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Section 4 **Processes and properties**

Markers of quality in self-bonded beech boards

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Markers of quality for self-bonded beech boards

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ABSTRACT

A self-bonding phenomenon takes place when five layers of beech (*Fagus Sylvatica* L.) veneers are pressed at temperatures higher than 200°C. If the pressing temperature between veneer surfaces reaches at least 225°C during pressing and if the pressure applied is optimal, water-resistant bonds are formed between veneers. This study investigates the relation of thickness reduction (marker of compression) and mass loss (marker of heat treatment intensity) to boards quality. The effect of water and water vapour on the bondings between veneer in boards pressed at 200, 225 and 250°C is studied. The conclusion is that pressing 5 layers of 2 mm rotary-cut beech veneer parallel-fibered at 225°C, 5 MPa and 300 s leads to a thickness reduction of 33.4 % and mass loss of 1.23 %; in such boards bondings are not resistant to liquid water but are resistant to vapour after one adsorption-desorption cycle. When pressing at 250°C, 5 MPa and 300 seconds, the thickness reduction is 50% and the mass loss 4%; in such boards no delamination was observed when soaked in water. Boards pressed at higher temperature show lower hygroscopicity. Their equilibrium moisture content (EMC) ranged between 3.6 and 7%. Based on the results of this study it is hypothesised that the decay resistance of self-bonded boards will increase when increasing the severity of the hot-pressing.

Keywords: self-bonding, thermo-mechanical treatment, mass loss, densification, veneer, beech, dimensional stability

1. INTRODUCTION

Pressing veneers at temperatures higher than 200°C leads to formation of compact laminated boards. The bonds formed between the wooden layers are the results of a short, intense thermo-compression treatment. No adhesive and no pre-treatment is needed. Although the pressing temperature has the strongest impact on the process, the quality of the bonding (hence boards strength) depends on the interaction between temperature, pressure and time (Cristescu 2015). The literature of wood thermal treatment was used as a source of inspiration in this study since hot-pressing without adhesives takes place at similar temperatures as heat treatment. The concept of markers (Inari *et al.* 2009, Chaouch *et al.* 2010) or quality control methods (Willems *et al.* 2015) that can predict the properties of heat treated wood was shown to be a useful tool in the understanding the treatment process. It has been shown that colour can predict hardness of the self-bonded laminated boards (Cristescu *et al.* 2015a). The aim of this study is to investigate whether the changes in thickness and weight before and after pressing predict the bonding-quality of the boards. These two potential markers - thickness reduction and mass loss after hot-pressing - were analysed in relation to the following properties of the board: equilibirum moisture content (EMC) at ambient conditions as well as MC and dimensional changes caused by humidity variation.

2. EXPERIMENTAL METHODS

The raw material used was rotary-cut beech (*Fagus Sylvatica* L.) veneer with a thickness of 2 mm, a density of 540 kg/m^3 and a surface area of 140 x140 mm^2. The veneers were conditioned at 23ºC and 50% RH to equlibrium MC of about 9%. Five layers were placed parallel oriented in an open laboratory press and pressed according to the parameter combinations in Table 1. Three replicates were pressed for each of the pressing parameter combination shown in Table 1. Nine boards were obtained in total.

The thicknesses of the conditioned veneers and corresponding boards were measured and the percentage thickness reduction was calculated. The mass loss during the formation of the self-bonded boards of beech was calculated based on the dry weight of the veneers before pressing and the dry weight of the boards after pressing. The EMC was determined after conditioning the boards for two weeks at 23ºC and 50% RH. To determine the hygroscopic behaviour (the response to changes in humidity) one sample 50 x 50 x 2 mm in size was prepared from each board and from two veneer sheets. All the samples were oven-dried and then placed in a chamber at 23ºC and 30% RH until they showed a constant weight. The moisture was increased up to 90% RH and samples were kept at this high humidity until they showed a change in weight dimensions lower than 0.5% between successive weightings. The humidity was then decreased to 30% RH and the samples were conditioned at 23ºC and 30% RH.

