Final technical report

"Complex analysis of the physico-mechanical and surface-physical properties of wood with low density"
ID: OTKA K 116 216
supported by

NEMZETI KUTATÁSI,
FEJLESZTÉSI ÉS INNOVÁCIÓS HIVATAL

National Research, Development and Innovation Office Hungary (NKFIH)

Researchers:
Prof. Dr. László Tolvaj – head of the research group
Dr. Norbert Horváth – project manager
Prof. Dr. Divós Ferenc
Dr. Csilla Csiha
Dr. Antal Kánnár
Éva Annamária Papp
Péter Szeles
Ádám Makk

Students:
István Eső, Domonkos Ete Farkas, László Rábai,
Luca Kovács, Richárd Ragács, Dávid Rózinger

Technicians:
Imre Horváth, István Schantl, Szabolcs Csikós

University of Sopron, Simonyi Károly Faculty

30.09.2019.

1. Scientific background and antecedents

Investigations on the Hungarian poplar were conducted in the past in the former budapester Wood Research Institute (FAKI) and were performed also at the University of West Hungary (nowadays: University of Sopron), Faculty of Wood Science (nowadays: Simonyi Károly Faculty). In the followings we make a short summary of establishments and results of relevant researches published before our OTKA K 116 216 project. In September 2011 a research group was founded at the Faculty of Wood Science with the aim to support the development of glued laminated poplar timber. Investigations were planned to be made on smaller scale models, at the beginning on straight later on curved beams. For 2012 the review of the scientific literature was foreseen, which ended with the following considerations: in the 1960s and 1970s due to the general lack of prime material investigations were made on replacing the spruce with poplar at the budapester Wood Research Institute. The physico-mechanical properties of the different refined poplar species were investigated. It was deduced that at medium load near prescribed technical conditions (wood preservation) first of all the Robusta poplar (*Populus* × *euramericana* cv. Robusta), but time to time the Marilandica poplar (*Populus* × *euramericana* cv. Marilandica) and the Serotina poplar (*Populus* × *euramericana* cv. *Serotina*) also can be used for structural purposes. Good quality poplar in Hungary is mostly used by the furniture industry for to manufacture hidden elements, whilst they are frequently used in Italy and French for structural purposes (glued laminated timber, structural beams etc.) as well. Generally the strength of the poplar is 20-30% lower than the one of coniferous species but in the same time the presence of knots has only a minor influence on their strength compared to Scots pine (*Pinus sylvestris*) and Austrian pine (*Pinus nigra*). Generally, it was stated that a higher density is associated with a higher strength (Molnár et al. 2006). The density varies strongly with the different hybrids causing high standard deviation of the mechanical properties (Table 1).

Table 1 - Poplar groups according to air-dried density of xylem

Group	Density	Poplar hybrids
Very low density	< 0,36 g/cm^3	I-214, Villafranca, etc.
Mediocre low density	0,36 – 0,40 g/cm^3	Kopecky, Sudár, etc.
Low density	> 0,40 g/cm^3	Robusta, Marilandica, Pannónia, etc.

Regarding coniferous species Hungary practically is restricted completely to import. Earlier investigations were done, targeting technological development which takes into account the distribution of species of the domestic forest stock. The researches justified that poplar species instead of coniferous species may also be successfully used as glued laminated (glulam) timber (Erdélyi et al. 1977). As top of the predecessors research work a 800 m^2 hall was planned and built using pin type joints never used before in Hungary. The hall built in 1974 at Velence was 2012 in a surprisingly good condition (Schlosser et al. 2012). This fact also proves that there is a great potential in the use of poplar and justifies further studies on the disposable hybrid poplar species (for example Pannónia poplar).

2. Aim of the research work

The aim of our research was the evaluation of base properties of Pannónia poplar wood. There is no complex, scientific data available regarding the poplar wood stock of rotation age. Well known, that the properties of xylem can differ according to the plantation characteristics (the quality and the composition of the soil), meteorological conditions (number of sunny hours, the quantity of rainwater, etc.). One of the targets was to reveal what properties are typical for the Pannónia poplar hybrids varying with the plantation characteristics. We planned to collect data to predict the strength properties of the Pannónia poplar by effectuating on-site measurements on different plantations (on living trees). Within the laboratory investigations done after the on-site data collection the investigation of the anatomical tissues structure, density, shrinkage and swelling, equilibrium moisture content, static mechanical properties, durability were the most important material scientific targets. During the surface-physical investigations we planned to describe the phenomena of the wood border surface The long time performance of glued-laminated beams is not properly investigated yet. Relevant data of a basic research is missing in case of Pannónia poplar, such as the surface free energy, parameters of wetting and wettability as function of surface roughness and the influencing possibilities in controlled condition to achieve a controlled adhesion with long time performance in outdoor conditions. Contrary to other homogeneous materials the physico-chemical status of wood surface with its inhomogeneous, anisotropic structure was not yet properly described especially due to the surface roughness, occurring due to machining and the peculiarities of the anatomical microstructure. One of our main targets was to understand and to influence the status of the wood surface prior to bonding (and coating) in controlled conditions in order to enhance the adhesion and the long-term durability.

