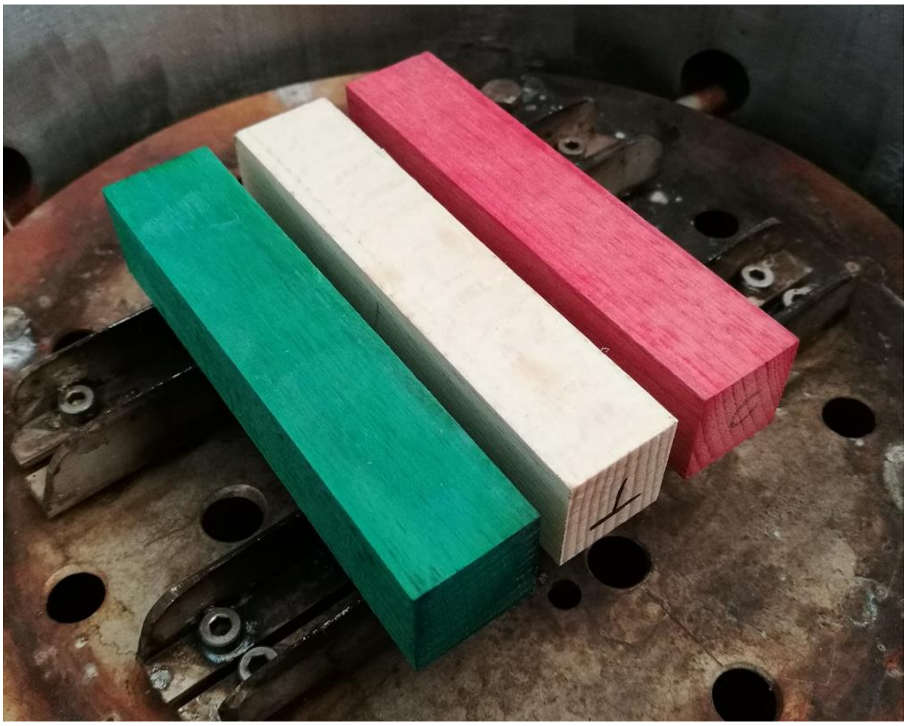
COST Action FP1407 WG1 and WG4 meeting

Wood modification in Europe: processes, products, applications

26th February 2018, Firenze, Italy

PROCEEDINGS



EDITORS: GIACOMO GOLI AND LUIGI TODARO

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COST ACTION FP1407

Understanding wood modification through an integrated scientific and environmental impact approach (ModWoodLife)

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Final program

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Wood modification in Sweden

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Keywords: acetylation, thermal modification, silicon treatment

Introduction

The concept of modified wood in Sweden has attracted considerable interest over the years both with industry and academia, with activities in several modification methods. Activities in acetylation were led initially by Chalmers University and later by SP (now RISE). For fibre acetylation, this led to a collaboration between British Petroleum, A-Cell acetyl cellulosics AB ("A-Cell"), and the BioComposites Centre (Sheen 1992). A detailed review of this collaboration has been recently published (Hill 2006), through which several key factors were identified:

- Feed fibres needed to have a moisture content around 5%
- Residual acetic acid inhibited the reaction at elevated levels (above 30%)
- Fibre damage occurred at temperatures above 130 °C
- Removal of residual acetic acid could be carried out by drying at around 50 °C

Despite the production of several batches of acetylated fibres, and their subsequent assessment, British Petroleum withdrew their interest in acetylation in the mid-1990s, leading to a temporary halt in the commercial development by the group as a whole, though A-Cell continued their activities, in association with Chalmers University (Sweden) and Forest Products Laboratory, Madison (USA). SP (RISE) also have a microwave reactor for the acetylation of larger timber samples.

Work into the furfurylation of wood was partly developed in Sweden, through the work of Mats Westin (Lande et al., 2004) in Association with Kebony in Norway (formerly WPT). Experiences gained with impregnation treatments and polymerization have allowed for the uptake of new treatments based on silicon.

The thermal modification of of wood in Sweden was developed in the intercommunion with wood drying research at Luleå University of Technology in Skellefteå. Improveents of existing processes and material studies were in focus in this research. The thermal modification is now well established in Scandinavia with several commercial groups involved in the ThermoWood Association, including Heatwood from Sweden.

Modification technologies and production volumes

There are a range of evolving modification processes being commercialized within Sweden, and due to the relative newness to the market are still in the expansion phase. Table 1 below gives a brief overview of these modification methods. In addition, Sweden has a high demand for quality products, meaning that there is a strong import demand for modified wood. Whilst acetylation processes are not commercialized at present, the expertise and facilities within groups such as RISE allow for good collaboration with industry.

Wood modification technology	Producer, process short description and website	Annual volumes produced and companies involved in the process
Thermal modification	HeatWood AB. Part of the ThermoWood Association. Treatments according the the ThermoWood S and ThermoWood D processes (www.heatwood.se/en)	6000 cu.metres/year, mainly used for cladding, decking and saunas

WTT process	Uteträ AB. Treatment accordin the WTT process, with improvements in treatment possible with the WTT2.0 process.	2000 cu. Metres/year mainly for cladding and decking
Acetylation	A-Cell was the commercial development for the acetylation of wood fibres,	No longer in operation
Silicate treatment	Organowood. Silicon polymers are bonded to the wood fibers creation a physical barrier against wood destroying organisms. (www.organowood.com/en)	8000 cu. Metres/year for 2017.
Silicate treatment	Sioo:x. Treatment with a range of silicon treatments (www.sioox.se/en)	No figures obtained. Mainly aimed towards self treatment markets with sales of 7000 cu. Metres/year of low concentrated silicate fluid.

Table 1: Wood modification technologies, producers, companies and production volumes

Wood from different commercialised modification processes (e.g. ThermoWood, Kebony, Accoya) are imported directly into Sweden for use.

Practical examples

Below are some examples of the uses of modified wood in Sweden:

(a) WTT furniture

(b) Microwave assisted acetylation reactor, RISE

(c) Hydrophobic properties of OrganoWood

Figure 1: Some examples of uses of modified wood in Sweden

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Wood modification in The Netherlands

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Keywords: innovation, substitute market, new functions, integrated solutions

Introduction

The Netherlands were involved in the pioneering stage of industrialized wood modification. Working under one roof in Wageningen since 1994, the separated R&D activities, led by Cr&Do (earlier: SHELL) and SHR wood research, have respectively culminated in the early offspring productioncompanies Plato and TitanWood. Other innovations include new processes for vacuum-heat treatment, pressurized superheated steam heat treatment and a pre-polymer furfuryl alcohol resin treatment, as summarized in Table 1. The oldest Dutch company in wood modification is Lignostone, producing phenolic resin densified beech plywood since 1917.
The demand for modified wood in the Netherlands is steadily increasing. In the early days, mainly serving as a substitute for tropical hardwoods and chemical impregnated wood in ground and waterworks, and Western Red Cedar in the building industry. Today, as the solution in high-end façade elements: windowframes, doors and cladding applications; in combination with prefabrication, latest buiding regulations (fire retardants) and public perception (Circulair Economy and the use of sustainable and local products). There are also good modified wood market opportunities in niche products and with limited series of customized products.

Modification technologies and production volumes

Wood modification technology	Producer, process short description and website	Annual volumes produced and companies involved in the process
Resin-densification Lignostone (since 1917)	Vacuum impregnation of beech veneers with thermosetting phenolic resin, curing and densification (170°C, 20 MPa). www.lignostone.com	Lignostone no data on production volume
2-stage thermal modification PLATO (since 2001)	Heat treatment of air-dried wood in subsequent hydrothermal (165°C, 6 bar) and dry heating stages (180°C), with intermediate kiln drying (<6%MC) www.platowood.nl	Platowood 3.500 m^3/a
Thermal modification Smartheat (since 2002)	Vacuum heat treatment of kiln dried wood between heating plates (<245°C). www.lignius.nl	Lignius 1.200 m^3/a
Acetylation Accoya (since 2007)	Autoclave acetic anhydride impregnation in kiln-dried (<6%) radiata pine with adjacent heat-curing and acetic acid removal. www.accoya.com	Accsys Technologies 39.000 m^3/a
Hygrothermolytic modification FirmoLin (since 2009)	Heat treatment of kiln dried wood (12%MC) under moisture-controlled conditions in pressurized superheated steam (<7 bar, <180°C).	FirmoLin Technologies 6.500 m^3/a

	www.firmolin.eu	
Furfurylation Nobelwood (since 2010)	Autoclave impregnation of pre-polymerized furfuryl alcohol in air-dried radiata pine. Subsequent drying and heat-curing in high-temperature kilns. www.foreco.nl	Foreco Dalfsen 1.000 m^3/a

Table 1: Wood modification technologies, producers, companies and production volumes

