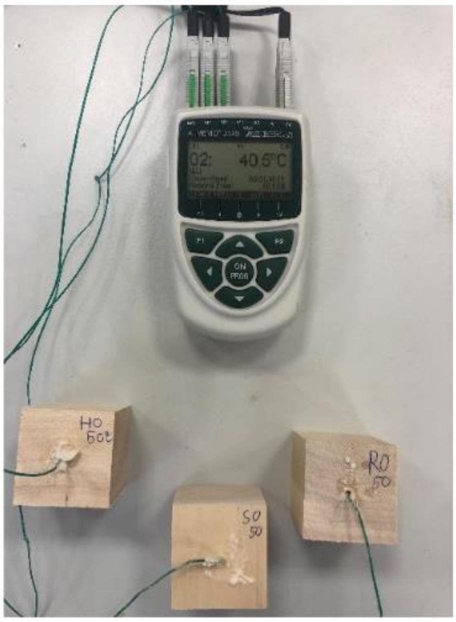

Figure 1: Measurement equipment and the positioning of the thermosensors

Numerical simulations

For the numerical simulations the followings are assumed: 1) considering the low initial moisture content of the samples and the heat treatment temperature, it can be inferred that they might be excessively dried during the treatment process, 2) The chemical reactions linked to the loss of water in the samples are not being considered, 3) the dimensional changes in the wood could be neglected, 4) no degradation of the solid material or heat generation within the wood occurred throughout the heat treatment process, 5) the sensor is represented as a node in the centre of the cube. To conduct transient thermal analysis, computational simulations were performed using Ansys Mechanical APDL (licensed product is Ansys® Academic Research Mechanical, Release 15). In all computations SOLID278 element was used. The element is applicable to a 3D transient thermal analysis. The FE model consist of 8000 elements. Orthotropic thermal conductivity was applied in the material model. The values were calculated according to Sitkei (1994). The specific heat capacity was calculated according to Molnár (2004). The thermal conductivity values and the specific heat capacity calculations were based on the density, moisture content and the temperature of the wood. Although the convective heat transfer coefficient may vary according the wind speed, the value was taken from Zhang et al. (2017).

Table 1: Material and heat treatment parameters applied in the simulation

Parameters	Value
Density $\rho/(\mathrm{kg\cdot m^{-3}})$ [a]	824.8
Moisture content (%) [a]	12
Longitudinal thermal conductivity $\lambda/(\mathrm{W\cdot m^{-1}\cdot K^{-1}})$[b]	0.60

Radial thermal conductivity $\lambda/(W\cdot m^{-1}\cdot K^{-1})$[b]	0.43
Tangential thermal conductivity $\lambda/(W\cdot m^{-1}\cdot K^{-1})$[b]	0.37
Convective heat transfer coefficient $h/(W\cdot m^{-2}\cdot K^{-1})$[c]	15.8
Specific heat capacity $C/(J\cdot kg^{-1}\cdot K^{-1})$[d]	from 1532 (20°C) to 1750 (70°C)
Initial temperature t_0/(°C) at 30°C treatment[e]	21.53
Initial temperature t_0/(°C) at 50°C treatment[e]	21.80
Initial temperature t_0/(°C) at 70°C treatment[e]	31.60
Target temperature t_0/(°C) at 30°C treatment[f]	29.51
Target temperature t_0/(°C) at 50°C treatment[f]	50.57
Target temperature t_0/(°C) at 70°C treatment[f]	71.50

[a]measured on the samples; [b]calculated according to Sitkei (1994); [c]adapted from Zhang et al. (2017); [d]calculated in 2°C steps according to Molnár (2004); [e] average of the temperatures measured in the samples; [f]average of temperature measured in the climate chamber

RESULTS AND DISCUSSION

The contour plot for the simulation at the time step of 600 s in case of 70°C heat treatment is presented on the Figure 2. The result of the different thermal conductivity values according to the anatomical directions are visible in the temperature distribution.