3. Results

3.1 Analysis of literary data

Willows and poplars belong botanically to the same family, the Salicaceae. The genus *Populus* is represented in the northern hemisphere with about 40 species. Sections such as *Aigerios* and partially *Leuce* in Hungary (Tóth and Erdős 1988), *Aigeros*, *Leuce* and *Tacamahaca* in Austria (Nebenführ 2007) have forestry importance. The European black poplar (*Populus nigra* L.) and the American black poplar (*Populus deltoides* Bartr. Ex Marsh.) and their clones (*Populus* × *euramericana*) are systematically assigned to the poplar section *Aigerios*. The Pannónia poplar (*Populus* × *euramericana* cv. Pannónia) is an artificial variety that washybridized by Ferenc Kopeczky, forest scientist at the Hungarian Forest Research Institute (ERTI) in Sárvár. According to Tóth and Erdős (1988), the parents of Pannónia poplar were *Populus deltoides* S-1-54 Belgium and *Populus nigra* Lébény 211. It has a similar rapid growth as the variety 'I 214' (*Populus* × *euramericana* cv. 214), and can reach a similar density as the wood of Robusta poplar (*Populus* × *euramericana* cv. Robusta) (Molnár and Bariska 2006). The industrial poplar breeding was started in Hungary mainly at the floodplain of the Danube in the 1920s. According to Tóth and Erdős (1988) the data shows a marked increase (more than 115.000 ha) in the total area of Poplar populations between 1949 and 1986. Thanks to its outstanding characteristics,

the poplar variety 'Pannónia' was one of the most important planting goods in Hungary in the 1990s (Tóth 2006).

Further information to this subtopic can be found in our published papers:

Éva Annamária Papp, Norbert Horváth
Nyár faanyagok anyagtudományi vizsgálataihoz szükséges hazai szakirodalom áttekintése, értékelése, In: FAIPAR 64. évf. 2. sz. (2016), DOI: 10.14602/WOODSCI.2016.2.63
http://epa.oszk.hu/02300/02321/00045/pdf/EPA02321_faipar_2016_2_022-028.pdf

Éva Annamária Papp, Norbert Horváth
Nyárkutatás új szempontok figyelembe-vételével, In: Erdészeti Lapok CLII. évf. 1. szám (2017. január) 1-5pp
http://erdeszetilapok.oszk.hu/01821/pdf/EPA01192_erdeszeti_lapok_2017-01_002-005.pdf

3.2 Results of "on-site" and material scientific, laboratorial investigations

Based on the data in the relevant literature, the researchers have mainly dealt with juvenile wood of Pannónia poplar (Molnár et al. 2006, Horváth 2008). Therefore, our material scientific investigations were focused on plantations over 20 years old. In the course of our research protocol, the non-destructive studies on living trees were performed first (Figure 1). We have used stress wave nondestructive test technique with "Fakopp" TreeSonic for measurements on standing (living) trees (Figure 1).

Figure 1 - On-site measuring with "Fakopp" TreeSonic device (left);
Újrónafő 11G plantation (right)

Fifty trees pro every plantation were investigated to determine the diameter at breast height, and the stress wave velocity in sapwood parallel to grain. Afterwards we have performed

laboratorial analysis of small samples from harvested logs (3 logs/plantation, random sample) in order to determine the selected material properties like:

- age of trees
- width of annual rings / radial growth rate
- heartwood proportion
- density at normal climate
- bending- and compressing strength at normal climate etc.

Our material scientific database it will be able to choose appropriate Hungarian plantation with most favourable mechanical wood properties. Raw material with favourable properties support the manufacturing of wood products with higher value (for example glulam beams). The laboratorial test results on small samples showed, that the density and strength values of Pannónia poplar were nearly the same as the literary data of spruce. Therefore it can be predicted, that Pannónia poplar wood could be a competitor of the mostly imported spruce wood, which is widely used in the Hungarian timber and construction industry nowadays. Here it should be emphasized that the occurrence of the house longhorn beetle, which often damages the built-in spruce timber, will not be expected in case of poplar wood. Therefore, the lifetime of roof, ceiling etc. made of Pannónia poplar wood will be longer than constructions from spruce.