Examples of remarable achievments with modified wood in the Netherlands

Figure 1: Accoya sunken pedestrian "Moses" bridge

Figure 2: FirmoLin extreme dimensioned TM Douglas fir

Figure 3: Platowood TM recycled-wood cladding

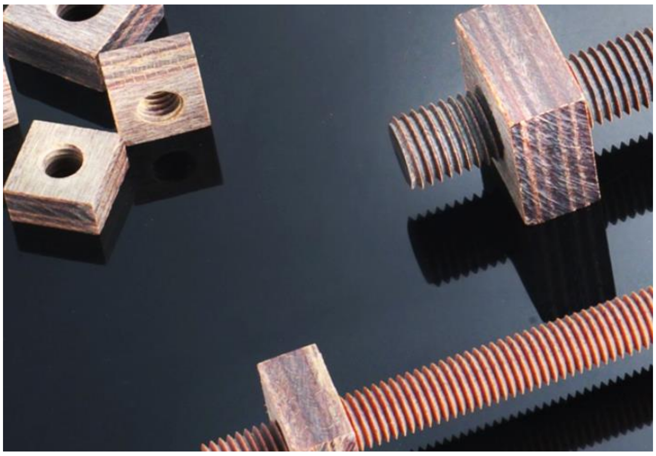

Figure 4: Lignostone electrically insulating threaded rods with bolts for use in transformers

Wood modification in United Kingdom

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Keywords: UK, acetylation, resin impregnation, design with imported modified timbers

Introduction

The concept of modified wood in the UK is one that has been considered for many years, with work undertaken by several groups, in particular Bangor University (Hill and Jones 1996 , Hill et al. 1998), The Building Research Establishment (Suttie et al. 1999, 2000), Imperial College and the Biocomposites Centre (Ormondroyd et al. 2015) as far back as the 1980s. Most of the work has focused on the lab scale development of treatments, usually with imported timbers (e.g. radiata pine) or with clear specimens (sapwood only) of selected UK species (e.g. Scots pine, Corsican pine, Sitka spruce, beech).

Modification technologies and production volumes

Whilst there have been laboratory and field study trials into modified wood for some time in the UK, the commercial development within the country has been very small. Instead, the UK depends on imported materials from the main commercial producers in Europe (e.g. Accoya, Kebony, ThermoWood). For thermally modified wood, it is estimated that the UK currently imports between 12000 and 15000 m^3, whilst for Accoya the estimate volume is around 9000 m^3 and for Kebony it is approximately 600 m^3 (volumes based on imported volumes of treated material and its curretny market price per cubic metre). There are a variety of ongoing activities, as listed in Table 1, which either do not produce significant amounts of modified wood at present or are still in production. Of these, the most interesting is the development of an acetylation plant for wood chips by Tricoya Ventures UK Limited (TVUK) – a consortium comprising BP (British Petroleum), Accsys Technologies through its subsidiary Tricoya Technologies Limited (TTL) and Medite Europe at the BP site in Hull. Whilst this is still under development – with production due to start in 2019, the ground preparation for the plant has already begun. There are also initiatives with other countries – e.g. Sioo:x has a UK base, an expansion of the Swedish company.

Wood modification technology	Producer, process short description and website	Annual volumes produced and companies involved in the process
Thermal modification	Coed Cymru. Small scale ovens for treatment of regional timber supplies at temperatures lower than ThermoWood process	<250 cubic metres/year, typically for supply to joinery manufacturers
Acetylation	Tricoya Ventures UK Limited (TVUK). Production due to start in 2019. Will involve the acetylation of wood chips for use in manufacture of Tricoya	30,000 tonnes of acetylated chips per year.
Resin impregnation/ polymerisation	Fibre 7. Production yet to start. (www.lignia.com)	No production volumes at present
Silicate treatment	Sioo:x. Whilst treatments are mainly provided for direct application, impregnation can be undertaken (in association with Russwood Timber). (www. Sioox.org.uk)	Treatments to order through services provided by Russwood timber.

Table 1: Wood modification technologies, producers, companies and production volumes

Other commercialised modification processes (e.g. ThermoWood, Kebony, Accoya) are imported directly into the UK for use.

Practical examples

Below are some examples of the uses of modified wood in the UK:

(a) Example of ThermoWood cladding, Telford

(b) First certified Welsh passive window manufactured from thermally modified larch

(c) Accoya solar shading, Edinburgh

(d) Beach houses made using Kebony, Camber Sands

Figure 1: Some examples of uses of modified wood in UK

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Wood modification in Slovenia

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Keywords: thermal modification, perceptions, architects, case study, users

Introduction

As of early 2018, Slovenia has two main providers of thermally modified wood. One company developed its own process while the other firm provides treatment. In addition to Slovenia's wood modification industry, researchers in the country are deeply involved in various aspects of wood modification, including gather user perspective and investigating case studies of the use of modified wood. Researchers at the InnoRenew CoE, the University of Primorska, and the University of Ljubljana pursue technological advancements in wood modification, study its environmental impact, and investigate material properties of modified wood.

Modification technologies and production volumes

Wood modification technology	Producer, process short description and website	Annual volumes produced and companies involved in the process
Silvapro wood	Silvaprodukt d.o.o. Chamber capacity of approximately 4 m^3, cycle duration between 18 and 36 hours, temperatures dependent on desired outcome and material thickness (approximately 170 to 230 °C). https://en.silvaprodukt.si	~1,200 m^3 / year.
I-Les, "Wood Treatment Technology"	I-les Iskra d.o.o. Chamber capacity of approximately 4 m^3, treatment temperatures between 160 to 180 °C. http://www.i-les.si/en-index.html	~1,000 m^3 / year; WTT A/S (DK) licenses the technology (http://www.wtt.dk/products/thermo-treatment).

Table 1: Wood modification technologies, producers, companies and production volumes

Practical examples

The Tango House, Ljubljana, Slovenia.
An instructive example of the use of thermally modified wood in Slovenia is in the Tango House in the country's capital, Ljubljana. The house is a small house with modern elements and a nod to the historic construction methods of the region. The building uses cross laminated timber for the structure on a piling foundation. The facade uses thermally modified spruce cladding, which will silver with age but offers resistance to the effects of the local climate and improved dimensional stability.



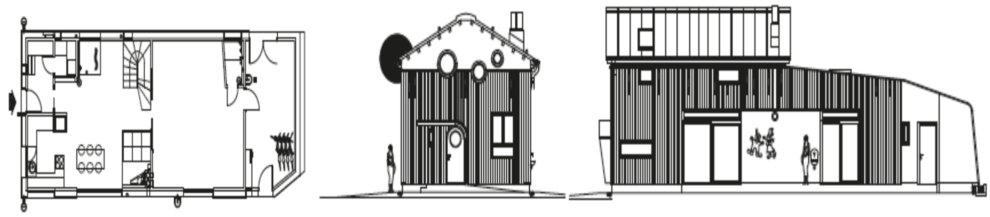

Figure 1: Tango house exterior with thermally treated spurce (material by Silvaprodukt d.o.o.) with interior and exterior drawings (Kitek Kuzman, 2015).

Architect's perceptions of modified wood in Slovenia.

Slovenian architects were surveyed to assess their perceptions of engineered wood products, including modified wood (Kitek Kuzman et al. 2017). There was a total of 557 respondents to the questionnaire phase of the survey. Approximately 80 % of respondents reported that they would use modified wood in architectural design, while only 70 % reported familiarity with the advantages of modified wood. Their primary interest in learning about modified wood products and processes were through technical specifications; however, visits to building sites and objects were highly ranked as well. Currently, the most common way respondents get information about products was from the internet. Manufacturers and building companies were another common way for Slovenian architects to receive information about construction products. Respondents reported a desire to receive more information about engineered wood products, in general.

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Wood modification in Germany

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Keywords: acetylation, DMDHEU, heat treatment, melamine-formaldehyde, phenol-formaldehyde

Introduction

Within the past decades, wood modification technologies were developed in different European countries, with focus on countries of the northern hemisphere (e.g. Austria, Finland, Germany, Norway, The Netherlands). Motivated to create alternatives to new, innovative building materials, preservative treated wood as well as endangered tropical timber, intensive fundamental research made possibly the commercialization of some of these technologies. In Germany, production plants for heat treatment (thermally modified timber) and various chemical modifications commenced operation towards the end of 20th century. Initially focused on solid wood, predominantly chemical wood modification was over time successfully applied with wood-based composites.

Modification technologies and production volumes

Tables 1 and 2 illustrate wood modification technologies, for which production plants do exist in Germany. The production volumes are premised either on estimates by the Institute of Wood Technology Dresden (IHD) in case of thermally modified timber (Scheiding 2018) or taken from manufacturer´s websites. Production volumes may differ to the precise and actual production of the respective company.

Wood modification technology	Producer, process short description and website	Annual volumes produced
Thermal modification at approx. 180 – 220 °C	BES Bad Essener Sägewerk GmbH & Co. KG; open process; http://www.bad-essener-saegewerk.de*	4 000 – 6 000 m³
	Timura Holzmanufaktur GmbH; closed vacuum process; www.timura.de	1 500 – 2 000 m³
	Holzbodenwerk Krottenthaler GmbH & Co. KG; closed pressure process; www.holzbodenwerk.de	1 500 – 2 000 m³
	JEP Hardwood Flooring GmbH; open process; www.jep-parkett.de	n.a.
	Holzindustrie Templin GmbH; open process (presumed); www.hitemplin.de	n.a.
	Firstwood (Golden Mile GmbH); open process; www.firstwood.de**	n.a.

