Proceedings of the International Convention of Society of Wood Science and Technology and United Nations Economic Commission for Europe – Timber Committee
October 11-14, 2010, Geneva, Switzerland

Densification of Wood Veneers

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Abstract

Most mechanical properties of wood are correlated to its density. In order to gain enhanced mechanical properties, various wood densification processes have been attempted in the past. A relatively simple open-system densification process for large veneers was used, and dimensional stability was determined. Additional physical and mechanical properties were measured before and after densification, and the effect of densification temperature on these properties was investigated. Aspen (*Populus tremuloides*) and hybrid poplar clone 15303 (*Populus maximowiczii* × *Populus balsamifera*) 700 × 700 mm wood veneers were densified in a 862 x 862 mm steam injection hot press under the effect of heat, steam, and pressure. Temperatures of 140, 160, 180, 200, and 220°C were applied. After densification, the oven-dry density of aspen and hybrid poplar increased significantly from 388 to 812 kg/m^3 or more and from 348 to 687 kg/m^3 or more, respectively. Veneers darkened after densification, especially at higher temperatures. After densification, lathe checks present on veneers before densification were conglutinated and veneer surface roughness decreased. Densified veneers showed markedly reduced hygroscopicity. The Brinell hardness of densified veneer was about two or three times that of control for both aspen and hybrid poplar. Tensile and bending strength also increased significantly after densification. However, the mechanical properties of densified veneers decreased slightly with increased densification temperature. A very high compression set recovery was found for veneers densified at low temperatures. Recovery decreased dramatically when densification temperature exceeded 180°C. Almost no recovery was found for veneers densified at 220°C.

Keywords wood densification, veneer, aspen, hybrid poplar, steam, heat.

Introduction

Wood mechanical properties are generally correlated with density. Many wood densification processes have been developed to enhance mechanical properties and improve physical properties (Seborg et al. 1945; Kollmann et al. 1975; Inoue et al. 1993; Higashihara et al. 2000; Navi and Heger 2004; Kamke 2006; Inoue et al. 2008). These processes increase wood density by compressing wood to reduce void volume, by impregnating the void volume with a fluid substance, or by using a combination of compression and impregnation. However, unlike physical or mechanical compression, chemical impregnation affects the natural and sustainable character of wood, and is usually more expensive (Navi and Heger 2004). Mechanical compression processes have been reported for over a century. However, this type of compressed wood is unstable, and recovers its original shape almost completely when re-moistened and heated. In order to improve dimensional stability, compression combined with steam and heat has been receiving more attention. Various densification processes combined with steam and heat have been attempted (Inoue et al. 1993; Higashihara et al. 2000; Navi and Heger 2004; Kamke 2006; Fukuta et al. 2008; Inoue et al. 2008). Some of these still cannot solve the problem of dimensional stability. Other processes are lengthy or complex and limited to batch processes. Furthermore, most deal with small wood samples.

The objective of this study was to investigate the potential of a relatively simple open-system densification process to improve the physical and mechanical performance of large veneers made from aspen (*Populus tremuloides*) and hybrid polar clone 15303 (*Populus maximowiczii* × *Populus balsamifera).* More specifically, this study evaluated the effects of densification temperature on the dimensional stability and selected physical and mechanical properties of densified veneers.

Material and Methods

Material

Aspen (*Populus tremuloides*) veneers were obtained from Temlam Inc., a laminated veneer lumber plant in Amos, in the northwest of the province of Quebec, Canada. Hybrid poplar clone 15303 (*Populus maximowiczii* × *Populus balsamifera*) trees were obtained from a plantation in Ste-Françoise-de-Lotbinière, southwest of Quebec City, Quebec, Canada. The nominal thickness of aspen and hybrid poplar veneers was 3.2 and 4.3 mm, respectively. Veneers were conditioned at 20°C and 60% relative humidity before treatment.

Densification Treatment

A steam injection 862 mm × 862 mm hot press was used for veneer densification. Holes used for steam injection and venting are distributed on both platens at 32 mm intervals. The two platens were pre-heated before treatment. Five temperatures were used: 140°C, 160°C, 180°C, 200°C, and 220°C. Veneers of 700 mm × 700 mm were pre-treated with steam at a line pressure of 550 kPa , and then compressed from initial to target thickness at a maximum hydraulic pressure of 4.5 to 9.0 MPa. After densification, the press platens were maintained in the same position during post-treatment. At the end of post-treatment, steam injection was stopped and steam was vented through the holes in the platens. Platens were opened and the veneer was removed from the press, at which time it was observed that the veneer had almost completely dried. Theoretical compression set was 50%. Compression set (C) was defined as $[(T_O – T_C) / T_O] \times 100(\%)$, where T_O and T_C are the veneer thickness at oven-dry condition before and after compression, respectively.