Further information to this subtopic can be found in our published papers:

Horváth Norbert, Schantl István
Hazai ültetvényes Pannónia nyár fatestének anyagtudományi vizsgálata
In: Imre Csiha (szerk.) Alföldi Erdőkért Egyesület Kutatói Nap: Tudományos Eredmények a Gyakorlatban, Kecskemét, Magyarország: Alföldi Erdőkért Egyesület, (2017) pp.149-154.
https://epa.oszk.hu/03400/03455/00001/pdf/EPA03455_kutatoi_nap_2017.pdf

Domonkos Ete Farkas, Norbert Horváth
Macroscopic properties and density of Pannónia poplar from West Hungarian sites
In: 8TH HARDWOOD CONFERENCE - WITH SPECIAL FOCUS ON "NEW ASPECTS OF HARDWOOD UTILIZATION -FROM SCIENCE TO TECHNOLOGY". Soproni Egyetem Kiadó, Sopron, pp. 20-21. ISBN 9789633590966
http://publicatio.uni-sopron.hu/1678/1/Farkas_E_and_Horvath_N_HWC2018.pdf

Norbert Horváth
Materialwissenschaftliche Untersuchungen an Pannónia Pappel aus Ungarn
In: Proceedings - 4. Holzanatomisches Kolloquium Dresden, Németország : Institut für Holztechnologie Dresden, (2018) pp. 140-142.
http://publicatio.uni-sopron.hu/1677/1/05_13_Horvath.pdf

Norbert Horváth, Antal Kánnár, Csilla Csiha
On-site and laboratorial investigation of Pannónia poplar plantation wood from three different Hungarian sites
21st International Nondestructive Testing and Evaluation of Wood Symposium
September 24-27, 2019 | Freiburg, Baden-Württemberg, Germany, pp. 141-145.
https://www.fpl.fs.fed.us/documnts/fplgtr/fpl_gtr272.pdf

3.3 Results of surface-physical analysis

The aim of our surface-physical investigations was to find answer whether is the plantation with a relevant influence on the wettability of the Pannónia poplar boards and furthermore are there sites which could be favoured due to the good wettability of their samples. Wetting of solids with different liquids is always a good indicator of the measure of spreading and in case of film forming liquids of the measure of adhesion of those to the wood surface. Generally, wettability is evaluated based on the contact angle θ, formed between a drop of liquid (a demi sphere) relaxed on an ideally smooth solid surface and the tangential drawn to the drop in the point of intersection (Figure 2).

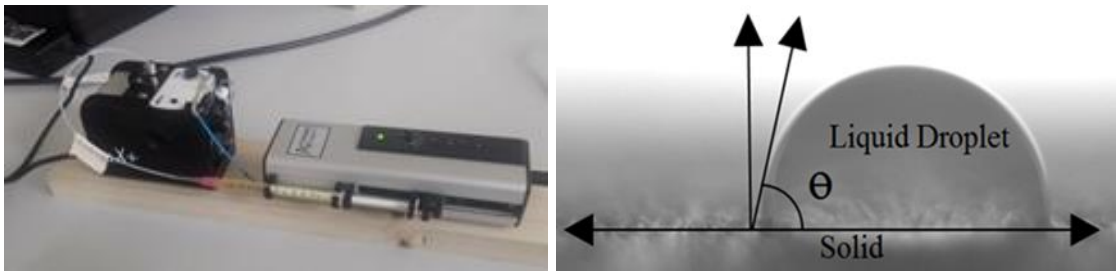

Figure 2 - Goniometer adjusted with separate tube for diiodo-methane measurements (left); contact angle θ (right, foto by Brahmia F.Z.)