Table 1: Wood modification technologies, producers and production volumes – Heat treatment. n.a. = not available; * currently insolvent; production continues; ** production plant shall be sold; production stopped

In comparison with thermal modification plants, a similar amount of companies operates chemical modification mainly with phenolic resins or treatment with hot-melting waxes (Table 2). Contrary to heat treatment applied to solid wood, phenolic resins are used to merge and finish veneers to plywood, laminated veneer lumber or synthetic resin densified wood. Such wood-based composites enable to meet a range of specific customer needs. Supplemented by specific additives (e.g. flame retardants), very individual customer requirements (mechanical strength, insulating properties, noise absorption, corrosion resistance, flame protection etc.) can be met with such technologies. Thus, since respective products are usually made to customized demands and some production plants are still in the start-up phase (e.g. BauBuche®), precise annual volumes produced are not available or disclosed (Table 2). Besides existing production plants using reactive modifying resins, a production plant for acetylated wood (Accoya®) is planned near Freiburg (Germany). However, the actual implementation was postponed up till now (EUWID, 2015).

Wood modification technology	Producer, process short description and website	Products (brand names)
Chemical modification with phenolic resins	Delignit AG/ Blomberger Holzindustrie GmbH; wood-based panels; synthetic resin densified wood; additional refining steps; www.delignit.de	Delignit®, Delignit®-Feinholz®, carbonwood®, obo-Festholz®, Panzerholz®, VANyCARE®
	Pollmeier Massivholz GmbH & Co. KG; laminated veneer lumber: parallel oriented veneers; https://www.pollmeier.com/en/	BauBuche®
	Röchling SE & Co. KG; synthetic resin densified wood; https://www.roechling.com/de/	Lignostone®
	Deutsche Holzveredelung Schmeing GmbH & Co. KG; synthetic resin densified wood; http://www.dehonit.de/page/en/homepage.php	Dehonit®
Wax treatment	Dauerholz AG; impregnation of solid wood with a hot-melting wax under temperature supply; http://www.dauerholz.de/	Dauerholz®

Table 2: Wood modification technologies, producers, companies and products – Chemical and wax treatment.

Practical examples

Fig. 1 illustrates products made out of modified wood for practical application. Besides several applications outdoors (deckings (a), facades, garden furniture), thermally modified wood is used and favoured for interior flooring and furniture due to its changed optical appearance. Innovative laminated materials as mentioned in Table 2, enable the use for wooden constructions (BauBuche® (b)), interior floors and walls inside transport vehicles (e.g. Delignit®) and many other customized solutions (c).

a b c

Figure 1: Thermally modified beech outdoor flooring (a, Holzbodenwerk Krottenthaler GmbH & Co. KG); compressed laminated wood, rods, nuts and threaded rods (b, Deutsche Holzveredelung Schmeing GmbH & Co. KG); laminated veneer lumber, carrier structure (c, Pollmeier Massivholz GmbH & Co. KG).

Future perspectives and processes ready to industrialize

Since the early 2000s, intensive research activities on chemical wood modification technologies were conducted by the University of Goettingen, closely linked to the wood-working industry. Focus was on wood modification with DMDHEU (formerly: Belmadur®) and a 'combi-treatment' of thermal treatment followed by an impregnation with melamine resins, in order to replace teak wood in the boat building industry. For both technologies, processes were developed up to pilot scale and ready to industrialize. Currently, several activities ongoing between the University of Goettingen, chemicals producer and wood-working industry show promising prospects for both modification technologies, pushed by an increasing demand for environmentally benign technologies to establish innovative biobased materials.

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Scheiding W. 2018. Personal communication.

Wood modification in Spain

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Keywords: Spanish timber market, thermally modified wood, wood industrial facilities

Introduction

According to the data of the last Spanish forest inventory in 2015, Spain has the second largest forest area within the EU-28 (27.6 million ha), which means that half of the Spanish land area is wooden land. However, the growing stock of timber available for wood supply in Spain was 943.98 m^3, well below of the volumes of countries such as Germany, France and Sweden, which present the largest growing stocks of the EU-28 (Eurostat, 2016). In Spain, coniferous species are mainly used as solid industrial wood in the following order: *Pinus pinaster* (40%), *Pinus radiata* (23%), *and Pinus sylvestri*s (15%). In contrast, hardwood species are most commonly used in the pulp and paper industry (principally *Eucaliptus* sp.), with reduced volumes of *Quercus robur* (1.5%), *Fagus sylvatica* (1.3%) and *Castanea sativa* (1.1%) used as raw material for wood processing (Anuario de Estadisitca Forestal, 2015). The wood sector in Spain has been delimited between first transformation companies, which provide semi-finished products, and second processing companies, which provide final products. This delimitation is equivalent to that of the statistical classification of economic activities in the European Community (NACE).

Concerning the state of the art of the wood modification technologies (Table 1), the first transformation sector produces in Spain themally modified products at medium industrial scale under the patent Termogenik (Maderas Torresar, Orozko, Spain), using a Mahild chamber (Mahild Drying Technologies, GmbH) with steam as heating medium, and modifying wood at temperatures between 192 and 212 °C. In the second processing sector, MH Parquets (Sigüenza, Spain) thermally modifies Eucaliptus and Ash wood at small scale for outdoor applications, and their products are presented as raw or coated with oils. Some practical examples are provided in Fig. 1. Products from chemical modification processes (acetylation, furfurylation) are commercialized in Spain, but at the present time there are no industrial facilities located in Spain. In addition, the use of new technologies such as nanotechnology or surface modification are only studied at academic research level.

Modification technologies and production volumes

Wood modification technology	Producer, process short description and website	Annual volumes produced and companies involved in the process
Thermal modification	- Maderas Torresar: Termogenik. *Pinus radiata* and *Fraxinus excelsior* wood (mainly) between 192-212 °C at saturated steam atmosphere. http://www.termogenik.com - MH Parquets: Thermal modification of *Eucaliptus globulus* and *Fraxinus excelsior* wood between 180-220 °C (process not provided by company). http://mhparquets.com/en/outdoor - Gabarró: Marketer in Spain of Lunawood TMT, which uses *Pinus sylvestris* and *Picea abies*, ranging from 190-212°C at saturaded steam atmosphere.	Annual volume: Not provided by companies. Termogenik process belongs to Torresar and Torrebaso companies. MH Parquets belong to Mariano Hervás S.A. Gabarró is marketer of Lunawood products that belong to the International Thermowood Association.

	http://www.gabarro.com/es/	
Acetylation	- Elaborados y Fabricados Gámiz: marketer in Spain of Accoya Wood (wood acetylation process) from *Pinus radiata* wood. http://www.grupo-gamiz.com/	Annual volume: Sales of approximated 300 m^3/year of Accoya products, according to Elaborados y Fabricados Gámiz
Furfurylation	- Euro Covering S.L: marketer in Spain of Kenoby wood (wood furfurylation treatment) from softwood species. Company without website	Annual volume: not provided.

Table 1: Wood modification technologies, producers, companies and production volumes in Spain

Practical examples

a

b

c

d

Figure 1: Façade of thermally modified Radiata pine, Madrid (**a**); Façade of thermally modified Eucalyptus, Segovia (**b**); Accoya interior panels, Google office Madrid (**c**); Accoya façade, congress palace Vitoria (**d**).

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Forti R., Henrard M. 2016. Agriculture, forestry and fishery statistics 2016. Luxembourg, Eurostats: 165–183 website:http://ec.europa.eu/eurostat/documents/3217494/7777899/KS-FK-16-001-EN-N.pdf/cae3c56f-53e2-404a-9e9e-fb5f57ab49e3

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Wood modification in Romania

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Keywords: hardwood, thermal modification, chemical modification

Introduction

Romania is situated on the eight position in EU considering the biggest forest area, this being of 6.5 milion hectares. At the same time, comparing to other European countries, Romania has a total forest coverage area of about 27.3% from its total surface, lower than the European media with about 5.1%. From the total surface of 6.5 milion ha, only 3.3 milion ha (51%) belong to the National Forestry Agency, the rest belonging to the private sector.
The most common wood species found in Romanian forests are: beech (about 30%), resinous conifers (30%), and oak (19%), while the rest of about 21% is composed by other hard and softwood species.
In the last years, it was recorded an accentuated exploitation of wood. In a report published by the NIS (National Institute of Statistics) (Nutescu, 2017) it is mentioned that from the total volume exploited in 2016: 36% was softwood (spruce, fir, duglas fir, larch, pine), 34.2% beech, 11.1% different hardwoods (hornbeam, acacia, sycamore, birch, ash, chestnut, cherry), 10.1% oak and 8.6% other low-density hardwood species like: poplar, willow, lime, and alder.
Considerinng the wood industry, in Romania most of the processing it is stopped after cutting the logs and kiln drying them. Further the processed wood is used as it is in different applications from construction to furniture or domestic uses or it is prepared for export.