Recovery Test

A cyclic recovery test was conducted to determine compression set recovery. After compression, oven-dried specimens were soaked in water until saturated and then oven-dried again. This procedure was repeated five times. After five soaking cycles, specimens were soaked in boiling water for 30 minutes and then oven-dried. Thickness at each saturated and oven-dried condition was recorded. Compression set recovery (R) was calculated as $[(T_R – T_C) / (T_O – T_C)] \times 100(\%)$, where T_R is the veneer thickness at oven-dry condition during the cyclic recovery test. For each densification treatment, a recovery test was performed on 12 specimens.

Determination of physical and mechanical properties

Oven-dry density, equilibrium moisture content at 20°C and 60% relative humidity (EMC), saturated moisture content after water soaking at room temperature (SMC), and wood color were measured. Brinell hardness tests were conducted according to European standard EN 1534(2000). The maximum longitudinal tensile strength were obtained according to ASTM D 1037-96a standard (1997). Three-point static bending tests were also performed according to ASTM D 1037-96a standard (1997) to obtain maximum strength in bending. All measurements were performed on 12 densified and 40 control specimens, except for tensile tests on hybrid poplar control specimens, which were not performed.

Results and Discussion

General Observations on Densified Veneers

The most visible change resulting from the densification treatment was wood color. Veneers darkened after densification and darkening increased in intensity with increased densification temperature. Another important visible effect of densification was the conglutination of lathe checks that were present on veneers before densification. This could be explained by the formation of cross-links between the fibers on the surface of checks under the effect of heat, steam, and pressure. The conglutination of lathe checks is expected to contribute to improve veneer mechanical properties. Furthermore, the surface roughness of densified veneers was found to be much lower than that of non-densified veneers.

The Problem of Densification with Saturated Steam

The steam used for densification was saturated at 140°C. Saturated steam treatment has been reported effective in the permanent fixation of densified wood (Inoue et al. 1993; Ito et al. 1998a; Navi and Heger 2004). However, these tests were performed on small wood specimens in a sealed vessel (closed-system). The permeation and distribution of saturated steam in small wood samples are relatively uniform. In the current study, the surface of the densified veneer was 700 mm × 700 mm and steam was injected through the tangential surface, in the radial direction of wood, for which gas permeability is much lower than in the longitudinal direction. As the steam was saturated, water condensed during densification processedat 140°C and did not permeate or distribute uniformly in the veneer. Consequently, severe variations in all the physical and mechanical properties of the same densified veneers were observed for both aspen and hybrid poplar densified at 140°C. Therefore, saturated steam appears to be unsuitable for large veneer densification.

Density and Compression Set

After densification, oven-dry density of aspen and hybrid poplar increased significantly from 388 to 812 kg/m^3 or more and from 348 to 687 kg/m^3 or more, respectively (Fig.1). A slight increase was found for veneers densified with increasing temperature. This was due to the higher compression set at higher densification temperatures (Fig. 1), although the theoretical compression set was 50%. This increase in density with increasing temperature could be attributable to the softening of solid wood at higher temperatures (Fengel and Wegener 1989).

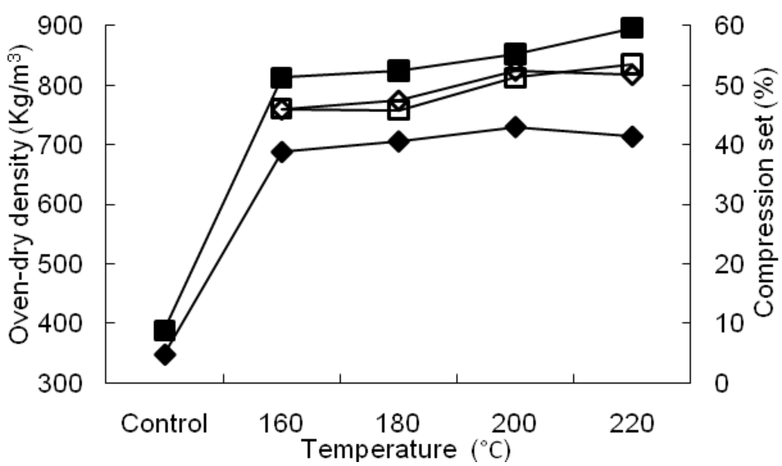

Fig. 1 Effect of densification temperature on oven-dry density (solid) and compression set (hollow) of aspen (square) and hybrid poplar (diamond).