3. RESULTS AND DISCUSSION

The results of the study are summarised in table 1.

Table 1 Pressing parameters and board properties. Standard deviations in brackets.

Pressing parameters: Temperature, Pressure, Time	Density* dry [kg/m^3]	Thickness reduction after pressing [%]	Mass loss [%]	EMC at 50 %RH [%]	Bonding resistance to soaking in water	Bonding resistance to moisture
200ºC, 5 MPa, 300 s	640	22.4 (1.8)	0.42 (0.09)	7 (0.8)	None	Partial
225ºC, 5 MPa, 300 s	774	33.4 (1.1)	1.29 (0.07)	5.8 (0.4)	Partial	Integral
250ºC, 5 MPa, 300 s	993	50 (1.5)	4.06 (0.17)	3.6 (0.1)	Integral	Integral

**average of three values*

The density and the bonding resistance to water soaking results obtained are in accordance with Cristescu *et al*. 2015b and Cristescu 2015.

3.1 Thickness reduction

Fig.1 presents a photograph of the raw material and self-bonded boards in which the difference in thickness can be seen. After each pressing, the percentage thickness reduction is much greater than the percentage mass loss. The density increases with increasing pressing temperature, though the pressure was similar in all tests. It was noticed that if the thickness reduction of a board exceeds 45%, the board can withstand five wetting-drying cycles without delaminating . The thickness reduction can be considered a marker of self-bonding quality only in tandem with an optimal level of mass loss (see below).

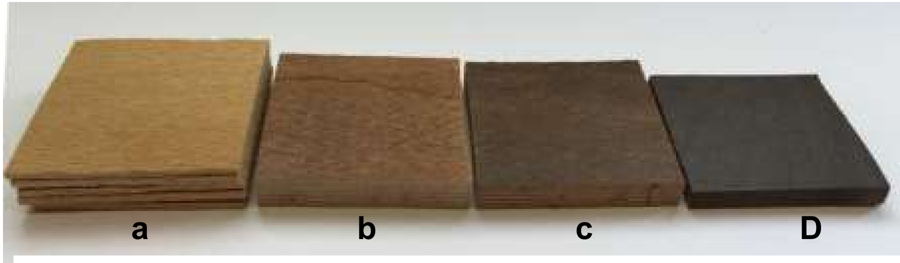

Figure 1: Veneers and boards pressed at different pressing conditions: a) the veneers before pressing, and after pressing at b) 200ºC, 5 MPa , 300 s, c) 225ºC, 5 MPa , 300 s, and d) 250ºC, 5 MPa, 300 s.

3.2 Mass loss

The mass loss is considered to be a marker for the extent of modification in thermally modified wood (Viitaniemi et al. 1997, Burgois and Guyonnet 1998). A mass loss greater than 1% (e.g. for boards pressed at 250ºC, 5 MPa, 300 s) can be related to a weak level of water-resistance, as seen in Table 1. A mass loss as high as 4%, (e.g. for boards pressed at 250ºC, 5 MPa , 300 s) can be related to the formation of strong water-resistance bonds, due to a chain of reactions taking place from which a major one (related to thermal treatment) is the depolymerisation and later on condensation and repolymerisation of wood compounds (Stamm 2006). It can be concluded that the difference in weight of the veneers before and after pressing can also be used as a predictor of water-resistance. A mass loss of 5 % or higher was related to blowholes in boards during pressing untreated beech veneers and also when pressing pre-treated (using hydrogen peroxide and an iron catalyst) beech veneers, as shown in Karlsson *et al.* 2015 and this value may represent the upper limit for a compact, water-resistant self-bonded board from beech.

3.3 Equilibrium moisture content (EMC)

The EMC decreases with increasing severity of pressing conditions as shown in Fig. 2. This development can be seen in the context of the degradation of wood compounds due to heat, of the dehydration of carbohydrates that involves the reduction of the quantity of certain functional groups, such as hydroxyl groups, considered responsible for the hydrophilic character of wood. It is however interesting to notice that the EMC and the mass loss have a rather different evolution above 225ºC, Fig. 2. The EMC decreases almost linearly with increasing pressing temperature whereas the mass loss is non-linear and increases strongly from 225 to 250ºC. The EMC values are in line with heat treated beech at 240 ºC : EMC of 4-5 % was reported by Vernois 2001.