Modification technologies and production volumes

Even Romania has a wide coverage of forest and the production of wood mass it quite high, the modification industry is not so developed. In Romania, we identified only three companies which produce thermo wood: J.F.Furnir SRL, S.C. INCO INDUSTRY S.R.L, and S.C. ECOLEMN S.R.L. (SEE Table 1) and many other companies selling the treated wood for different applications.

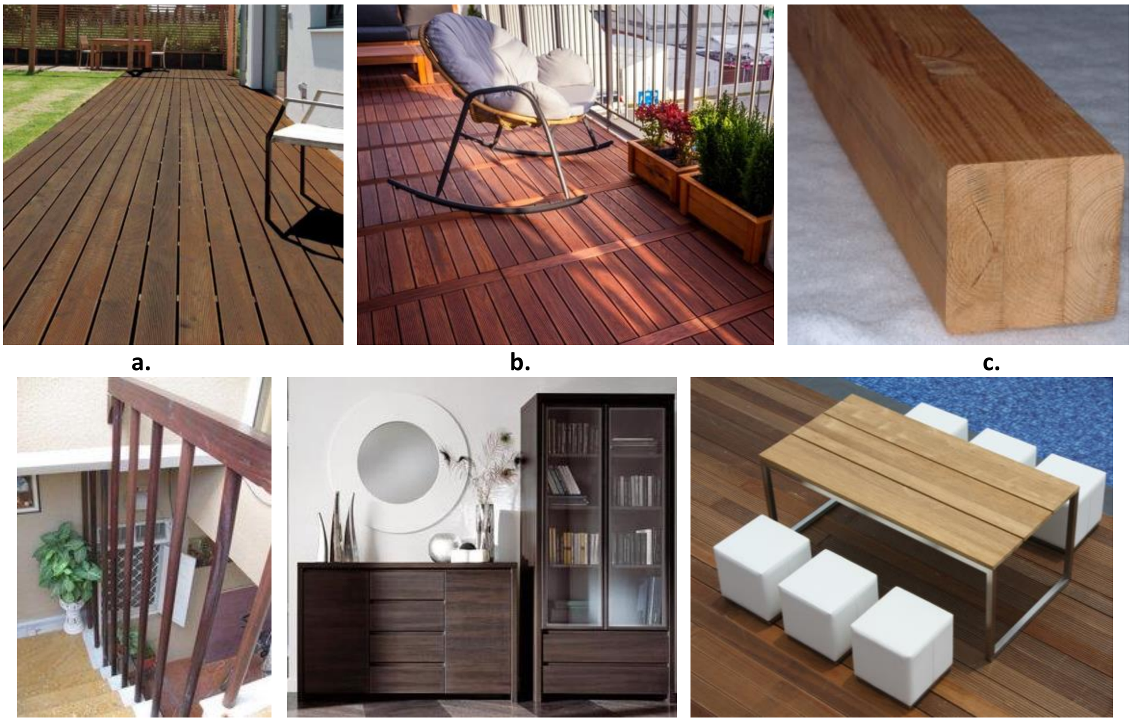
Wood modification technology	Producer, process short description and website	Annual volumes produced and companies involved in the process
Thermo wood technology	J.F.Furnir SRL Thermal treatment of ash at 208 °C, in an oven of 14-15 m^3. http://www.jffurnir.com/ro/produse/lemn_termotratat	J.F.Furnir SRL Annual volume 2016 = 1600 m^3 Annual volume 2017 = 1450 m^3
Thermowood technology	S.C. INCO INDUSTRY S.R.L The process consist in three steps: drying phase at 140 °C; treatment phase at 220-250 °C for 3-4 h, and cooling and conditioning phase – the temperature is reduce with a constant rate in the presence of steam. One cycle takes about 4 days for a quantity of 25-30 m^3 / one chamber. Maximum capacity is of 120 m^3 / cycle. http://lemntermotratat.ro/en/index.php/thermo-layered-wood/	S.C. INCO INDUSTRY S.R.L Maximum capacity = 5000 m^3 (depending on the costumers request)

Thermowood technology	S.C. ECOLEMN S.R.L. Heating the wood in low oxygen atmosphere at temperatures between 165 and 240 °C. www.ecolemn.ro/content/ro/noutati/lemn-termotratat	S.C. ECOLEMN S.R.L.

Table 1: Wood modification technologies, producers, companies and production volumes

Practical examples

The thermal modified wood provided from the Romanian companies or imported from Europe or Russia is widely used in differnet applications, such as: thermal treated pine and ash mostly used for cladding, decking and flooring (Fig. 1a and 1b), laminated beams made with polyurethane glued thermally treated timber (Fig. 1c), balisters made from thermally treated ash wood (Fig. 1d), and indoor and outdoor furniture (Fig. 1e and 1f).



a. b. c.
d. e. f.

Figure 1. Termally modified pine for decking (image provided from http://www.pardoseli-lemn.ro/deck/autohton/pin-termotratat/), thermally modified ash for decking and flooring (image provided from https://decolandia.ro/terase-din-lemn-si-pardoseli-exterioare/podele-terasa-decking--frasin-thermo), reinforced beams made from thermally treated pine (image provided from http://www.lemntratat.ro/detaliiprodus/amenajari_lemn_terase/grinzi_stratificate_neportante_molid_termotratat/grinzi_stratificate_/5/16/18.html), balisters of thermally treated ash (image provided from www.lemntratat.ro/detaliiprodus/dusumele_si_lambriuri/balustri_si_mana_curenta_lemn_termotratat/balustrii_si_mana_curenta/7/38/34.html), furniture from masive thermal treated hardwoods – beech, oak or ash (image provided from www.lemntratat.ro/detaliiprodus/dusumele_si_lambriuri/mobilier_interior_lemn_termotratat_masiv/mobilier/7/41/36.html), outdoor table (image provided from www.lemntratat.ro/categorie/amenajari_lemn_terase/5.html)

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Wood modification in Belgium

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Keywords: wood modification, TMT, furfurylation, acetylation, Belgium

Introduction

Wood modification has since several decades been important in Belgium and this was underlined by the organization of the first European Wood Modification Conference in Ghent in 2003 by the European Thematic Network for Wood Modification. The presence of several production plants in the Netherlands definitely delayed the start of specific production sites in Belgium. Today we still see this is an ongoing process and both the use of tropical wood species and the presence of international harbours like Antwerp seem to be drivers in this respect.
There seems to be similarities in the approach in the Netherlands and developments in Flanders, the northern part of Belgium. Both have low forest cover and depend largely on import of timber and forest products. Import of tropical timbers is significant and there is tradition of trading forest products. Open border systems existing since the introduction of the BeNeLux in 1958 allowed since long to transfer raw materials up to finished products between the Netherlands and Belgium. Today we can observe a clear presence of modified wood from the Netherlands on the Belgian market, but we also observe that specific companies provide treating products in opposite direction. Additionally also products from the main countries involved in producing modified timber are present on the Belgian market and competing for specific markets related several commodities and applications, mainly cladding and decking but also for exterior joinery.

Modification technologies and production volumes

Actually at this moment there are only a few companies producing modified wood in Belgium. As you can see from Table 1 only thermal wood modification is present and relates primarily to modification of (tropical) hardwoods alongside common softwood species.

Wood modification technology	Producer, process short description and website	Annual volumes produced and companies involved in the process
ThermoWood	LDCwood ThermoWood process https://ldcwood.com/en/	Estimated capactity 20000 m³
Thermo VacWood	Debeuckelaere Gebroeders nv ThermoVuoto process http://www.debeuckelaere.com/	Estimated production 1500 m³

Table 1: Wood modification technologies, producers, companies and production volumes in Belgium

Besides the producers of thermally modified wood LDCwood (joint venture of the timber importing companies Lemahieu en Decolvenaere) and Debeuckelaere there are also some companies active in promoting and interacting on the Belgian market with specific products based on production sites in other countries. The company SWP (Stockmans Wood Products - http://www.swp-timber.com) is commercializing ThermoDUR products, which are linked to Smartheat products (https://www.lignius.nl/, the Netherlands). The company Carpentier (http://www.carpentier.be) sells amongst others HOTwood ash. Often focus is on decking and cladding but also window frames (e.g. so-called TMT Fraké based on *Terminalia superba*), insulating wood materials (e.g. products based on low density hardwoods like Thermo Ayous, *Triplochiton scleroxylon*) and other high end products often originating from specific treating facilities that are using vacuum plate systems as part of the process.

Besides TMT (Thermally Modified Timber) there is also scope for chemically modified wood. Accoya products from the Accsys acetylation plant in Arnhem, the Netherlands (https://www.accoya.com/) are since long present on the Belgian market and available from the distributor company Hout van Steenberge nv (https://www.vansteenberge.be) that also is selling the Medite Tricoya wood based panel. Orginating mainly from the Netherlands modern window frames based on finger jointed laminated beams are not only using thermally modified wood species often in combination with spruce, but also acetylated radiate pine is used in combination with Scots pine (www.ibrid.nl).