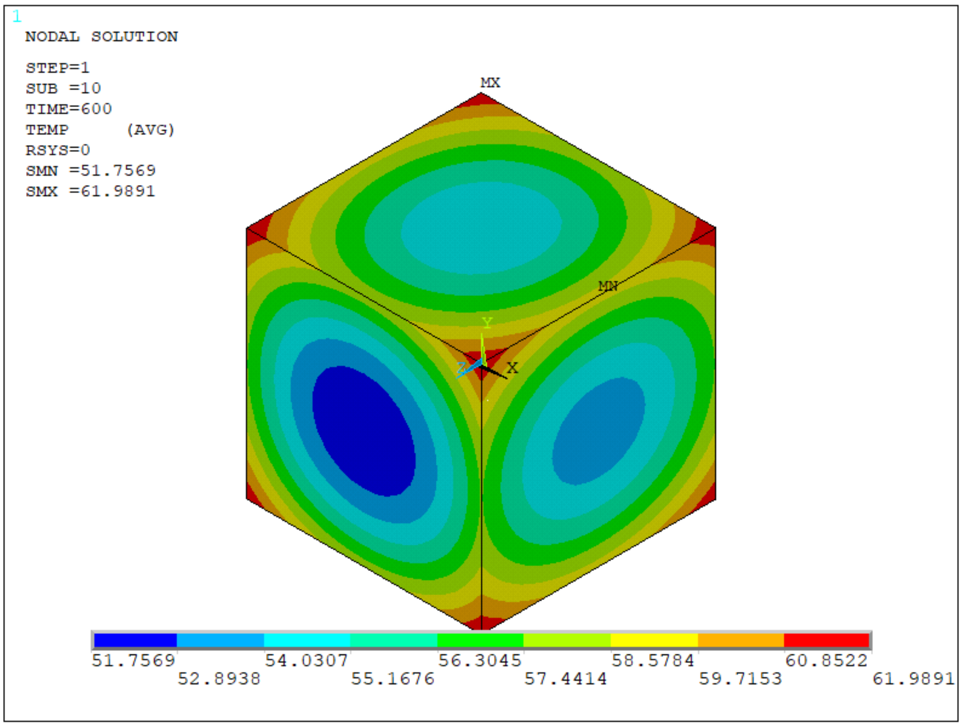

Figure 2: Temperature nephogram at 600 s at 70°C heat.

The heat was applied to all of faces of the cube. The sensor was in the center of the cube, the temperature of the node at the center point was analysed. In case of 30°C heat treatment (Figure 3), the Sample 1 curve shows some measurement discrepancy compared to the other two samples, because the measured values up to 25th min are a bit higher.

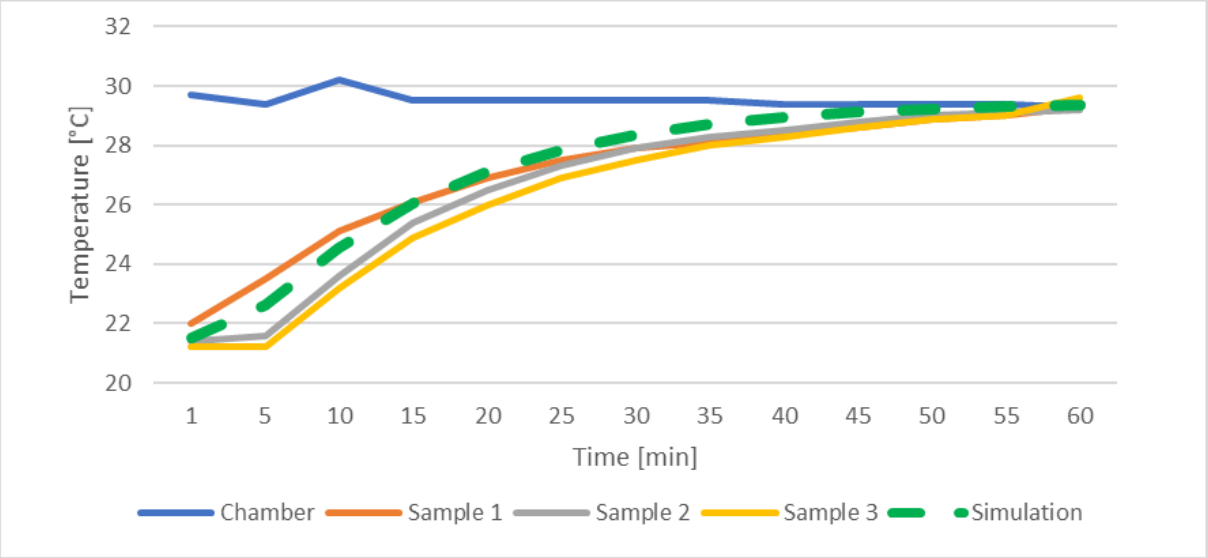

Figure 3: Comparison of experimental and simulated temperatures at 30 °C heat

In case of 50°C heat treatment (Figure 4), the misalignment is negligible. In case of 70°C treatment (Figure 5), the beginning and the middle phase of the curve is following the experimental values. However, the simulation achieved the intended final temperature, but the experimental values did not. This difference may be attributed to variations in the heat conductive coefficient and the convective heat transfer coefficient, which fluctuated with temperature. Additionally, there may thermal resistance present between the samples and their surroundings. The differences between the measurement results and the model were up to 0.6°C, 1.3°C and 3.6°C in case of 30°C, 50°C and 70°C temperatures respectively.