A higher contact angle than 90° means low wettability, a contact angle smaller than 90° means high wettability and it can be expected that the liquid will spread well. For maximum wettability contact angle should be 0° (Yuan et al. 2013). After conditioning the samples were freshly planed in order to enable the detection of the contact angle of the freshly machined surface, as in practice freshly machined surfaces are glued in course of glulam production. Although the samples were prepared in the same way, their surface roughness also was measured, to enable an eventual comparison of these results with other researcher's data. Surface roughness of the samples was determined based upon 5 consecutive stylus tip measurements, performed on each sample, along a 17,5 mm trace, using a Mahr Perthen SP3 instrument, equipped with a stylus, with diamond head of 2 µm radius. Both Ra and Rz roughness parameters, considered widely used to describe the status of the surface (Magoss 2000) were calculated. Contact angle of the surfaces was measured using a PGX Goniometer (FIBRO SYSTEMS AG, Sweden purchased in the frame of our OTKA projct, Fig. 2), dynamic method, and a 5 µl test liquid volume. The contact angle was determined in the 1st second after release, as by this time the drop consolidated and 3 measurements were performed on each sample. Contact angle was determined both with distilled water (DW) and with diiodo-methane (DIM). The measurements were performed with two different tube sets for distilled water and diiodo-methane. In order to

evaluate wettability, Young's equation was considered and the Fowkes model was used for surface tension (also quoted surface free energy) calculation. The contact angle values measured with distilled water are roughly two times higher than the one measured with diiodo-methane, and with both test liquids show significant difference (t test, p=0,05) between all the different plantations. The higher the contact angle the worse the wettability of the surface is. The surface free energy (SFE) calculated upon the Fowkes model was the highest in case of two investigated plantations: Győr 540B and Kapuvár 35A. According to the Young-Dupré equation, high surface tension of the solid indicates good wetting. In this two case, the surface free energies are significantly higher than in all other cases. As both tangentially and radially cut surfaces were tested, resulted, that the tangentially and radially cut samples machined by sanding manifest higher surface free energy than the samples machined by planing. Considering all the tested samples, the highest surface free energy was manifested by the samples originating from Győr 540B, on tangential cut surfaces. The second place was occupied by samples originating from Kapuvár 35A, on radial cut surfaces, machined by sanding, but in case of these samples the difference between the surface free energy of the radial and tangential surfaces was not significant: so the final statement is, that it is equal in case of these samples whether they are cut radially or tangentially. In this context, the type of machining has significantly stronger effect on the surface free energy than the anatomical direction. The general statement was drown that the machining type has a major influence on the expected adhesion of the adhesive, and sanding should be favoured against planeing Pannónia poplar boards for adhesive bonding. As the sanded surfaces manifest significantly lower surface roughness, can be deduced, that surface roughness also has a significant influence (p=5%, t=2,99) on the surface free energy (Rábai 2018). As general conclusion we summarised that there is a significant difference in the surface free energy of the samples from different plantations, thus the plantation type influences the wettability of the boards, but in the same time the type of machining and the associated surface roughness are also of major influence.

We tested the variation of the contact angle and thus the variation of the surface free energy with elapsing time also (Figure 3), as not all the adhesive technologies impose freshly cut surfaces.

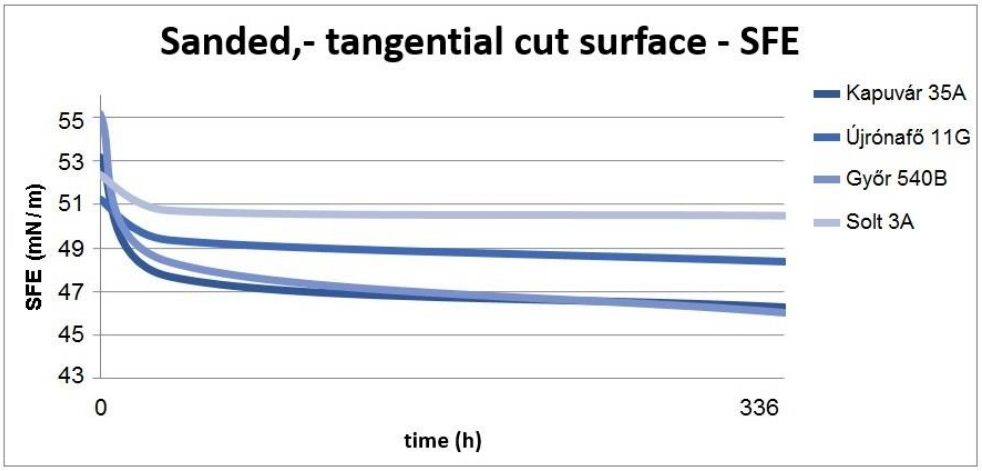

Figure 3 - Typical surface free energy (SFE) development with time, after machining

Based on surface free energy calculations of sanded and planed surfaces, both on radial and tangential direction we concluded that the highest, and most convenient surface free energy can be expected on the freshly cut surfaces.
According to the results of our investigations, the convenient wood material can be selected from the several Hungarian plantations. Based on our wettability measurements can be stated, that the Pannónia poplar timber can be suitable for glulam production. In the same time when compared with literary average values of Spruce samples, the surface free energy values of Pannónia Poplar were somewhat lower. We have to add, that complex analysis will be needed for statistical comparison of these two data.

