ONLINE ISSN 2069-7430
ISSN-L 1841-4737

PRO LIGNO
www.proligno.ro

Vol. 11 N° 4 2015
pp. 324-329

SELECTED PHYSICAL AND MECHANICAL PROPERTIES OF VISCOELASTIC THERMAL COMPRESSED WOOD FROM FAST GROWING POPLAR

Stanislav HORNÍČEK
Mendel University in Brno, Faculty of Forestry and Wood Technology, Department of Wood Science
Zemědělská 1, Brno, Czech Republic; E-mail: stanislav.hornicek@mendelu.cz

Peter RADEMACHER
Mendel University in Brno, Faculty of Forestry and Wood Technology, Department of Wood Science
Zemědělská 1, Brno, Czech Republic

Radim ROUSEK
Mendel University in Brno, Faculty of Forestry and Wood Technology, Department of Wood Science
Zemědělská 1, Brno, Czech Republic

Andreja KUTNAR
University of Primorska, Andrej Marušič Institute, Muzejskitrg 2, SI-6000 Koper, Slovenia; University of Primorska, Faculty of Mathematics, Natural Sciences and Information Technology
Glagoljaška 8, 6000-Koper, Slovenia; E-mail: Andreja.Kutnar@upr.si

Frederick A. KAMKE
Oregon State University, Department of Wood Science and Engineering
119 Richardson Hall, Corvallis, OR, USA; E-mail: Fred.Kamke@oregonstate.edu

Abstract

Densification techniques, combined with other treatment processes, helping additionally to improve wood properties, play an important role in wood modification. An innovative example of this combination with other techniques is the viscoelastic thermal compression (VTC) process.

In this study, material of poplar wood from fast growing short rotation plantation (SRP), modified by VTC process, was used for investigation and results were compared with non-modified native wood of plantation grown poplar. Selected physical and mechanical properties, i.e., density, equilibrium moisture content (EMC), and modulus of elasticity (MOE) were investigated.

The material, used for this investigation, was obtained from plantation grown poplar clone Max-4 (Populus nigra x Populus maximowiczii) from the Czech Republic.

Results show that compression and heat treatment of the viscoelastic thermal compression process lead to significant changes in physical and mechanical properties of the treated material. The density of material depends on the degree of densification and has a crucial effect on properties.

The goal of this study was to examine the improvement of properties of SRP poplar clone after applying the VTC densification process. Property improvement of plantation grown poplar wood has a huge potential for future use of this low-cost and fast-growing material, which would save high value materials for special uses.

Key words: *modification of properties; fast growing poplar; viscoelastic thermal compression.*

INTRODUCTION

Densification of wood has been known for several decades; the first patent appeared at the beginning of the 20th century (Kollmann et al. 1975). Nowadays, it is combined with other treatment processes to improve additional wood properties. An innovative example of this combination is the viscoelastic thermal compression (VTC) process, which is a type of thermal-hydro-mechanical treatment.

In this study, material of poplar wood from fast growing short rotation plantation (SRP), modified by the VTC process, was used for investigation. Results were compared with non-modified native wood of plantation grown poplar. Selected physical and mechanical properties, i.e., density, equilibrium moisture content (EMC), swelling / shrinkage and modulus of elasticity (MOE) were investigated.

The viscoelastic compression of wood

Wood is a viscoelastic material and the behaviour of viscoelastic properties depends on the combination of temperature and moisture treatment, as well as the exposure time and the intensity of these conditions.

Viscoelastic properties of wood can exhibit special behaviour – glassy and rubbery conditions. In the range between these two behaviour points, there is a region characterized by the glass transition temperature (Tg). Temperature Tg causes a rapid decrease in material stiffness (Wolcott 1989) Additionally, high moisture content caused by saturated steam will soften the structure and reduce Tg. If the moisture content is transient, further softening will occur under applied load; this phenomenon is called mechano-sorption (Kutnar et al. 2008). The viscoelastic properties of wood have been widely studied in the past (Lenth 1999; Lenth and Kamke 2001; Wolcott and Shutler 2003).