Hygroscopicity

In order to characterize the effect of densification treatment on wood hygroscopicity, EMC in air-dry conditions and SMC after water soaking were measured. EMC decreased markedly after densification for both aspen and hybrid poplar (Fig.2). Furthermore, the higher was the densification temperature, the lower the EMC. This could be explained by the reduced hygroscopicity of cell wall components. Of the three major materials in cell walls (lignin, hemicelluloses, and cellulose), hemicelluloses have the highest affinity for water (Berry and

Roderick 2005). Heat and steam treatment are well known to hydrolyze polysaccharides, especially hemicelluloses (Ito et al. 1998a; Navi and Heger 2004). The extent of hydrolysis and degradation are positively related to treatment temperature (Ito et al. 1998a; Borrega and Karenlampi 2008).Similar results were found for SMC (Fig.2). After water soaking, SMC depends mainly on saturated bound water content in cell walls, which is determined by the hygroscopicity of cell wall components and the free water content in lumens, which is determined by wood porosity. The reduced cell wall hygroscopicity could partly explain the reduced SMC. The reduced wood porosity after densification was the main cause of reduced SMC. However, after water soaking, some compression set recovery occurred (see below), and less recovery was found at higher densification temperatures. This indicates that, after water soaking, samples densified at higher temperatures had lower porosity, as recovery was mainly caused by the re-opening of cell lumens. This explains why SMC decreased with increased densification temperature.

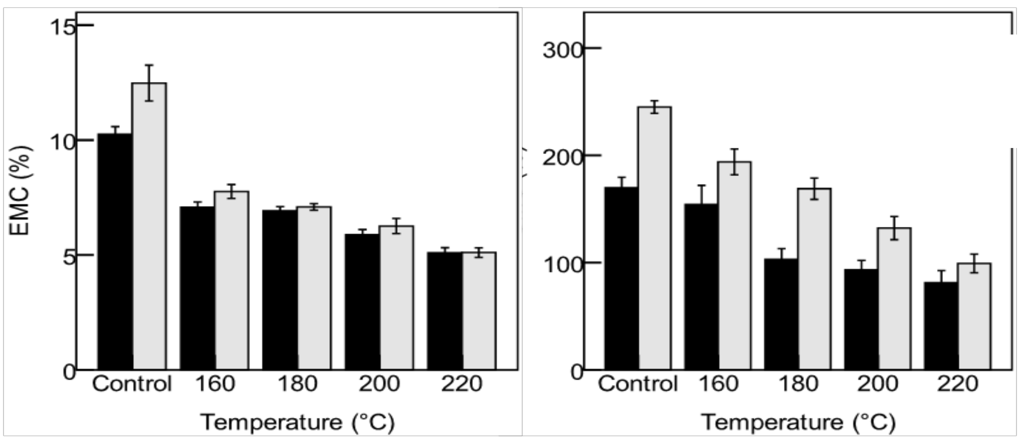

Fig. 2 Effect of densification temperature on equilibrium moisture content at 20°C and 60% relative humidity (EMC) and saturated moisture content after water soaking (SMC) of aspen (black) and hybrid poplar (grey).

Mechanical Properties

The Brinell hardness of densified veneers was about two or three times that of control for both aspen and hybrid poplar (Fig. 3). A significant change in hardness due to densification has also been reported for different densification processes (Inoue et al. 1993; Navi and Heger 2004; Kamke 2006). Such a high increase in hardness might be due to the closing of the vessel and fiber lumens. As explained above, lathe check conglutination also contributed to the increased hardness, as well as increased tensile and bending strength (Fig. 4). However, a slight decrease in hardness with increased densification temperature was observed. This reduction might be caused by the more advanced degradation of the matrix (hemicelluloses and lignin) due to the higher temperatures.

