Densification of Wood Veneers Under the Effect of Heat, Steam and Pressure

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Abstract

Wood modification by polymer injection, thermo-mechanical compression and thermal treatment is drawing more and more attention. It is expected that those treatments improve the wood properties desired for specific applications. Among those, thermo-mechanical compression of wood has been used for many years. However, compression recovery over time following moisture adsorption is often a problem with this type of product. Wood densification under the effect of heat, steam and pressure could be an efficient way to increase wood density while resulting in a stable material in service. This process could be called thermo-hygromechanical (THM) densification. The objectives of this project are to develop the THM process parameters necessary to produce high-density aspen veneers and determine their physical and mechanical properties. The densification of 700 × 700 mm aspen veneers from 3.2 mm to 1.6 mm thick was performed at 200, 220 and 240°C in a steam injection press. Densified wood showed a reduced saturated moisture content and equilibrium moisture content at 20°C and 50% relative humidity. Radial swelling including compression set recovery after water soaking was 40% higher for densified wood at 200°Ccompared tothe control. It decreased for wood densified at 220 and 240°C. The moduli of elasticity and rupture in tension and bending and the Brinell hardness were overall about twice as much as the control at 200°C and decreased at higher temperature. We are currently focusing on treatment parameters resulting in an improved dimensional stability.

Key Words: wood modification, densification, recovery.

Introduction

Wood modification by polymer injection, thermo-mechanical compression and thermal treatment is drawing more and more attention. It is expected that those treatments improve the wood properties desired for specific applications. Among those, thermo-mechanical compression of wood has been used for many years. However, wood densified by this process is not dimensionally stable. There is currently a renewed interest in the densification of wood under the effect of heat, steam and pressure also called thermo-hygromechanical (THM) process (Kutnar et al. 2008, Fukuta et al. 2007,Kamke 2006, Navi and Girardet 2000, Ito et al. 1998).Most of the densification processes involving steam were developed in laboratories and are performed in closed systems. The objectives of this project are to develop the THM process parameters necessary to produce high-density aspen veneers in a steam injection hot press and determine their physical and mechanical properties.

Material and Methods

Material

Aspen (*Populustremuloides*) wood veneers were obtained from the Temlam LVL plant located in Amos, Québec, Canada in the northwest region of the province. The nominal thickness of the veneers was 3.2 mm. They were conditioned at 20°C and 50% relative humidity before treatment.

Methods

Densification Treatment

A steam injection 862 mm ×862 mm hot press (Fig. 1) was used for veneer densification. On both platens, holes used for steam injection and venting are distributed at an interval of 50 mm. The two platens were pre-heated before the treatment. Three temperatures were used: 200°C, 220°C and 240°C. Veneers of 700 mm × 700 mm were densified using the procedure depicted in Figure 2. The veneers were pre-treated with steam then compressed from their initial thickness of 3.2 mm to a target thickness of 1.6mm. After densification, the platens were stopped and maintained in the same position during the post-treatment. At the end of the post-treatment, steam injection was stopped and steam was vented through the holes in the platens, the platens were opened and the veneer was removed from the press. A compression set of about 50% was obtained. The compression set value C was calculated as $[(R_o - R_c) / R_o] \times 100$, where R_o and R_c were the thickness of the veneer before and after compression respectively.

Density Measurements

The oven-dry density of the control and densified specimens (50×30 mm, T ×L) was measured using a QMSX-ray densitometer.

a) b)

Figure 1. Steam injection hot press used for the densification treatment a) 862 mm×862mm hot press, b) press platen with steam injection holes.