Further information to this subtopic can be found in our published papers:

Rábai László, Horváth Norbert, Csiha Csilla
Study on the wettability of Pannónia poplar (*P.*× *euramericana* cv. Pannónia) from two Hungarian plantations: Győr and Soltvadkert, Proceedings of the 7th International Scientific Conference on Hardwood Processing, Delft, 2019. the proceedings is under editing
https://www.tudelft.nl/citg/over-faculteit/afdelingen/engineering-structures/sections-labs/biobased-structures-and-materials/conferences/ischp-2019/

Rábai László
Különböző ültetvényekről származó Pannónia nyár faanyagok nedvesíthetőségének vizsgálata. BSc Dissertation, University of Sopron. (2018).
http://diploma.uni-sopron.hu/4491/1/RLszakdolgozat.pdf

3.4 Mechanical properties of Pannónia poplar lamellas / layers

The aim of this part-research was to investigate the suitability of Pannónia Poplar timber for structural purposes. Static and dynamic modulus of elasticity (MOE) was determined on samples (18 lamellas / layers from each plantation) cut out and prepared from the experimental logs of the different Hungarian plantations. MOE of samples was determined with two different methods: on one side by sound velocity measurements performed with the Fakopp-PLG non-destructive timber-grading instrument, and on the other side by static four point bending tests. The bending strength measurement was carried out according to EN 408. Fakopp-PLG is a dynamic MOE measuring instrument, which provides data on the bending strength upon calculation too. The measuring principle of the instrument is based on the detection with a microphone of the longitudinal sound frequency emitted by a hammer. After the measurements the results of the static and the dynamic tests were compared in order to check the reliability of the dynamic tester when measuring Pannónia poplar timber also, as those measurements are easy to perform even on site. The results of the dynamic test exceeded with a few percent those of the static test, showing a good correlation of the two measurements. As a result it can be stated that the domestic Hungarian Pannónia poplar lamellas have in average 11000 N/mm^2 modulus of elasticity (Figure 4). This exceeds considerably the threshold limit value necessary for structural applications (7000 N/mm^2 in the lowest strength class C14 according to EN 338).

Therefore, poplars of these sites are suitable for structural applications, and are a good alternative of the widely used coniferous species in construction sector.

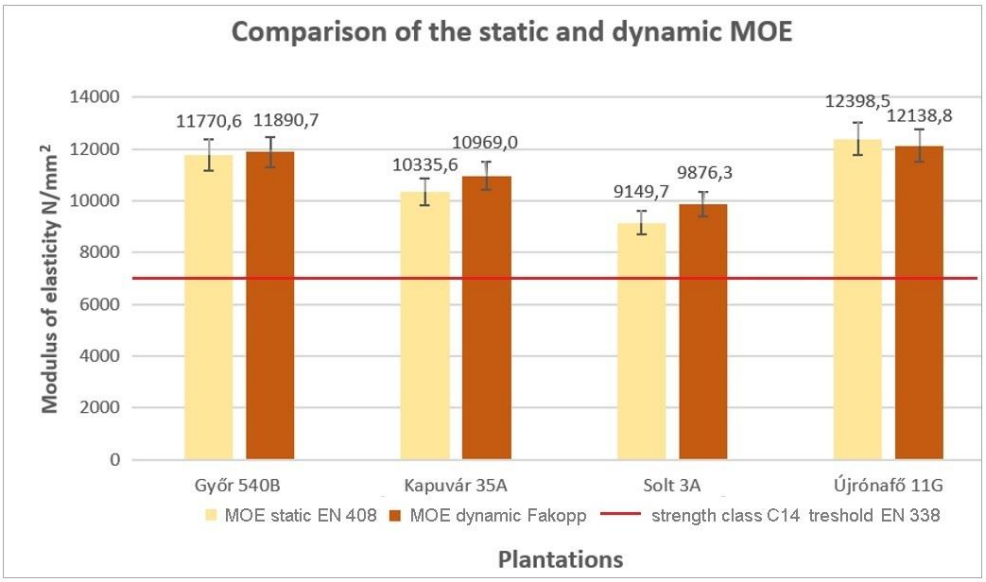

Figure 4 -The average static and dynamic MOE values of the Pannónia poplar lamellas