The method for wood densification using the viscoelastic thermal compression (VTC) process, developed in 2005 by Kamke and Sizemore, is intended to improve the properties of wood combining several procedures in rapid and continuous treatment of thin lamina. This process combines steam, mechanical compression and heat. Elevated steam pressure is one of the main parts of VTC process and it leads to the conditions above glass transition temperature (Tg) of wood. Due to these conditions, cell walls can transfer stress and resist strain, and the softened wood structure can be compressed without cleaving. Very high densification is achieved without destroying the micro-cellular structure of treated wood. Finally, the density of the material can be increased by compression in a range between approximately 25% and 500% (Kamke 2006). Increased temperature is used to assist the stress relaxation of compressed cells. High temperature causes thermal modification of cell walls. The final step in modification of wood properties by VTC process is the decreasing of the temperature below Tg and the increasing of the moisture content (MC).

VTC wood shows high density, unfractured cellular structure, reduced hygroscopicity and very high performance of mechanical properties (Kamke and Sizemore 2005).

This modification process was developed for a better utilization of fast-growing low-density wood species, like plantation grown poplar. Furthermore, it can be used for any wood species of various densities and MC (Kutnar et al. 2008).

Plantation grown trees

During last years the number of plantations with fast growing species has been increasing. The main species for fast growing plantation or short rotation coppice (SRC) are hybrids of poplar, for example *Populus nigra, Populus maximovitzii, Populus deltoides, Populus trichocarpa* and others. The hybrids of these poplars are used due to their fast growing and undemanding character, high resistance to pests, and regenerative capability. These hybrids are collectively called Japan poplar due to the origin of the first hybrid. The cultivation of poplar hybrids in Europe began in the 1960s for energy and industry purposes.

The most popular poplar hybrid for SRC in the Czech Republic is MAX-4 (*Populus nigra* x *Populus maximovitzii*). The effective operating reproduction after cuttings and harvest periods of 2–6 years and their fast growth have resulted in an increasing utilization of this clone. The yearly growth depends on the climatic and the soil conditions, the height growth is about 2.5–4.5 m. After every harvest, the stump recreates new shots and the development starts again for a continuous growth period, sustainable for 20–25 years. The final step after these periods is the removal of old stumps and the planting of new cuttings (Silva Tarouca Research Institute cit. 2015).

Harvest is performed in winter by special plantation harvest machines including a wood chipper (small diameters) or chain saws for solid wood harvest after five years (big diameters).

The wood material can be used in many ways; low price material is predominantly used for energy; in the median price segment, poplar wood can be used as pulp and paper; higher prices are possible in utilizations for buildings, noise barriers, toys or furniture. However, during the last years, the energetic purposes have manifested the main potential for utilization and wood is mainly used for heating. The calorific value of fast growing poplar wood can approach that of brown coal, approximate value of 1kg of wood with 20% moisture content is about 15 MJ (Vypěstuj si les cit. 2015).The aim of this investigation is to show the possibilities of using this low-cost wood more efficiently in a larger industry range and replacing higher valued wood species, at least in some applications.

MATERIAL AND METHODS

The VTC process

The process of VTC was carried out in a pressurized vessel equipped with a heated hydraulic press. It consisted of three main phases (Kutnar et al. 2008) (Fig. 1). During the first phase, the steam was injected under pressure of 621kPa and specimens were steamed for 3.5min in 170°C temperature. After this step, the steam was released with pressure, specimens vented for 100 s and lost moisture. The next phase was the compression of the specimens, which was carried out for 2.5min with temperature of press plates increasing to 200°C. Thickness control was provided by mechanical stops at 2. mm. The first group (VTC1) was compressed from an initial thickness of 4 mm and the second group (VTC2) from 6 mm. This third phase took 6.7min. After the final phase of cooling to 100°C for 7min, the press was opened and samples were conditioned in a conditioning chamber with 65% air humidity and a temperature of 20°C.

Differences in groups (VTC1, VTC2, CTRL) and the view of the final modified material compared with CTRL are shown in Fig. 2.