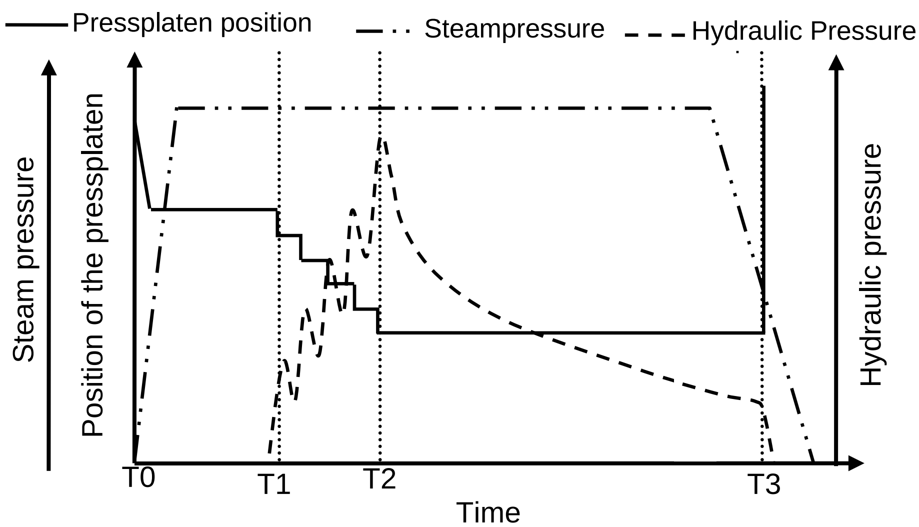

Figure2. Schematic diagram of the densification process: pre-treatment (T0~T1); compression (T1~T2) and post-treatment (T2~T3). Maximum steam pressure: 550 kPa; Maximum hydraulic pressure: 4.5 to 9.0 MPa; Total treatment time: 15 to 55 min.

Moisture Adsorption Measurements

The control and densified specimens were kept in a conditioning room until a constant weight (m_a) was obtained. They were then oven-dried at 105°C and weighted (m_o). They were reweighted (m_s) after water soaking with vacuum cycles until a constant weight was reached. The equilibrium moisture content (EMC) in air dry condition and the saturated moisture content after water soaking were calculated as $[(m_a - m_o) / m_o] \times 100$ and $[(m_s - m_o) / m_o] \times 100$, respectively.

Swelling Measurements

The control and densified specimens (50×30 mm, T×L) were oven-dried at 105°C and their dimensions (D_o) were measured to the nearest 0.001 mm. In order to minimize errors, a point was marked at the centre of each surface of the specimen and measurements were always made on these points. The dimensions (D_s) were measured again in the saturated state. The swelling was calculated as $[(D_s – D_o) / D_o] \times 100$.

Longitudinal Tensile Tests

The longitudinal tensile modulus of elasticity (MOE) and modulus of rupture (MOR) were obtained. The tests were performed on both control and densified veneers. Specimen shape and dimensions are shown in Figure 3 and correspond to the ASTM D 1037-96a standard. The tensile strain was measured with a displacement sensor installed on the middle section of the specimen.

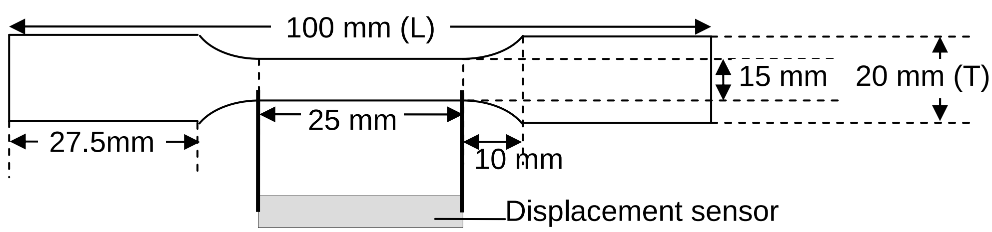

Figure 3. Shape and dimension of specimens used for tensile test. L: longitudinal direction, T: tangential direction.

Bending Tests

Three-point static bending tests were performed on both control and densified specimens according to the ASTM D 1037-96a standard. The modulus of elasticity (MOE) and modulus of rupture (MOR) in bending were obtained.

Hardness Tests

Brinell hardness tests were carried out on both control and densified specimens according to the European standard EN 1534.

Results and Discussion

Effect of Densification on Wood Physical Properties

The veneers were compressed to about half of their original thickness. At first sight, densified wood shows a higher hardness and a darker color. The anatomical structure of the densified veneer is shown in Figure 4. It is clear that densification is the result of buckling of the cell walls as also noticed by Kutnar et al. (2008). The reduced lumens of fibers and vessels can easily be observed.