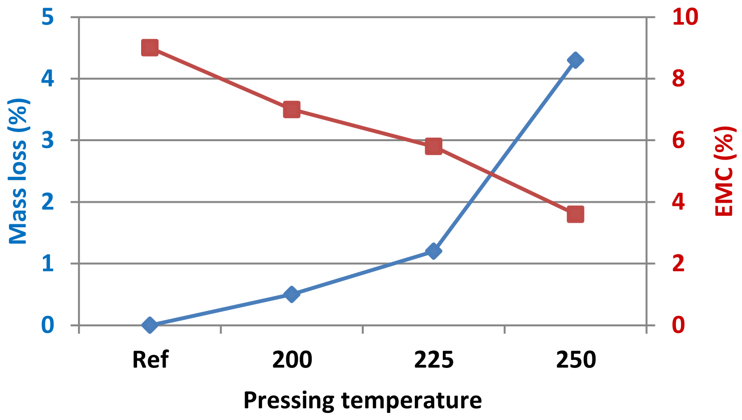

Figure 2: Mass loss and EMC of self-bonded boards.

3.4 The effect of changes in humidity on dimensional stability

Fig. 3 shows examples of boards after an adsorption-desorption cycle. Only boards pressed at 200ºC were slightly delaminated.

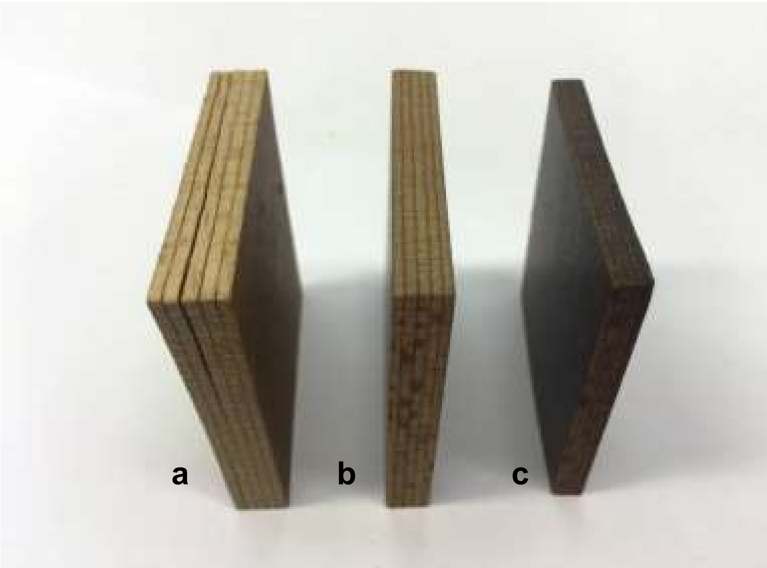

Figure 3: Samples after an adsorption-desorption cycle from 30 to 90% RH. Boards pressed at a) 200ºC, 5 MPa , 300 s, b) 225ºC, 5 MPa , 300 s, and c) 250ºC, 5 MPa , 300 s.

It can be concluded that the effect of water vapour on the self-bonding is less drastic than the effect of liquid water since samples pressed at 225ºC delaminated when soaked in water, see Table 1 and Cristescu *et al.* 2015a.
As seen in table 1, the MC decreases with increasing severity of pressing conditions. Furthermore, if a humidification cycle is applied by increasing the RH from 30% to 90% (adsorption) and then back to 30% (desorption), there is a greater hysteresis effect with pressed boards than with veneers, see Fig. 4. Hysteresis means in this context the difference between the MC value of boards acclimatized at 23ºC and 30% RH during adsorption and desorption.