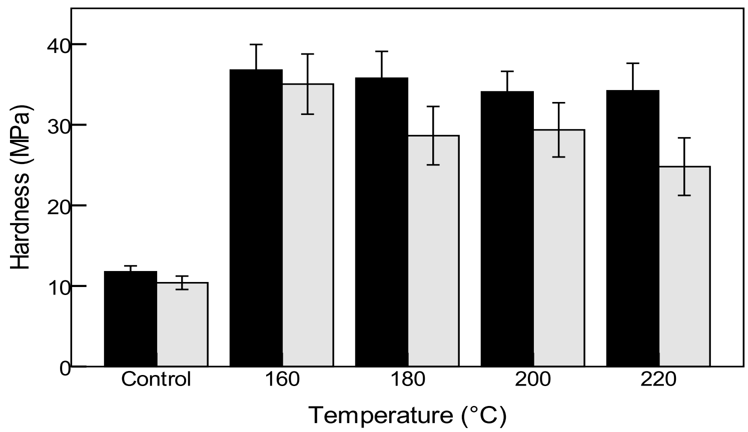

Fig. 3 Effect of densification temperature on hardness of aspen (black) and hybrid poplar (grey).

Similar results were found for maximum bending and tensile strength (Fig. 4). Strength decreased to varying extents with increased densification temperature, which could be explained by the same reason for the decreased hardness, except for the bending strength of aspen, which could be due to the variation in compression set. The strength of densified wood is expected to be positively related to its compression set at a given temperature. In the current study, bending and tensile strengths were affected by both temperature and compression set. However, temperature appears to have had more influence, given the small variation in compression set (Fig. 1).

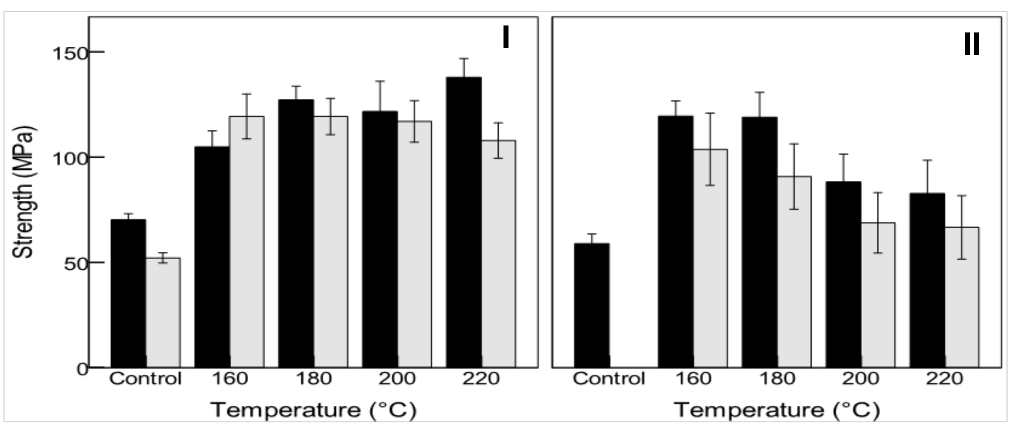

Fig. 4 Effect of densification temperature on maximum bending strength (I) and tensile strength (II) of aspen (black) and hybrid poplar (grey).

Compression Set Recovery

Results of compression set recovery are shown in Figure 5. It has been reported that the elastic strain energy stored in the semicrystalline microfibrils and lignin of wood is the main cause of compression set recovery (Higashihara et al. 2000; Navi and Heger 2004). In order to prevent compression set recovery in densified wood after water soaking, Norimoto et al. (1993) proposed three mechanisms: 1) formation of cross-linkages between molecules of the matrix constituents to prevent the relative displacement of microfibrils; 2) relaxation of the stresses stored in the