The company TFC (Transfurans Chemicals - https://www.polyfurfurylalcohol.com/building-construction) is a main producer of furfurylacohol used for the chemical modification called furfurylation and also producer of the Biorez resin used for treatment of the Nobelwood products by Foreco in the Netherlands (http://www.foreco.nl/nobelwood.html). The construction of a new production plant for furfurylated wood was started in 2017 by Kebony Belgium nv (https://kebony.com/sv/blog/second-factory-belgium/) as a second factory envisaging an initial capacity of 20000 m^3 with potential to increase to 40000 m^3.

Alongside thermal and chemical wood modification, there has been an interest in hydophobation of wood with organosilicon compounds since beginning this century by the company Dow Construction Chemicals having their research facilities in Seneffe, Belgium. They just finished succesfully an EU Life+ project SILEX showing the potential of some of their formulations.

This is a compilation of info available beginning 2018 for Belgium and it is expected that additional wood modification plants will be functional later that year and the coming years especially when considering all innovative technologies being introduced as indicated by Sandberg et al. (2017) and linked to the impact of high ranked publication(s) appearing recently (Song et al. 2018).

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Wood modification in Ukraine

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Keywords: adhesive, alkaline aluminosilicate binder, deformation properties, particleboard, plywood

Introduction

Forest occupies 17% of the territory of Ukraine, being an important component of the Ukrainian economy. However, until recently, most of the timber was exported as a round timber. After the introduction of the moratorium on the export of round timber, the main wood product is sawn softwood, sleepers, billets for euro pallets and hardwood billets.

Furniture companies use mainly Ukrainian wood, but furniture made of natural wood is too expensive and it is much cheaper to purchase furniture from chipboard.

Disadvantages of traditionally used organic binders are hazardous working conditions for workers at wood-processing/woodwork and living conditions of building occupants experienced acute health problems because of emissions of hazardous substances, so-called “sick building syndrome” (SBS). One of such solutions to improve indoor air quality is to replace organic binders by inorganic ones and the use of the alkaline aluminosilicate binders of the system R_2O-Al_2O_3-SiO_2-H_2O is a highly advantageous solution due to simple manufacturing process and no need to preliminary treatment of wood.

The alkaline aluminosilicate binders of the following structural formula: R_2O-Al_2O_3-SiO_2-H_2O can be a vital alternative to traditionally used inorganic adhesives for the production of wood board materials. These binders are successfully used in anticorrosive and fire resistant coatings, decorative finishing materials, etc., including wood-based materials. The increased rigidity of these binders did not allow to use the resulted wood-based materials in high humidity environment.

In order to remove this disadvantage the studies were held dedicated at optimization of the binder composition to produce health safety and ecologically friendly wood-based materials with required physico-technical characteristics.

As it follows from Table 1, internal bond of the particle board in which the alkaline aluminosilicate binder of the reference composition (without modifiers) (binder content - 40% by mass) was 11.5 MPa, which did not meet the requirements of EN 312. Vinapass and Agocel make it possible to increase the internal bond of the particle board to 14.5-14.8 MPa, which meets the requirements of EN 312 for particle board of this thickness, for which the internal bond should be ≤ 14 MPa.

The formulated alkaline aluminosilicate binders were tried in pilot production of the adhesive-bonded plywood (Table 2). As it follows from Table 2, the plywood produced using the reference composition of the alkaline aluminosilicate binder (without additives) did not met the requirements of EN636 – 1 for plywood used in dry conditions. The addition of Vinapass slightly reduced internal bond to 68 MPa, tensile shear strength of the lap joint and modulus elasticity in bending, but increased water resistance of the plywood.

No	Modifier	Design of boards, % by mass		Characteristics of boards			
		binder	wood chips	thickness, mm	density, kg/m^3	internal bond, MPa	swelling in thickness, 24 h, %
1	Reference	40	60	10	809	11.5	30
2	Agocel	40	60	10	808	14.8	22

3	Vinnapas	45	55	10	815	16.1	19

Table 1: Characteristics of the adhesive (alkaline aluminosilicate binder)-bonded particle boards (pressure – 3.0 N/mm^2; pressing time– 10 min)

No	Modifier	Consum-ption of binder, g/m^2	Characteristics of plywood				
			thickness, mm	tensile shear strength of lap joint, MPa	internal bond, MPa	modulus elasticity in bending, GPa	immersion for 24 h in water
1	–	190	12	1.81	80.5	12.8	-
2	Vinnapas	190	12	2.73	68.2	10.7	+

Table 2: Characteristics of the adhesive (alkaline aluminosilicate binder)-bonded plywood (pressure – 1.65 N/mm^2, pressing time – 12 min)

Practical examples

a

б

Figure 1: Photos of the samples of the adhesive (alkaline aluminosilicate binder)-bonded wood- based materials (a) – particle boards and (b) – plywood after testing for internal bond

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Wood modification in Italy

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Keywords: thermal modification, chemical modification, physical modification

Introduction

With the development of thermal modification technologies in northern countries, Italy has also developed its own processes and technologies starting since the years 2000. In the country the industries active in the wood drying process, starting from their technologies, have developed different treatment processes. As regards the physical modification of wood intended as densification processes, the sector is active in Italy since 50 years ago. Products and plans for the chemical modification of wood are also very rare apart impregnation with salts with different purposes such as durability or fire-retardant. Mild processes, such as treatment with water, at temperature below 100°C in alkaline medium and vaporization, are often used in Italy.

Modification technologies and production volumes

As shown in Table 1, in the field of thermal modification technologies plants, 4 industries are actually active in Italy.

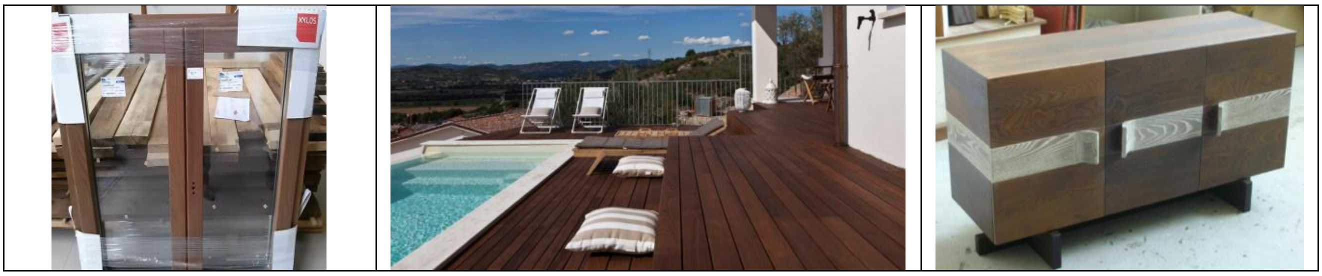
Wood modification technology	Producer, process short description and website	Annual volumes produced and companies involved in the process
Thermal modification	Baschild - http://www.baschild.com – produces plants for thermal modification since 2002. The ovens operate in superheated stem under very small overpressure conditions. Ovens vary between 10-12m^3 to 80-100m^3. Treatment temperatures can be up to 230°C. A complete cycle is 2 or 3 days.	Baschield has installed about 60 plants. One in Italy of 60m^3 - http://www.pozzialbino.it – the others in Croatia, Germany, Latvia, Romania. The Croatian company Evolen is directly owned by Baschild - http://evolen.hr
Thermal modification	BIGonDRY - http://www.bigondry.com – The ovens operates under superheated steam conditions in controlled overpressure and controlled conditions of oxygen. Samples conditions moisture content is also monitored during cycle and used as an input of the process. Ovens vary between 9 and 30 m^3.	BIGonDRY has installed 18 plants. Three plants in Italy for a total volume of 56 m^3. http://www.segheriavallesacra.it https://www.cpparquet.it http://www.fabianolegnami.it Other plans in Serbia, Russia, Romania, Poland, Turkey, Mexico.
Thermal modification	ISVE - http://www.isve.com – produce small plans working under vacuum (0.2 bar) conditions where the heat transfer is done by contact using electrically heated plates. Ovens vary between 2 and 4 m^3. Treatment temperatures can be up to 230°C. A complete cycle can be 3-5 days.	ISVE has installed a total number of 10 plans for thermal modification of wood. The main business of ISVE is the production of plans for double vacuum impregnation.
Thermal modification	WDE Maspel – TermoVuoto - http://www.wde-maspell.it – produce plans working under vacuum (0.2 bar) where heat is transferred by a high efficiency air ventilation system. Wood is dried under	WDE Maspell has installed a total number of 21 plans whom one of 6 m^3 in Italy. Alac –Recanati (MC). Alac produce between 500 and 600

	vacuum condition and treated at temperature varying between 150 and 230°C. Ovens vary between 6 and 30 m^3 but ovens up to 80 m^3 are under development. The complete cycle can be 1 or 2 days. Patented process and hardware. Vacwood registered trademark.	m^3 year of Vacwood. The other plans are installed Belgium, Brazil, Chile, France, Korea, Norway, Poland Portugal Sri Lanka and USA.
Physical modification	Rancan – Ranprex - http://www.rancan.com – produces technological laminates by impregnation of beech wood with thermosetting resisns and by densification.	Rancan offers 5 types of product made with parallel sheets, crossed, crossed at 90 and 45°, crossed in more than four directions.
Chemical modification	Renner – PAA – New consolidating and preservative products based on Polyamidoamines (PAAs) functionalized with siloxanes.	Patent WO2015004590 A1, Renner Italia SpA, 2015.