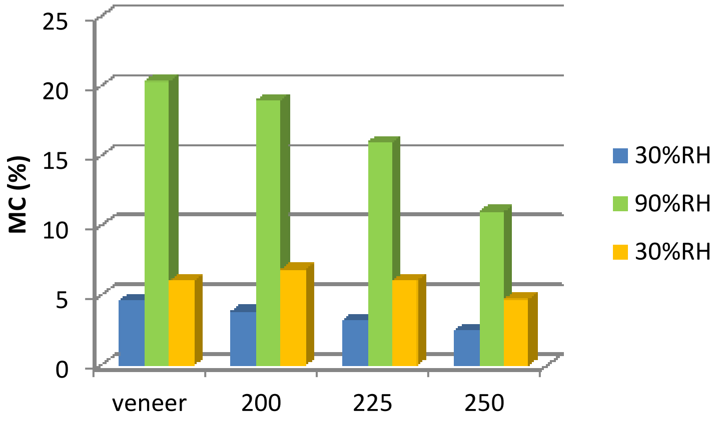

Figure 4: MC of veneers and boards pressed at 200, 225 and 250ºC during an adsorption-desorption cycle at 23ºC.

The adsorption-desorption cycle leads to different responses with regard to swelling and shrinkage in the thickness and width direction of veneers and boards, (Fig. 5 and Fig. 6). Width refers to the direction perpendicular to the fibre direction of the veneer, and length refers to the direction parallel to the fibres. The length changed insignificantly and is therefore not included in the figure. The thickness of the boards is the dimension that is most affected by moisture changes, whereas the veneer has the highest swelling in its tangential width direction.

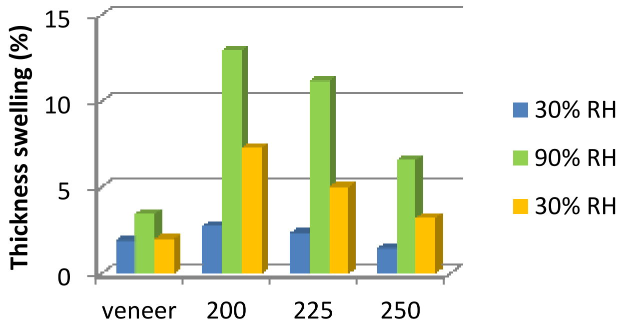

Figure 5: Swelling in thickness of veneers and boards pressed at 200, 225 and 250ºC during an adsorption-desorption cycle at 23ºC.

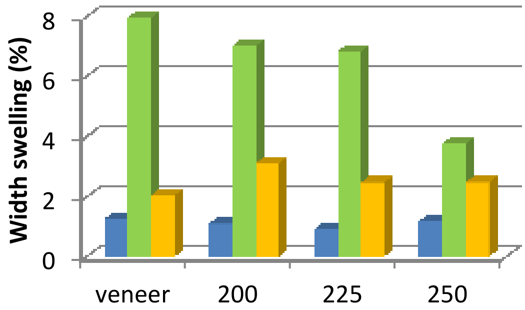

Figure 6: Width swelling of veneers and boards pressed at 200, 225 and 250ºC during an adsorption-desorption cycle at 23ºC.

The differences in dimensions at the initial and final 30% RH level are greater for boards than for veneers, in accordance with the evolution of MC hysteresis (Fig.4). In the case of thickness swelling, the explanation of boards thickness swelling may be that the water vapour has a relaxation effect on the stresses introduced during hot-pressing.

4. CONCLUSIONS

Thickness reduction together with mass loss during pressing can be considered markers for the self-bonding quality in boards, they are related to EMC, hygroscopicity, dimensional stability and water resistance in boards. The levels of mass loss and EMC reveal that pressing veneers at such a high temperatures and pressure results in chemical modification which is further on

responsible for obtaining strong chemical bonds capable to withstand water. The intensity of this modification depends on the pressing parameters combination.
Mass loss and EMC show similar values with those of thermal-treated wood, thus the decay resistance of the self-bonded boards might follow a similar trend as for retified wood: the higher the pressing temperature, the better the durability. This hypothesis needs to be verified.

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