3.5 Colour modification of poplar wood by steaming for creating pleasant brown colour

In this part of research, colour change possibilities of Pannónia poplar were investigated to obtain an attractive brown wood colour suitable for various indoor applications. Steaming was chosen as an industrially used colour modification technique. Wide range of steaming parameters, temperature ranging from 90 to 120°C, treatment time up to 20 days were applied to obtain all possible colour variations. The colour change was monitored by objective colour measurement according to the CIE Lab system. Steaming was found to be a proper technique to turn the naturally unattractive colour of poplar wood to a pleasant brown colour. Additionally, the colour of steamed poplar samples was homogeneous throughout the whole cross section proving that the hydrothermal process affected not only the surface of wood. It is considered to be an important result for wood industry that the colour saturation can be doubled by steaming. The applied treatment increased both redness and yellowness values and reduced the lightness (Figure 5). The maximum lightness decrease was 44 units while the initial redness value was multiplied 4 times by steaming. Good correlation was found between the lightness and hue values of poplar generated by the applied treatment schedules. It means that the darkening determined the colour shift towards brown.

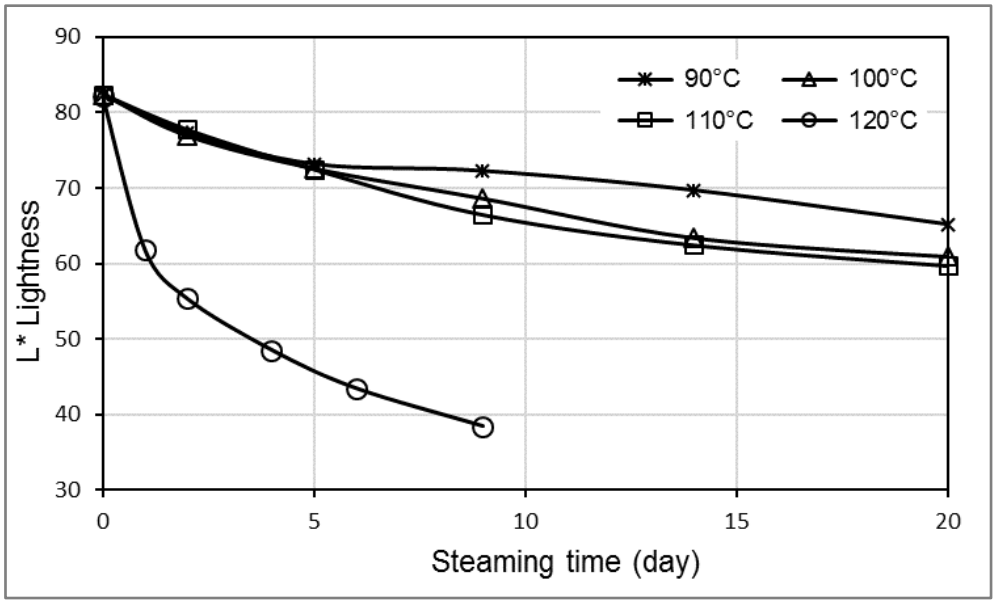

Figure 5 - The lightness decrease of heartwood for poplar

It is important to know whether the steam generated attractive brown colour of poplar wood is stable during light irradiation. The steamed samples were irradiated by strong UV emitter mercury lamp for testing their colour stability. The colour change was evaluated and presented in CIE Lab colour coordinate system. For control, unsteamed poplar specimens were irradiated using the same mercury lamp. Significant increase of colour saturation for the specimens was generated by steaming, and the value of saturation increased even more during UV treatment. The lightness value of unsteamed control specimens decreased continuously during the whole UV irradiation period. In contrast, the lightness value of steamed samples decreased only during the first seven hours of UV treatment and remained constant afterward (Figure 6).