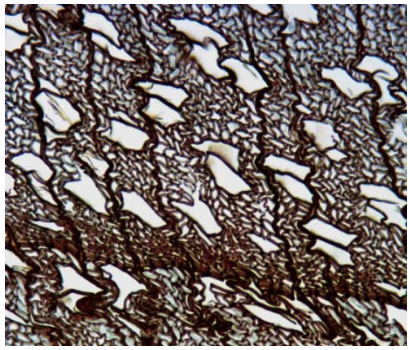

Figure 4. Anatomical structure of densified aspen wood after compression set recovery.

Wood Density

The oven-dry density of the control and of densified wood is presented in Figure 5. After treatment at 200°C, the oven-dry density increases from about 374 to924 kg/m^3 representing a relative increase of 147%. The oven-dry densities obtained at 220°C and 240°C were of 755 and 706kg/m^3. The reduction in oven-dry density at temperatures higher than 200°C is likely due to the degradation of the cell wall components.

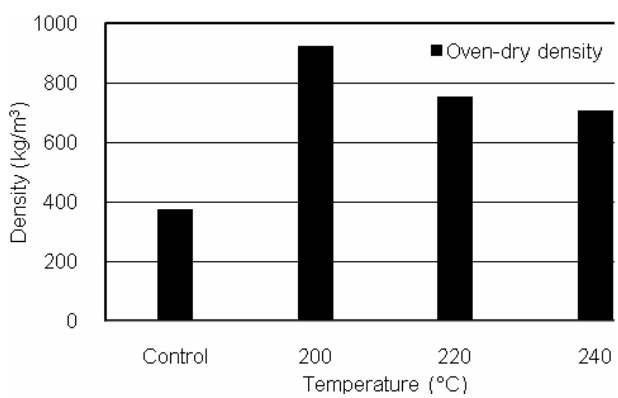

Figure 5. Effect of densification treatment on aspen wood oven-dry density.

Wood Hygroscopicity

Saturated MC after water soaking and EMC in air (20°C, 50% RH) are presented in Figure 6. Saturated MC decreased by about 50% after densification. The same behavior was observed for the EMC in air. This can be explained by the reduced porosity of wood after densification and by the reduced hygroscopicity of the cell wall.

Wood Swelling

Wood swelling including compression recovery after saturation with water is presented in Figure 7. Densified wood presented a radial swelling of up to 40%, much higher than the control. This includes normal cell wall swelling plus compression recovery. However, swelling was reduced significantly with an increase in treatment temperature, down to

9% at 240°C. Tangential swelling did not vary from 200 to 220°C but decreased significantly at 240°C. The variation of the longitudinal swelling is minimal despite the slight decrease at 240°C.Current work is focused on treatment improvement to reduce the radial swelling of densified wood.

Effect of Densification on Wood Mechanical Properties

The effect of densification on bending and tension moduli of elasticity and hardness are presented in Figures 8 and 9. The MOE in tension and bending of wood densified at 200°C was about twice as much as for the control. It decreased for wood densified at 220°C and 240°C. About the same behavior can be observed for the MOR in tension and bending but the increase is more important for bending than for tension. The Brinell hardness increased from 17 MPa for the control to 45 MPa for wood densified at 200°C. The hardness decreased for densification at 220°C and 240°C.

Figure 10 shows the clear linear relationship obtained between the MOE in bending and tension and the oven-dry density of wood. The MOE increased linearly with the oven-dry density.