Table 1: Wood modification technologies, producers, companies and production volumes

Practical examples

Thermally modified material is at present produced in Italy for different purposes such as durability in external applications, aesthetics in internal applications. Practical uses are furniture, boat flooring, cladding, decking, fences. Ranprex is used in different contexts where a stable, light and resilient material is needed. Some examples are shown in Fig. 1 and Fig. 2.



a **b** **c**

Figure 1: [a] certified window in thermally modified beech (courtesy Luigi Todaro), [b] decking in thermally modified ash (courtesy Margaritelli), [c] furniture in thermally modified ash (Courtesy WDE Maspell).

a **b**

Figure 2: [a] decking in thermally modified ash (courtesy of Evolen), b) cladding in thermally modified ash (courtesy Alac), [c] gears made of Ranprex.

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Performance of modified wood – Bio4ever project - how to convince people to use bio-based building materials?

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Keywords: modified wood, service life performance, facades, visualization

Introduction

Today's bio-based building materials, even if well characterized from the technical point of view, often lack reliable models describing performance during their service life. The overall goal of the BIO4ever project is to contribute to public awareness, by demonstrating the environmental benefits to be gained from the knowledge-based use of bio-based materials in buildings.

Modification technologies tested within the BIO4ever project

Performance of 120 selected façade materials provided by over 30 industrial and academic partners from 17 countries is under evaluation. The experimental samples were classified in seven categories, according to treatment applied: natural wood (or other bio-based materials), chemical modification, thermal modification, impregnations, coatings and/or surface treatments, composites, and hybrid modification, that include combination of at least two different treatments (Table 1).

Wood modification technology	Samples examples	Number of tested materials
natural	wood, bamboo	19
chemical	acetylation, furfurylation	5
composites	panels, bio-ceramics, tricoya, wood plastic composites	7
coating & surface treatments	different coatings, carbonized wood, nanocoatings	16
impregnation	DMDHEU, Knittex, Madurit, Fixapret	28
thermal modification	vacuum, saturated steam, oil heat treatment	20
hybrid modification	thermal treatment + coating, thermal treatment + impregnation, acetylation + coating etc.	25

Table 1: Categories of bio-based facades materials tested within BIO4ever project

Performance of investigated samples

All bio-materials are under extensive characterization before, during and after degradation by biotic and abiotic agents (natural weathering in San Michele, Italy, 46°11'15''N, 11°08'00''E), in order to provide experimental data to be used for better understanding the bio-materials performance/degradation as a function of time. The appearance change, being result of the progress of natural weathering is presented on Figure 1.

The experimental data, acquired during BIO4ever project duration are used for development of the numerical models simulating the material degradation in a function of time and exposure. The weather data calculated according to the ASHRAE 2013 database allows numerical simulation of cumulative radiation and temperature on building facades, situated in 6000 locations all over the world. Dedicated algorithms simulating material deterioration by taking into account specific material characteristics, kinetic and intensity of weathering process as well as specific architectonic details are extensively tested. The main project output is a software simulating biomaterials aesthetic performance integrated with LCA interactive calculation. The tool, dedicated for investors, architects, construction engineers, professional builders, suppliers and other relevant parties, including also final customers is now under validation and integration with the BIM software.

a **b**

Figure 1: Apperance of investigated samples at the beginning of the test (a) and after 12 months of natural weathering at the southern esposure (b).

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Wood modification in Poland

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Keywords: wood modification, densification, M-M, T-M, TM-M, superheated vapour

Introduction

Traditionally changes of surface properties were obtained in aging treatment, nowadays due to wood modifications. The most popular aged wood species are those that age in the nicest way, at the same time preserving their durability, such as oak, larch, pine, robinia (black locust) or ash. As a result of treatment, wood changes occurring (depending on the modification conditions) such as: improvement in dimensional stability and resistance to biodegradation, unfortunately often followed by reduced MOE, MOR, abrasion resistance and tendency for cracks and splits, reduced hygroscopicity.

Modification technologies

In order to improve wood properties, it is densified (mechanically), thermally and thermo-mechanically modified. Another way to change initial properties of wood is modification with thermo-chemical components, treatment with superheated vapour, modification in smoke and fumes, etc. There are also combinations of modification methods, such as: thermal modification in vapour together with superheated vapour and surface densification with the use of single impulse and pulse densification (gradual densification causes less stress). The problem of densified wood is maintaining the effect of compression, especially at variable humidity, hence also studies related to the use of oil as a stabilizing agent. T-M densification may apply to natural wood or wood T-M before. Stages of T-MD are: heating wood over temperature of lignin softening (1), and wood mechanically, pulsating pressing (2).

Aplications and practical examples

Modifications in Poland are carried out in industrial and laboratory conditions. Research is conducted in two major scientific centres: in Warsaw University of Life Sciences – SGGW and Poznan University of Life Sciences, related with colour stability of wood modified for example with isocyanates, water vapor sorption in different artificial climates, influence of treatment on polysaccharides composition, influence of modification on cutting resistance during drilling and specific cutting resistance. Another field of interest is a use of modified timber in construction as well as acoustic emissions from densified wood useful for musical instruments. The densification of wood with hot rolls is a combination of the thermochemical method and surface densification. Such modification is performed on solid wood, as well as veneers and face veneers. SGGW in collaboration with business partnership developed a new wood product based on the SGGW patent on wood modification through heating and subsequent pressing. Project was organized as part of MSODI by UMWM and International Development Norway AS. Another field of interest is thermal modification of panel products (MDF) and thermal modification of veneers. Densification provides for a greater homogeneity and water tightness of MDF. Modified wood chips could be used to manufacture chipboards. Another research direction is secondary HDF densification, which provides an extra-high density of boards.

Veneers could be also chemically modified and then subjected to secondary TM treatment. Veneers are modified in order to obtain better aesthetical and mechanical properties to produce plywood, bent-glued

elements or carpentry panels. SGGW analysed also possibility of plywood with higher water resistance technology production.
In polish industry veneers are modified in TM treatment in order to achieve better aesthetical and mechanical properties to produce plywood, bent-glued elements. Usually, modified wood is used as parquet material: as solid wood (oak, ash, elm, beech) as the top layer in laminated parquets. Densified wood in Poland is produced by 4 companies (Jablonski, Drewspan, Versal, Gajewski), T-M wood by a several dozen of facilities, chemically by only two (Drymar and Dreweko).
Modified wood could be also applied in reconstruction of antique parquets. Oak wood modified chemically with ammonia and thermally, however these methods lead to less durable colours in comparison with natural black oak. In Poland exists several high temperature scalding houses.

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Wood modification in Estonia

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Keywords: long-standing tradition, innovative development

Introduction

According to the statistics of the year 2016 direct added value in forest and wood sector for Estonia was 5,3% of all. Percentage of wood, paper, and furniture industry in manufacturing industry was 35%. The revenues from sales made up 3,3 billion €. Products of timber have been always important part of export for Estonia during the centuries. Export of Estonian timber companies consist a wide range of different product groups as sawn and planed timber, pre-fabricated structural details for construction and for furniture manufacturers, or element and modular buildings. During the last decade ever more and more wood products with higher added value are included (EMPL 2017).

Modification technologies and production volumes

Wood modification production volumes by categories are shown in the Table 1 (EMPL 2017).

Wood modification product	Year 2016	Unit
Sawn material	2 183 000	m3
GL and CLT	359 600	m3
Woodpellet	1 166 514	t
Thermo mechanical pulp	172 900	t
Unbl paper	65 300	t
Plywood	55 700	m3
Veneer	108 400	m3
Chipboard	120 000	m3
Fiberboard	7 123 800	m2

Table 1: Wood modification production volumes (total) in Estonia 2016

Main producers of wood modificated products are shown in Table 2.