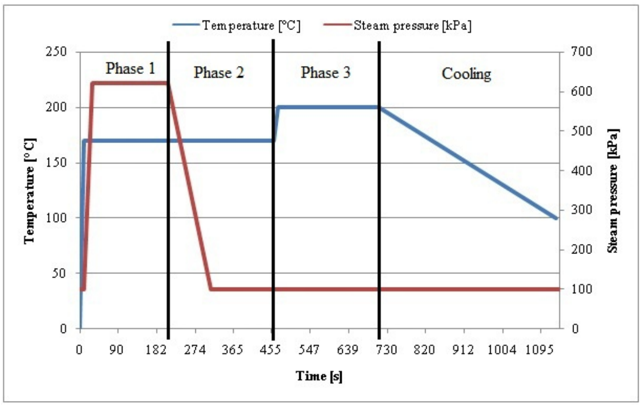

Fig. 1.
Schedule of the viscoelastic thermal (VTC) process

Plantation poplar

The material used for investigation consists of wood from plantation grown poplar clone Max-4 (*Populus nigra* x *Populus maximowiczii*) from the SRC near Holice town in the Czech Republic. The site is very dry, placed at 245 m a. s. l., in a medium slope position with north exposure and an average annual temperature between 7 and 9°C. The trees were 6 years old, harvested in November 2014.

The samples were prepared from split and debarked logs, stored under room conditions, and cut by a circular saw (Fig. 2). The dimensions of the samples were 4x70x550mm^3 (RxTxL) for the first group (VTC1) and 6x90x550mm^3 for the second group (VTC2), 12 pieces per group. Two groups of control samples with the same dimensions and numbers as VTC1 and VTC2 were prepared for comparison. The specimens included macroscopic defects like knots, pith and splits. The samples were conditioned before treatment in a conditioning chamber with relative air humidity of 65% and a temperature of 20°C.

Fig. 2.
Debarked and split logs and the final modified material (VTC2) compared with CTRL sample (right)

Experimental measurements

Measurements of physical and mechanical properties were carried out by non-destructive methods; each treatment group consisted of 12 replications of original size (see above), including all knots and other failures in order to show semi-practical material quality for future utilization. EMC (EN 13183-1), shrinkage (ČSN 490104) and MOE (Fakopp 2D ultrasonic timer) were measured after conditioning of all samples in 65% air humidity and 20 °C compared to samples dried at 103 °C (density [ρ_0]). MOE was measured in several areas without knots and other failures by means of each of 12 full size samples per treatment, using a distance of 100 mm between source and target sensors and fitting to the gap between knots and other failures (Fig. 3).

Fig.3.
Measuring of modulus of elasticity (MOE)

RESULTS

Density ratios after compression of materials were 1: 2.3: 2.9. A significant decrement of EMC was observed in the case of both treated materials (Fig. 4), showing similar behaviour for both densification ratios.

The same improvement is visible (Fig. 4) in the case of MOE with three times higher values of both compressed materials compared to control. Higher densities of materials – native as well as compressed – result usually in higher mechanical properties. Due to high variability of MOE for semi-practical sized samples, no differences could be determined in this study between varied intensities of densification.

Interesting results were achieved in the case of shrinkage due to drying from 65% relative air humidity conditions to dry wood, where the effect of heat treatment of the most densified material VTC2 resulted in the minimal shrinkage compared to lower VTC1- or non-densified CTRL-materials (Fig.4). A possible explanation for this result could be the spring back effect of the insufficient thermal-stabilized low densified material VTC1, whereas VTC2 due to higher density and higher thermal conductivity could be thermo-stabilized due to more effective and faster heat flow and heating. Higher density corresponds to higher thermal conductivity and probably more intense exposure to heat and the resulting thermal degradation of hemicelluloses. In addition, higher density promotes reactivity of thermal degradation products and molecular entanglements due to the compression of the polymer network in the cell wall.

The final values of the results are summarized in table (Tab. 1).