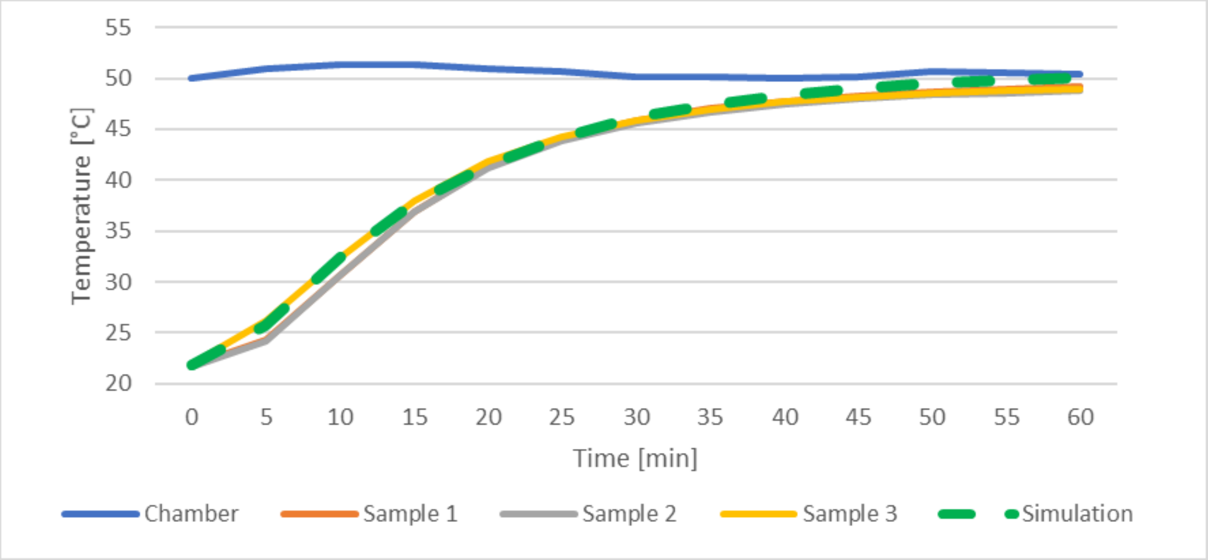

Figure 4: Comparison of experimental and simulated temperatures at 50 °C heat

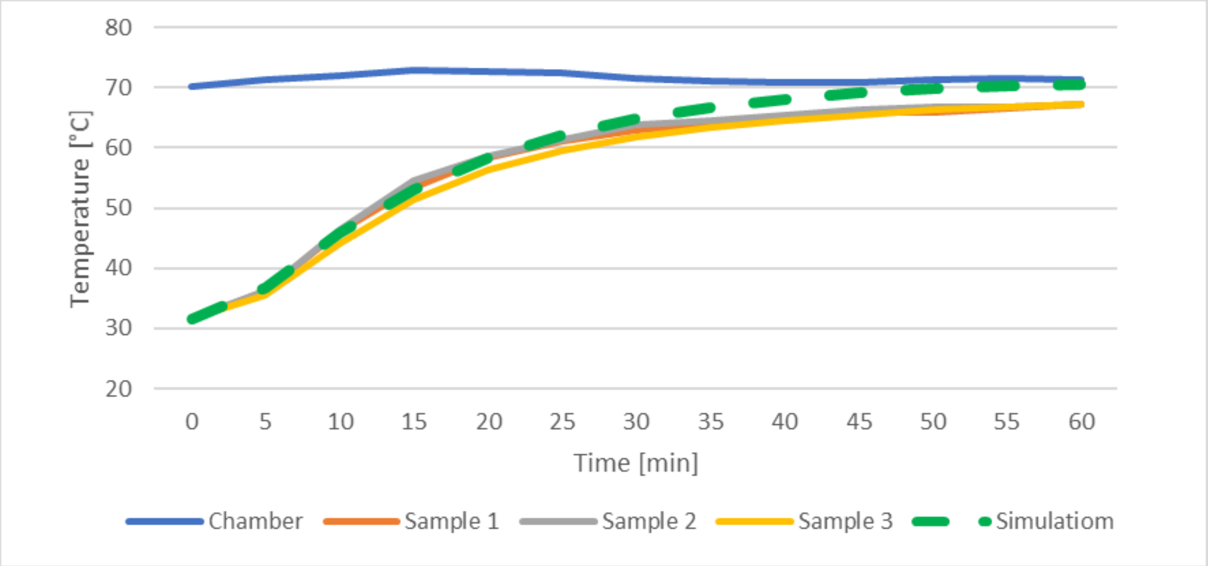

Figure 5: Comparison of experimental and simulated temperatures at 70 °C heat

CONCLUSIONS

Throughout the diverse technological processes in the wood industry, it is necessary to treat and store raw materials at given temperatures. Therefore, the heat transfer process should be carefully investigated. In order to gather more physical properties from hardwoods, the thermal conductivity of Turkey oak was modelled using the finite element method. Comparing the modelled and measured temperatures, a maximum difference of 3.38°C was observed, indicating a maximum relative deviation of only 5.35% at higher heating temperatures. At a lower heating temperature, the model is even more precise. In this case, at the vast majority of measurement points, the relative deviation was less than 3%. This accuracy can be used for planning the necessary technological time of different heat technological processes. The determination of the more accurate technological times saves time, energy and cost.

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