Wood modification technology	Producer, process short description and website	Annual volumes produced and companies involved in the process
GL, GL-panels, finger-jointed structural timber, DUO-TRIO, CLT	Peetri Puit OÜ. GL: length 1.0-29.5 m, max height 2.3m. CLT: max measurements 3,5x15 m, thickness of panels 60–300 mm. http://www.arcwood.ee/en	
Finger jointed timber, GL components	Lemeks AS (Pinest AS). GL components glued into blocks, L and T profile. Length up to 6 m. http://www.pinest.ee/en/you-have-discovered-pinest-welcome.html	
Finger jointed timber, GL	Barrus AS. http://www.barrus.ee/en/	60000 m3/a (80% export)

pine		
Vacuum-pressing treatment, finger jointed timber	Tapa Mill OÜ. http://www.tapamill.ee/	
Treatment	Lotus Timber OÜ. Deep-impregnated wooden poles, fire protection. http://www.lotustimber.ee/en	
Pressure treated timber	Imprest AS. Machine rounded timber products, outdoor playgrounds, preservative - treated wood. http://www.imprest.ee/EN/company/introduction/	(95% export)
Hot oiling, treatment	Hansacom OÜ. Deep impregnation of timber (Koppers). http://www.hansacom.ee/en/	
Timber strips, coloring	Trives OÜ. Production of strips and components made of softwood, coloring. http://trives.ee/en/	
Timber strips, coloring	Combiwood OÜ. Wooden mouldings finished with primer and surface paint. http://www.combiwood.ee/en/node/9	
Birch veneer, plywood	Kohila Vineer OÜ. Production of birch veneer and plywood. http://kohilavineer.ee/	45000m3/a
Veneer, plywood	UPM-Kymmene Otepää AS. Uncoated and coated WISA birch plywood for construction, furniture and transport industries. http://www.wisaplywood.com/Contacts/production-units/otepaa/Pages/Default.aspx	90000 m3/a
Birch veneer, plywood	Tarmeko Spoon AS. Production of rotary cut birch veneer. http://tarmeko.ee/companies/veneer/production	
Veneer (mainly birch), plywood	Valmos OÜ. Rotary cut veneer and sliced veneer, but also plywood veneer and formatted veneer of various thicknesses. http://www.valmos.ee/en/	10000m3/a
GL components of timber, planned timber products	Stora Enso Eesti AS (Imavere, Näpi). http://www.storaenso.com	

Table 2: Wood modification technologies, main producers, companies and production volumes in Estonia

Practical examples

The Winner of Wooden Buildings 2016 in Estonia was Arcwood`s new office and industrial building, made of their own produced CLT (walls, ceilings, stairs, commercial stend etc) and GL details (columns, beams, railings) shown on Fig.1.

Wood modification in Turkey

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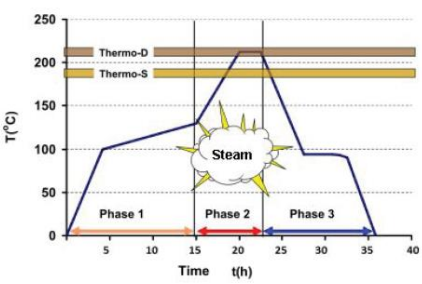
Keywords: Wood modification, ThermoWood, Heat treatment

Introduction

The total land area of Turkey is about 80 million ectares while the forested area of the country is 28.6% (22.3 million ha) of the country land area (URL 1). Turkey has rich and diverse herbaceous and woody plant species (endemism of almost 34%). The main tree species used for roundwood production are pine species (*Pinus* sp*)*, beech (*Fagus orientalis*), fir (*Abies bornmülleriana/alba/nordmaniana*), spruce (*Picea orientalis*), cedar (*Cedrous libani*), and oak (*Quercus*) (URL 2).
Roundwood production in Turkey is about 13 million m^3 annually (Tolunay and Turkoglu, 2014). The forest products industries in Turkey have increased their capacity over the last decade. 70% of timber produced in Turkey is used in construction, 20% is used in furniture production and 10% is used in packaging and other industries (URL 2).
Pressure and heat treated wood materials in Turkey are commonly found in the market as well as in practical examples but acetylated wood products have not gained enough attention yet. Acetylated wood products are not produced in Turkey; however, because of the demand on acetlayed wood products such as in decking, cladding, siding, flooring, Turkish Accoya distributer has started to sell Accoya products in Turkey (URL 3).
There are three companies dealing with thermal modification in Turkey and all of them use Thermowood technology developed by VTT in Finland.

Modification technologies and production volumes

Wood modification technology	Producer, process short description and website	Annual volumes produced and companies involved in the process
Thermal modification	There are three producers namely Novawood, Naswood and ARIN in Turkey dealing with thermal modification. All three producers use Thermowood techonology developed by VTT in Finland. The heat-treatment process used by these companies is summarized in the figure below;  The producers websites; http://novawood.com http://www.nasreddingroup.com	Novawood is the first company to introduce the thermal modification technology “Thermowood” in Turkey. The plant is located in the Bolu Gerede Industrial Area; the Novawood plant produces 18,000 m^3 of heat-treated lumber and 600,000 m^2 of heat-treated finished goods annually. The main range of Thermowood products by Novawood include Exterior Cladding, Panel Cladding, Decking, Decking Tiles, novathermowood Door and Window Profiles, novathermowood Pergolas and Fences (URL 4). Nasthermowood plant is located in Muğla and produces about 5,500 m^3 of heat-treated lumber. The softwoods of the Syberian and North European Taiga forests, Hardwoods of the Black Sea Region, Tropical trees of African and South Asian forests as source, Naswood pays attention to work with FSC cetified

	http://www.arin.com.tr	suppliers of rawmaterial. The main range of Thermowood products by Naswood includes decking, flooring and siding (URL 5). ARIN forest products plant is located in Düzce and produces about 4,200 m^3 of heat-treated lumber. Pine species, ash, iroko and other tropical species are used. The main range of Thermowood products by ARIN includes decking, flooring and siding (URL 6).

Table 1: Wood modification technologies, producers, companies and production volumes

Practical examples

a

b

Figure 1: Thermally modified wood decking (a) and thermally modified iroko wood cladding (b).

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Wood modification in Macedonia

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Keywords: wood production, modification, sawn lumber

Introduction

The territory of Macedonia that is under forests is 988.835ha, of which 82% are decidious, 12% are coniferous and 6% are mixed forests. The total wooden mass is 74.343.000 m3, and the annual growth is 1.830.000m3, with an average growth of 2.02 m3 per hectare. The planned cuttable etat is around 1.3000.000 m3, and 70% of it is used. Around 80-85% of the mass is used as firewood. Although the country has a large forestry potenttial, the downsides are the low quality of the wooden mass becase of which is used as firewod and not as technical wood, lack of modern equipment and automatization systems. Manufacture of wood and of products of wood and cork, except furniture is around 70.000m3 annually in 2014. Wood waste during the production in 2014 is 1153.32t, of which, non-hazardoues is 1137.19t and hazardous is 16.14t. The wood products being produced are: parquett, wood flooring, inside and outsied wall leaf, doors, buildings and similar.

Modification technologies and production volumes

The modification of the wood products is mainly oriented on thermal modification, such as: drying and steaming the wood products.

Wood modification technology	Producer, process, short description and website	Annual volumes produced and companies involved in the process
Total production	Companies in Macedonia	70.000 m3
Thermal modification: Drying and steaming	Ela-Mak, GamaDizajn etc.	1500m3 (only Ela-Mak)

Table 1: Wood modification technologies, producers, companies and productio volumes

The most common thermal modification process is as follows. At first a steaming of the wood is made, which ussualy takes 2-3 days. The steaming is conducted on a temperature of around 100-130°C with a high humidity in the steaming chamber. Afterwards, the wooden product is taken into drying chamber. Depending on the wood the drying process can be: 14-17 days for firwood, 24-25 days for beech, 30-33 days for oak, up to 60 days for birch. The drying process is computerized and there are 17 steps in the process in which the temperature inside the chamber is gradually increased strating from 30°C until 70°C, while the humidity is declining.
The company Ela-Mak from Macedonia, works with beech and fir wood to produce sawn lumber, (boards, planks, beams), slats, parquet and wooden floors as well as briquettes. The production capacity is 1500m^3. During the production, the beech wood is dried to 10% humidity and steamed to protect it from insects and afterwards is used in production of furniture. The fir wood is usually 40% humidity and is used for

construction works of roofs and walls.
In the country there is certain number of companies that produce laminated wood, among which is Bulart.

Wood products	Producer, process, short description and website	Annual volumes produced and companies involved in the process
Total production	Companies in Macedonia	70.000 m3
Wooden boards	Elkotehna	/
Wooden houses	MDC Architectonica, HotHot, Pijana Plackovica, Geoing	/
Laminated wood	Bulart (www.bulartconstruction.com) - mechanical pressing, glues type - D3, D4	

Table 2: Wood products

Practical examples

There are several companies in Macedonia that produce and construct wooden houses such as: MDC Architectonica, Hot i Hot etc.



a. Laminated wood (Bulart) b, c. Wooden house

Figure 1: Wooden constructions

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Wood modification in Slovakia

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Keywords: thermally modified wood, steamed logs

Introduction

Wood-based industries in Slovakia have also implemented modification processes. Thermal wood processing involves temperatures of 100-260°C. The most used modification technologies of solid wood are thermo-hydro processes, which involve the combined use of temperature and moisture. According Sandberg and Kutnar (2016) it can distinctly different purposes: 1) controlled changes in wood structure at temperatures between 150°C and 260°C with the purpose of improving its shape stability and decay resistance or 2) softening the wood in steam or water to release internal stresses and make the wood easier to further process.