microfibrils and matrix; and 3) formation of polymers that are inaccessible to water from hydrophilic cell wall constituents, especially hemicelluloses, to prevent their re-softening by moisture and heat. It is well known that under the effect of steam and heat, polysaccharides, especially the hemicelluloses, are hydrolyzed to some extent. This is demonstrated by the reduced hygroscopicity of densified wood (Fig. 3). In this study, it is assumed that during treatment, the hydrolysis and elution of hemicelluloses allowed the cellulose to move, thereby weakening or breaking linkages between microfibrils and lignin. Therefore, the stresses stored in the microfibrils and matrix were relaxed to some extent, depending on the treatment conditions such as duration and temperature (Norimoto et al. 1993; Higashihara et al. 2000; Navi and Heger 2004; Inoue et al. 2008). However, Ito et al. (1998a) reported that hemicelluloses and lignin do not affect the fixation of compressive transformation. They supposed that the inner stress is released because the paracrystalline region of cellulose is partially hydrolyzed. Furthermore, hydrolyzed constituents are reformed into crystalline regions under the action of steam, keeping the compressed shape intact. Figure 5 shows that the higher the densification temperature, the lower the compression recovery for both aspen and hybrid poplar. Furthermore, recovery decreased dramatically when temperature exceeded 180°C. These results are comparable with those reported by Inoue et al. (2008) on the fixation of compression deformation by pre-steaming. Around 0% recovery was found for specimens densified at 220°C. However, we found decreased hardness and strength with increased densification temperature.
Incidentally, negative recovery (under 0%) was found. Similar results were found by Ito et al. (1998b). These authors speculated that part of the hemicelluloses became water-soluble and therefore were extracted from the specimen during treatment, resulting in wood shrinkage. This mechanism could also explain the negative recovery seen in Figure 5.

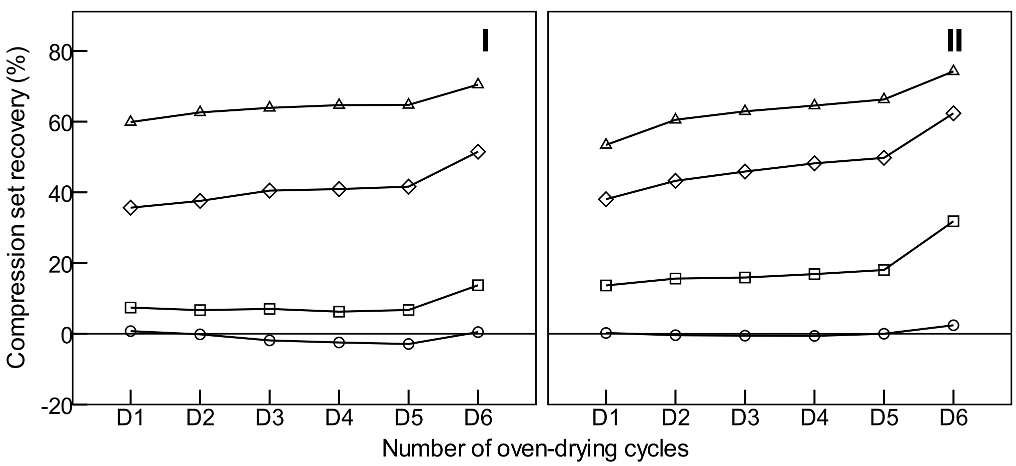

Fig. 5 Compression set recovery for aspen (I) and hybrid poplar (II) veneers densified at 160°C (triangle), 180°C (diamond), 200°C (square), and 220°C (circle), respectively.

Conclusions

After densification, the oven-dry density of aspen and hybrid poplar increased significantly from 388 to 812 kg/m^3 or more and from 348 to 687 kg/m^3 or more, respectively. Veneers darkened after densification, especially at high temperatures. After densification, lathe checks that were present on veneers before densification were conglutinated and veneer surface roughness decreased. Densified veneers showed markedly reduced hygroscopicity, and the higher the densification temperature, the lower the hygroscopicity. The Brinell hardness of densified veneers was about two or three times that of control for both aspen and hybrid poplar. Tensile and bending strength also improved significantly after densification. However, these mechanical properties decreased to some extent with increased densification temperature. Very high compression set recovery was found for veneers densified at low temperatures. Recovery decreased dramatically when densification temperature exceeded 180°C. Almost no recovery was found for veneers densified at 220°C. Due to their high mechanical properties and low hygroscopicity, densified veneers show good potential for appearance products such as engineered wood flooring, stairway steps, and table tops.

Acknowledgments
The authors wish to thank the Fonds québécois de recherche sur la nature et les technologies (FQRNT), FPInnovations and Réseau Ligniculture Québec for funding of this project. We also thank Temlam Inc. for providing aspen veneers and Réseau Ligniculture Québec and Ministère des Ressources naturelles du Québec for providing hybrid poplar veneers.

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