ONLINE ISSN 2069-7430
ISSN-L 1841-4737
PRO LIGNO
www.proligno.ro
Vol. 11 N° 4 2015
pp. 324-329

Table 1

Material	Density ρ_0 (kg/m^3)	EMC (%)	MOE (MPa)	Shrinkage αV (%)	Density ratio
CTRL	340.3	14.9	6773.6	5.1	1.0
VTC1	791.1	8.3	20492.2	7.8	2.3
VTC2	979.0	6.9	18752.6	3.9	2.9

Selected properties of density [ρ_0], $EMC_{65\%}$, $MOE_{65\%}$, Shrinkage αV and Density ratio

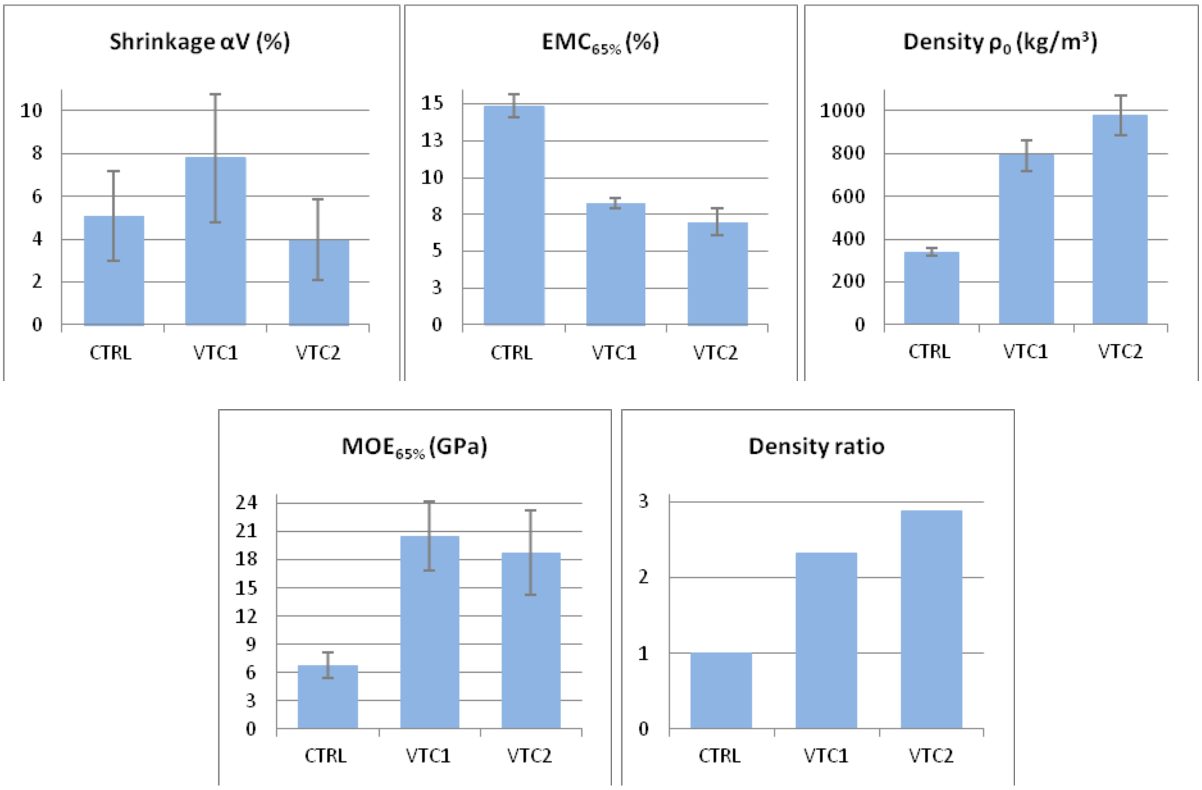

Fig. 4.
Selected physical and mechanical properties of shrinkage, $EMC_{65\%}$, density [ρ_0], and $MOE_{65\%}$