Modification technologies and production volumes

Wood modification technology	Producer, process short description and website	Annual volumes produced and companies involved in the process
Thermally modified wood “Thermowood”	TECHNI-PAL, Banská Bystrica Production of thermally modified ash, oak, beech and pine wood. Adress: Malachovská cesta 92, 974 05 Banská Bystrica. Production: Polkanova 3183, 976 02 Staré Hory	400 m^3
		Annual volumes processed and companies involved in the process
Thermo-hydro modified wood “steamed logs”	SLOVINCOM, spol. s r. o., Hurbanovo Production of flat poplar plywood and blockboard cores. http://www.slovincom.sk/	26 000 m^3
	DYHA TIROLA, spol. s r. o., Moldava nad Bodvou Production of beech structural veneer. http://www.dyhatirola.sk/	10 000 m^3
	A-Z LOKOMAT, spol. s r. o., Kraľová Lehota Production of beech structural veneer and flat beech plywood. http://www.lokomat.sk/	12 000 m^3
	FIBRA, spol. s r. o., Šahy Production of beech structural veneer and molded beech plywood. http://www.fibrasro.sk/	6 000 m^3
	MS TECHNOLOGY, spol. s r. o., Bardejov - production of beech structural veneer. http://www.mstechnology.sk/	4 000 m^3

Table 1: Wood modification technologies, producers, companies and production volumes in Slovakia

Thermal treatments of sawn timber are representing a small proportion. In Slovakia are few small producers: TECHNI-PAL (Banská Bystrica) and others with annual produced volume less than 500 m^3 per year. The actual import of thermally treated wood (cladding and decking boards, strucal building profiles and other) from other European countries to Slovakia is *app.* 1 000 m^3 per year (trade companies *e.g.* RM drevo s.r.o., JAF HOLZ Slovakia s.r.o., PMP stav s.r.o.).

Thermo-hydro processing is specially applied for the plastification and conditioning of logs prior to cutting veneer (in following producers of veneer and plywood in Slovakia: SLOVINCOM (Hurbanovo), DYHA TIROLA (Moldava and Bodvou), A-Z LOKOMAT (Kraľová Lehota), FIBRA (Šahy), and MS TECHNOLOGY (Bardejov). Their annual logs processed volume is about 58 000 m^3 per year (Tab. 1). Other new processing companies: BIO ENERGO (Žarnovica) and EUROPLAC (Topoľčany) are actually under construction.

Practical examples

Especially thermally modified wood (imported or produced) is widely used material for both exterior and interior applications. Here are some uses from Slovakia – see Fig. 1.

Figure 1: Thermally modified pine wood facade (a), gate and hence (b), bridge (c), terrace by the pool (d), garden furniture (f), flowerpots and stairs (g), washbasin (h). Thermally modified ash or beech wood terrace (e), bathing or cooling off tub (i). Thermally modified quercus parquet floors (k).
(Foto: references from companies RM drevo s.r.o., TECHNI-PAL and Rostaco Slovakia s.r.o.)

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Wood modification in Norway

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Keywords: cladding, decking, furfurylation, Norway, thermal modification, wood modification

Introduction

In Norway, there is one large manufacturer (Kebony ASA) of chemically modified wood known also to the international market and at the moment one small manufacturer of thermally modified wood for the domestic market.
The end-use of modified wood is mainly claddings and deckings, where some large prestige multi-story buildings have been built the last years with facades of modified wood. Most of the modified wood, except furfurylated wood, for these projects are however imported from other European countries. There is an increase in demand for "maintenance free" wooden cladding and deckings for the consumers.
The demand for envriomental product declarations (EPD) is relatively high in Norway and several of manufacuteres have therefor prepared EPDs. In construction projects, there are also sometimes demands for an LCA for the whole building with a focus on carbon footprint.

Modification technologies and production volumes

In Table 1 the producers of modified wood in Norway have been listed together with process description and production volume.

Wood modification technology	Producer, process short description and website	Annual volumes produced and companies involved in the process
Furfurylated wood	Kebony ASA Impregnation with furfuryl alcohol which give locked-in furan polymers in the wood cell walls. www.kebony.com	Approx. 22.000m^3 produced by Kebony
Thermally modified wood	Marnar bruk AS. Has installed thermal modification equipment and have had some production, but has had a large increase in demand for their main product (royal impregnated pine) and hence have postponed the thermal treated pine production.	Zero production at the moment.
Thermally modified wood	Sæteråsen Sag & Høvleri. Thermally modified at 210˚C. www.saeteraasensag.no	Approx. 350m^3 produced by Sæteråsen.

Table 1: Wood modification technologies, producers, companies and production volumes

Kebony ASA has performed life cycle assessment (EPD) for their products and documented the results in environmental product declarations (EPD). Marnar Bruk AS has EPD for their main product, royal impregnated pine, but not yet for the modified wood products. Sæteråsen Sag & Høvleri has not performed any known LCA work. There are several large importers of modified wood products. Moelven Prosjekt AS is importing thermally modified spruce, pine and ash from Thermory in Estonia and has developed EPD for these products. Accoya are imported and sold by Fritsøe Engros, and Accoya has also developed an EPD which is registerd at EPD-Norway.

Practical examples

In Stavanger municipality, a building program for using more wood in multi-story residential and non-residental buildings was activated in 2012. One of building project was Vannkanten which have used a high degree of wood, and the cladding material is thermally modified pine (Fig. 1).

Figure 2: Vannkanten, Stavanger, Norge. Built 2014. Thermally treated pine (Delivered by Moelven). Photo: NIBIO/Lone Ross Gobakken

The building project Lislebyhallen Flerbrukshall (multi use sports arena) was a lighthouse project for Fredrikstad municipality and the use of chemically modified wood as cladding is shown in Fig.2. The building project had several innovative feutures, including first passiv house standard applied in Norway for a sport arena, cross laminated timber construction, low carbon footprint concrete in foundation, minimalistic material use and the carbon footprint was calculated for the materials, energy use and transport of users during the reference service life of the building. Lislebyhallen was also rewarded as the sport facility of the year in 2016 and the users are highly satisfied (Tellnes and Rønning, 2018).

a **b**

Figure 2: Chemically modified radiata wood cladding (Accoya) (a) and (b). Photo: Ostfold Research/Lars Tellnes.

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Wood modification in Hungary

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Keywords: thermo-hygro-mechanical treatment of wood, accordionisation, steaming, wood bending

Introduction

Wood modification technologies date back from decades at the University of Sopron. First investigations were high pressure and temperature steaming, and ammonia treatment of black locust. The demand for modified wood material increased Europe-wide, due to the commercialisation of different wood modification processes during the last decades. Wood modification indicates a lot of research objective in our institute. Wood modification processes indicate continuously new challenges. During the last years we gave special attention to heat treatment processes in vegetable oils and paraffin, acetylation and some impregnation processes. As in the last years nanotechnology came to the front, we investigated the application possibility of nano-scale materials in wood industry. Unfortunately, the wide-spread research activity in the field of wood modification is not coupled with active industrial applications in Hungary. However, there were some trials with heat treatment technologies.

Modification technologies and production volumes

THERMO-HYGRO-MECHANICAL TREATMENT OF WOOD – COMPWOOD PROCESS
Compression parallel to the grain, to improve the bendability of wood (accordionization). The purpose of the longitudinal compression of wood is to make it bendable. Several factors influence the outcome of compression (wood species and quality, moisture content, temperature, compression rate, etc.) Most hardwood species with initial moisture content above 20% can be compressed. The wood is normally softened by steaming, and during the process, kept at temperatures above 80°C. While compressed in fibre direction it needs to be restricted within the compression chamber to prevent the wood from suckling. Frictional forces need to be minimized so that the transformation is performed at even rate. The middle lamellae, mostly consisting of lignin and hemicelluloses are softened by thermo-hydro wood processing, allowing of the wood fibres with high cellulose content to slip during compression, and the longitudinal cell walls crinkle. Consequetly, the elasticity of the wood decreases, thus it will be much easier to bend, even when dry and at room temperature.

Wood modification technology	Producer, process short description and website	Annual volumes produced and companies involved in the process
Compressed wood parallel to the grain (accordionisation)	Compwood Products Kft. Thermo-Hygro-Mechanical treatment. www.compwood-products.com	~20 m3 (2016) 50 m3 (Production capacity)

Table 1: Wood modification technologies, producers, companies and production volumes

Practical examples

There is a wide range of utilization fields for the wood material produced by the compwood technology. One of the most interesting utilization is the production of wooden springs (Fig. 1a). With the use of these springs, it is possible to produce upholstered furnitures based only on biomaterials. Another common field of utilization is the production of bent furnitures and parts (Fig. 1b). Special applications are design elements (Fig. 1c) in interior design, or music instruments, sport instruments, ship building, toys, medical aid equipments, etc.

a **b** **c**

Figure 1: Thermally modified alder wood bench (a) and hermally modified beech wood window (b).

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