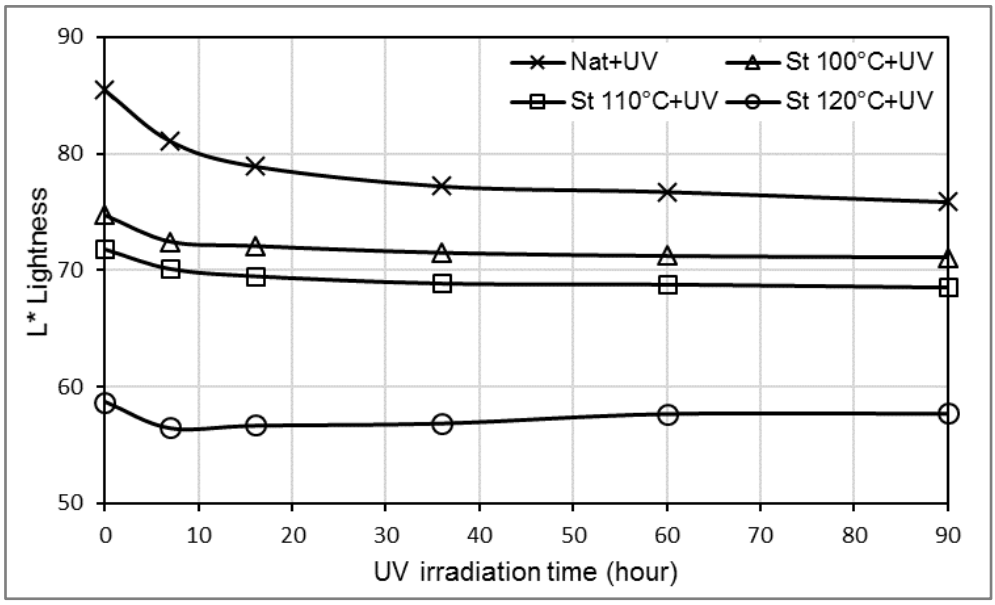

Figure 6 - Lightness change of untreated (Nat) and steamed (St) poplar samples caused by UV light irradiation

Steaming enhanced the redness stability of poplar wood against UV irradiation. Modification of wood components during steaming at 120°C stabilised the redness of poplar wood against short term photodegradation. Steaming slightly reduced the sensitivity of yellow colour of poplar to photodegradation. The colour alterations showed that the steam generated brown colour of poplar wood is more stable to UV radiation than the colour of natural poplar wood.

Further information to this subtopic can be found in our published papers:

Endre Antal Banadics, Laszlo Tolvaj
Colour modification of poplar wood by steaming for brown colour.
European Journal of Wood and Wood Products (2019) 77:717–719
IF: 1.401
https://doi.org/10.1007/s00107-019-01397-9

Endre Antal Banadics, Laszlo Tolvaj, Denes Varga
Colour Stability of Steamed Poplar Wood during Short-term Photodegradation.
BioResources (2019) 14 (4) 8250-8256
IF: 1.396
https://bioresources.cnr.ncsu.edu/wp-content/uploads/2019/08/BioRes_14_4_8250_Banadics_TV_Color-_Stability_Steamed_Poplar_Wood_Photodegradation_16053.pdf

4. Other papers related to our research project and with NKFIH acknowledgement

Domonkos Ete Farkas - BSc dissertation
Egyes hazai ültetvényekről származó Pannónia nyár faminták szövetszerkezetének vizsgálata (Investigation of macro- and microscopic properties of Pannónia poplar samples from selected Hungarian plantations)
http://diploma.uni-sopron.hu/4767/1/Szakdolgozat.docx

László Rábai - BSc dissertation
Különböző ültetvényekről származó Pannónia nyár faanyagok nedvesíthetőségének vizsgálata (Investigation of surface wettability of Pannónia poplar timber from different plantations)
http://diploma.uni-sopron.hu/4491/1/RLszakdolgozat.pdf

Levente Nagy - MSc dissertation
Ültetvényes Pannónia nyár faminták laboratóriumi vizsgálata különös tekintettel a gombaállóságra (Investigation of Pannónia poplar plantation wood samples with special emphasis on natural durability against basidiomycetes)
http://diploma.uni-sopron.hu/4805/1/nagylevente_diplomamunka.pdf

Norbert Horváth - book
A száraz termikus kezelés a technikai faanyagvédelem szolgálatában
Sopron, Magyarország: Soproni Egyetem Kiadó (2019), p. 84.
ISBN: 9789633343319

Fatima Zohra Brahmia, Tibor Alpár, Péter György Horváth, Csilla Csiha - article
Comparative analysis of wettability with fire retardants of Poplar (*Populus × euramericana)* and Scots pine (*Pinus sylvestris*). In: Surfaces and Interfaces (in press)

Horváth Norbert - article in proceedings
Pannónia nyár ültetvények helyszíni és laboratóriumi anyagvizsgálatainak aktuális részeredményei
Alföldi Erdőkért Egyesület Kutatói Nap: Tudományos Eredmények a Gyakorlatban, Kecskemét, Magyarország: Alföldi Erdőkért Egyesület, expected publishing 11.2019