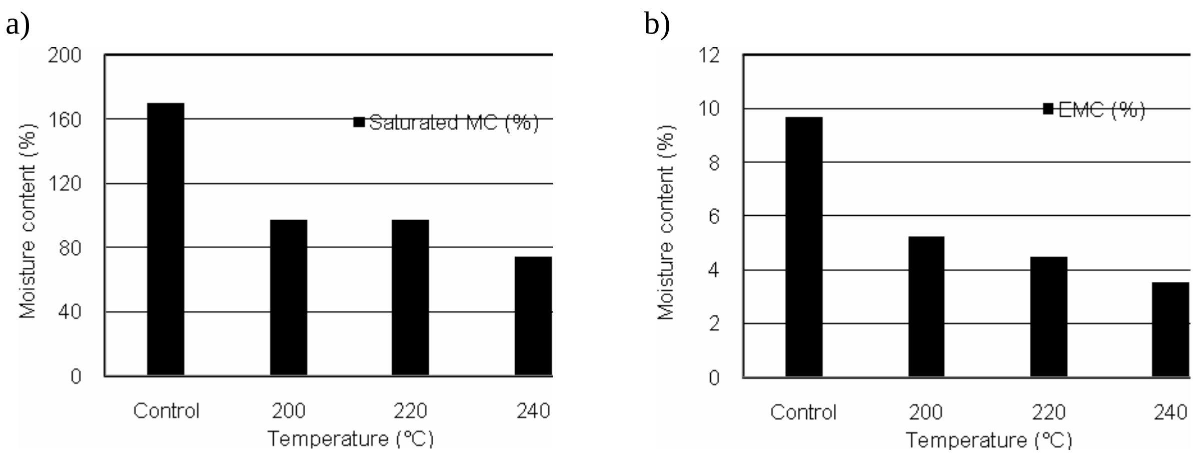

Figure 6. Effect of densification temperature on a) saturated moisture content and b) equilibrium moisture content (EMC) at 20°C and 50% relative humidity.

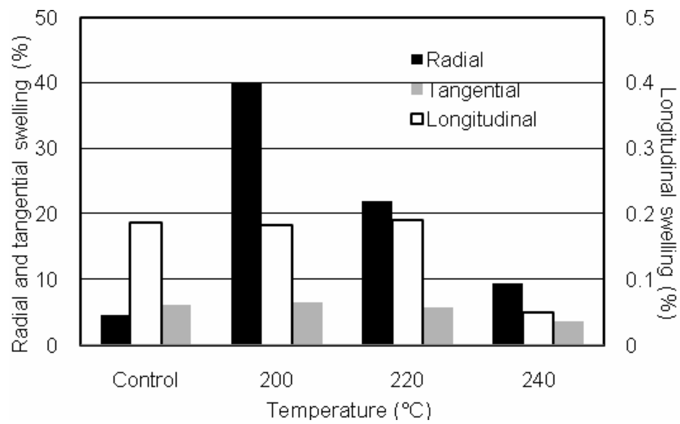

Figure 7. Effect of densification temperature on the radial, tangential and longitudinal swelling and recovery (samples saturated in water after densification treatment).

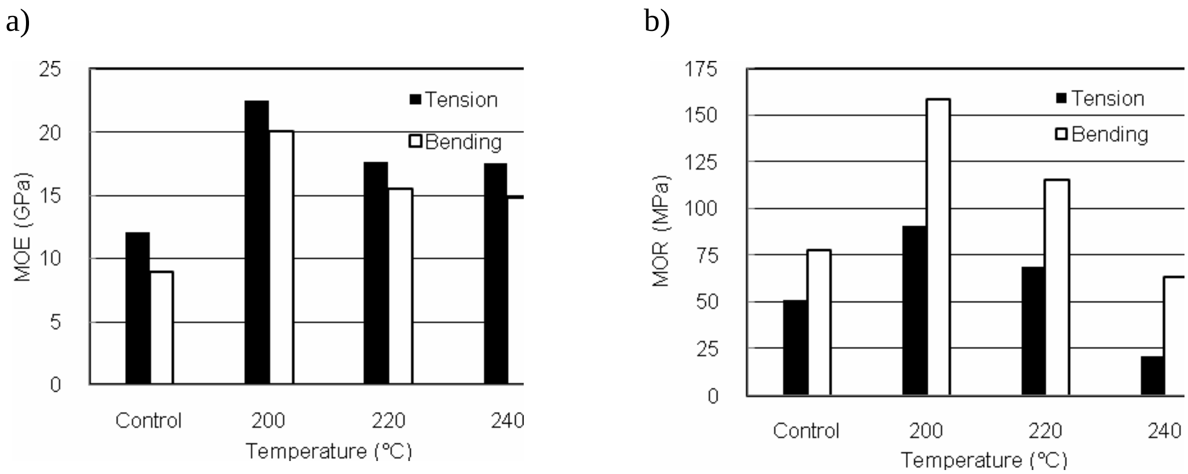

Figure 8. Effect of densification temperature on a) modulus of elasticity in tension and bending and b) modulus of rupture in tension and bending.