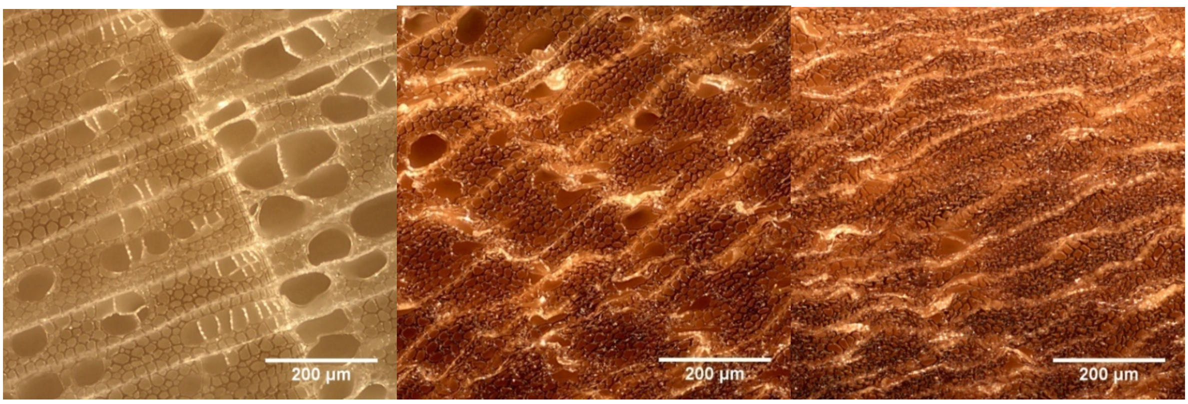

Fig. 5.
Reflected light microscopy images of untreated poplar (left), VTC1 (middle) and VTC2 (right). The cross sections show compression in vertical direction

Changes in structure of wood are shown in Fig. 5. Deformation of compressed cell walls is without any fracture due to the VTC process, adequately providing plasticization of the compressed wood and resulting in a viscous buckling of the cell walls.

CONCLUSIONS

The results show that compression and heat treatment in the viscoelastic thermal compression process lead to significant changes in physical and mechanical properties of the treated material.

The density of material depends on the degree of densification and has a crucial effect on properties. This effect is visible in the case of shrinkage, EMC and MOE (Fig. 4).

The goal of this study was to examine the improvement of properties of SRP poplar clone after applying the VTC densification process.

Property improvement of plantation grown poplar wood has a huge potential for future use of this low-cost and fast-growing material, which would save high value materials for special uses.

REFERENCES

Kamke FA, Sizemore H III (2008) Viscoelastic Thermal Compression of Wood. U.S. Patent No. 7,404,422 B2. July 29, 2008.

Kamke FA (2006) Densified radiata pine for structural composites. Maderas: Cienc Tecnol 8(2):83–92

Kollmann FP, Kuenzi EW, Stamm AJ (1975) Principles of Wood Science and Technology. Vol. II: Wood Based Materials. Springer, Heidelberg.

Kutnar A, Kamke FA, Sernek M (2008) Density and morphology of viscoelastic thermal compressed (VTC) wood. Wood Sci. Technol. 43(1):57–68.

Lenth CA (1999) Wood material behaviour in severe environments. Ph.D dissertation. Virginia Tech, Blacksburg.

Lenth CA, Kamke FA (2001) Moisture dependent softening behaviour of wood. Wood Fiber Sci 33(3):492–507.

Silva Tarouca Research Institute for Landscape and Ornamental Gardening. [online] [cit. 2015-07-15]. Available at: http://www.vukoz.cz/index.php/cs/rychle-rostouci- dreviny/zajimavosti.

Vypìstuj si les [online] [cit. 2015-07-15]. Available at: http://www.vypestujsiles.cz/japonsky-topol/co-je-japonsky-topol/.

Wolcott MP (1989) Modelling viscoelastic cellular materials for the pressing of wood composites. Ph.D dissertation. Virginia Tech, Blacksburg.

Wolcott MP, Shutler EL (2003) Temperature and moisture influence on compression – recovery behaviour of wood. Wood Fiber Sci 35(4):540–551.