5. Submitted project proposals related to our research project

5.1 ÚNKP program of Emberi Erőforrások Minisztériuma (New National Excellence Program Of The Ministry Of Human Capacities - Hungary)

Domonkos Ete Farkas BSc student
Topic: „Ültetvényes Pannónia nyár faanyagának, vizsgálata" (Investigation of the xylem of Pannónia poplar plantation wood)
Supervisor: Norbert Horváth
Research period: 09.2017. - 06.2018.
Status: supported, finished

Stadler Bence BSc student
Topic:„Pannónia nyár alapanyagú, kísérleti rétegelt-ragasztott szerkezeti faanyagok vizsgálata" (Investigation of experimental glued laminated timber made of Pannónia poplar)
Supervisor: Norbert Horváth
Research period: 09. 2019. - 06.2020.
Status: supported, preparing contract in course

5.2 Horizon 2020 Sustainable wood value chains ID: LC-RUR-11-2019-2020

Participating organizations:
Universiteit Gent (Coordinator), Belgium
STABILAME, Belgium
GARNICA, Spain
TecnoLegno Fantoni, Italy
Hárswood Kft, Hungary
Contemporary Building Design, Slovenia
Universidad de Granada, Spain
Art et Métiers ParisTech , France
University of Florence, Italy
University of Sopron, Hungary
InnoRenew, Slovenia
Institut Technologique Forêt Cellulose Bois-construction Ameublement , France
WOOD.BE Research institute, Belgium
Fundación CESEFOR, Spain
Cluster Eco-Construction, Belgium
InnovaWood, Belgium

World Agroforestry Centre, Kenya / Kyrgyzstan
CLUSTER Centro de la Construcción Sostenible de Andalucía, Spain
BONSAI Arquitectos, Spain

Topic: Poplar based engineering wood poducts as fit-for-purpose technology for building with wood (POPTECH ID:LC-RUR-11-IA)
Status: submitted

6. References

Erdélyi, Gy.; Csizmadia, P.-né; Dudás, L.; Molnár, T.-né; Petri, L.: A fenyőfa felhasználás korszerű eljárásai In: Faipari kutatások 1976, Faipari Kutató Intézet, 1977., pp. 7-27.

Horváth, N.: The effect of thermal treatment on wood properties with special emphasis on wood resistance to fungal decay, PhD. Diss., University of West Hungary. Sopron, 2008. http://doktori.nyme.hu/240/1/disszertacio.pdf

Molnár, S.; Bariska, M.: Magyarország ipari fái. Publisher: Szaktudás Kiadó Ház, Budapest, 2006.

Molnár, S.; Fehér, S.; Komán, Sz.; Ábrahám, J.: Nyárfajták összehasonlító faanyagjellemzői az ipari felhasználás tükrében. In: Poceedings, Alföldi Erdőkért Egyesület Kutatói Nap, Szeged, 2006., pp. 101-109.

Magoss, E.: Evaluating of the Surface Roughness of Sanded Wood. Wood Research 60 (5). (2015) 783-790.

Nebenführ, W.: Biomassegewinnung durch Pappel und Weide im Kurzbetrieb, eine Frage der Sorte. 2007.
http://bfw.ac.at/050/pdf/Folien_Nebenfuehr.pdf

Schlosser, M.; Horváth, N.; Bejó, L.: Glulam beams made of Hungarian raw materials. In: Németh, R; Teischinger, A (szerk.) The 5th Conference on Hardwood Research and Utilisation in Europe 2012 : Proceedings of the "Hardwood Science and Technology", pp. 383-392. http://publicatio.uni-sopron.hu/1688/1/Schlosseretal.Hardwood2012.pdf

Tóth, B.; Erdős, L.: Nyár fajtaismertető. Publisher: Állami Gazdaságok Országos Egyesülése Erdőgazdálkodási és Fafeldolgozási Szakbizottsága, Budapest, 1988.

Tóth, B.: Nemesnyár-fajták ismertetője – Irányelvek a nemesnyár-fajták kiválasztásához. Publisher: Agroinform Kiadó, 2006.

Yuan, Y.; Lee T.R.: Contact Angle and Wetting Properties. Bracco G, Holst B (eds.) Surface Science Techniques, Springer Series in Surface Sciences (2013) pp 3-34, DOI 10.1007/978-3-642-34243-1_1.

Young, T: An essay on the cohesion of fluids. philos. trans. ray. soc. London 65 (1805)sur