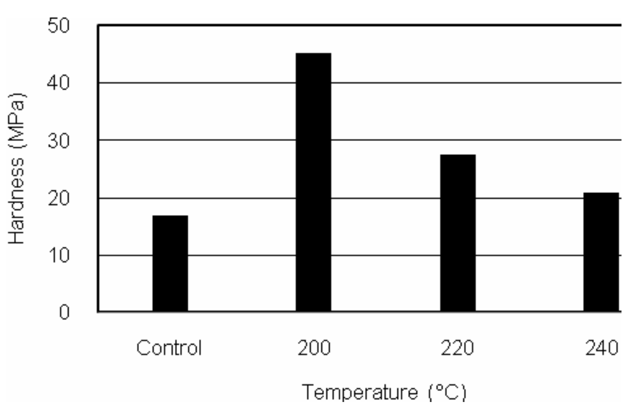

Figure 9. Effect of densification temperature on Brinell hardness.

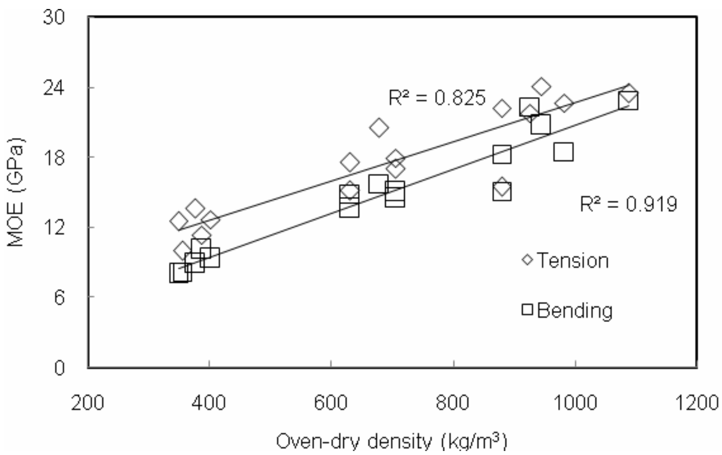

Figure 10. Modulus of elasticity in tension and bending as a function of densifiedand non-densifiedaspen wood oven-dry density.

Effect of the Densification Treatment on Wood Color

The effect of the densification treatment temperature on wood color is shown in Figure 11. Wood darkens when the densification temperature increases, particularly at temperatures higher than 200°C.

Control 200°C 220°C 240°C

Figure 11. Effect of densification temperature on wood color.

Conclusions and Recommendations

The objectives of this project were to determine thethermo-hygromechanical densification process parameters necessary to produce high-density aspen veneers in a steam injection hot press and determine their physical and mechanical properties. Densification of aspen veneers from 3.2 mm to 1.6 mm thick was performed at 200, 220 and 240°C. The results show a very significant increase in density due to buckling of fibers and vessel cell walls. Densified wood showed a reduced saturated moisture content and equilibrium moisture content at 20°C and 50% relative humidity. Radial swelling including compression set recovery after water soaking was 40% higher for densified wood at 200°Ccompared to the control. It decreased for wood densified at 220 and 240°C.The moduli of elasticity and rupture in tension and bending and the Brinell hardness were overall about twice as much as the control at 200°C and decreased at higher temperatures. Treatment temperature had a very significant effect on wood color; temperatures higher than 200°C resulting in much darker wood. This project is still ongoing. We are now focusing on treatment parameters resulting in an improved dimensional stability.

Acknowledgments

The authors wish to thank the Fondsquébécois de recherchesur la nature et les technologies (FQRNT), FPInnovations – Forintek Division and RéseauLigniculture Québec for funding of this project. We also thank Temlam Inc. for providing aspen veneers.

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