A new methodology to predict the optimum pressing time for wood-based panels produced with low formaldehyde emission resins

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ABSTRACT

Hot-pressing is the most important and costly operation in the manufacture of wood-based panels. Therefore, a rigorous control of all processing variables is necessary to ensure product quality and reduce pressing time. This is particularly relevant because of the changes in resin formulations that have occurred along the last decade, due to the stringent regulations on formaldehyde emissions from wood-based panels. In many industries, the scheduling of the press cycle is still performed based on past operating conditions, developed for traditional formulations. Fothe new low formaldehyde emissions resins, the interaction between resin cure kinetics, bond strength development, mat rheological behavior and heat and mass transfer during pressing is still not fully understood.

The aim of this work is to understand the influence of the pressing operating conditions on the performance of particleboards bonded with a Carb II class fortified UF resin. Several trials were carried out on a computer controlled lab scale hot-press, varying the venting start time, the total pressing time and the moisture content on the mat face layer. Analysis of variance (ANOVA) was performed in order to evaluate the significance level of the effects of these factors on particleboard physico-mechanical properties and formaldehyde emission. A new methodology has been developed by combining results of mat internal temperature evolution and bond strength development curves obtained using ABES apparatus, in order to estimate the internal bond strength of the particleboards. This methodology allowed predicting the minimum pressing time needed to obtain a panel that meets the standard specifications.

1. Introduction

In wood-based panels hot-pressing process, several coupled physico-chemical-mechanical phenomena are involved making this operation quite complex. The main mechanisms are heat and mass transfer, polymerization of the adhesive and rheological behavior. Due to the multiplicity and interdependency of these phenomena, the development of mathematical models that enable the simulation of this operation is of great importance, because it will enhance the understanding of either the interactions or the effects of operating variables and parameters on the product properties and consumption of energy and time (Aguilar Ribeiro et al., 2011). Therefore, mathematical models are recognized as important tools for optimization, control and scheduling of this operation, offering a great potential for innovation in processes and products (Carvalho et al., 2003; Carvalho, 2008; Carvalho et al., 2010). According to Maloney (1989) several parameters the hot-pressing operation: resin type and hardener, press temperature, wood raw material (species, particle geometry), moisture content and moisture distribution, steam pressure inside the board, time of pressing closure, press scheduling and density profile.

Several works have been attempted to develop models for the hot-pressing process (Humphrey, 1982; Humphrey and Bolton, 1989a; Zombori, 2001, 2003; Fenton et al., 2003; Carvalho et al., 2003; Dai and Yu, 2004; Pereira et al, 2006; Thoemen and Humphrey, 2006). Carvalho et al. (2010) presented a state of the art about the transport phenomena involved, not only for the hot-pressing process, but also for other processes in the manufacture of wood-based products, such as drying of particles/fibers and conditioning.

Adverse health effects from exposure to formaldehyde have concerned wood-based panels producers in last decades, mostly from 2004 when the *International Agency for Research on Cancer* (IARC) from WHO recommended the reclassification of formaldehyde "carcinogenic to humans (group 1)". As a consequence, various authorities and institutions have been concerned about formaldehyde as an indoor priority pollutant and new regulations have emerged considering exposure limits increasingly lower. Along the last decade, changes in resin formulations have been occurred, due to the stringent regulations on formaldehyde emissions from wood-based panels (Salthammer et al., 2010). Facing the new guidelines and emission standards, a considerable effort has been made by wood panel manufactures to provide products with even lower formaldehyde emissions. To attain this objective, the resin formulations have been changed (e.g. reduction of molar ratio formaldehyde/urea or use of formaldehyde scavengers).

In many industries, the scheduling of the press cycle is still performed based on past operating conditions, developed for traditional formulations and are not adapted to the new low formaldehyde emissions resins. For these new resins, the interaction between resin cure kinetics, bond strength development, mat rheological behavior and heat and mass transfer during pressing is still not fully understood.

In this study we intend to understand the influence of the pressing operating conditions on the performance of particleboards bonded with a low formaldehyde resin (Carb II class fortified UF resin). The optimization of this operation depends on many parameters, namely pressing time, pressing temperature and moisture content of the face layer. This work focus in particular "the venting", an additional compression followed by an expansion of mat, performed during the hot-pressing to promote the heat transfer to the mat core. The process of venting the mat prior to press opening serves to reduce the internal gas pressure and minimize the potential for panel delamination. Venting is caused by a slow and controlled rate of mat expansion in the vertical direction as the press platens separate. The wood particles exhibit elastic expansion and the voids between the particles open, thus increasing mat permeability and gas flow (Kamke, 2004). When venting begins (prior to press opening), water vapor pressure decreases and equalizes throughout the mat, while temperature stays high. The venting gas may move toward the edges and surfaces of the mat (Carvalho et al., 2010).

2. Materials and methods

Raw materials

Wood particles for the face layer and core layers were provided by Sonae Indústria PCDM (Oliveira do Hospital plant). Standard mixtures were used, which are composed of different proportions of pine, eucalyptus, pine sawdust and recycled wood. A commercial UF resin fortified with melamine was provided by Euroresinas (Sonae Indústria). Resin characteristics are presented in table 1. For ABES testing steamed beech veneers (Fagus Sylvatica) were supplied by Sonae Indústria PCDM (Mangualde plant).

Table 1: UF resins properties

Properties	Values
Reactivity (s)	60-100
Viscosity (cP)	150-300
pH	8.5-9.5
Solids content (%)	63-64

Particleboard production

Particleboard panels were produced at laboratory scale and then characterized in order to quantify the physical and mechanical performance as well as the formaldehyde emission or content. The production of particleboards is essentially divided into five stages: raw-material preparation, blending, mat formation, pressing and sanding. The moisture content of the standards mixture was checked before blending, using an infrared balance. The average of the moisture content of the core layer particles was 3.5%. Wood particles for the face layer were conditioned in a climate chamber in order to attain 11 and 15 % of moisture content. Wood particles were then blended with the resin systems (resin, catalyst and paraffin) in a laboratory glue blender. The gluing factor for the face layer was 6 % resin solids, but for the core layer two gluing factors were tested: 5 % and 7 % in the core, based on the oven-dry weight of wood particles. The resin was more catalyzed in the core layer (3% solids based on oven-dry weight of resin) than in the face layer (1 % solids based on oven-dry weight of resin). The paraffin level was 0.15 % solids (based on oven-dry weight of wood). Three-layer particleboard was hand formed in an aluminum container with 220x220x80 mm. Boards were then pressed in a laboratory scale hot-press, controlled by computer and equipped with displacement sensor (LVDT), thermocouples and pressure transducers. This lab-scale press permits to measure real time temperature and gas pressure and to manipulate thickness and measure the response in compressive stress.

Press scheduling

The pressing cycle (stage duration, press closing time, platen temperature) was scheduled in order to study the effect of venting (see figure 1). The typical press cycle in a continuous pressing (pressing rate) was transposed to the batch cycle (press cycle time). The target thickness was 17 mm. The average density of the final boards was 650 ± 20 kg/m^3. The temperature inside the mat was monitored using a type K thermocouple. The thermocouple was positioned during the forming stage.

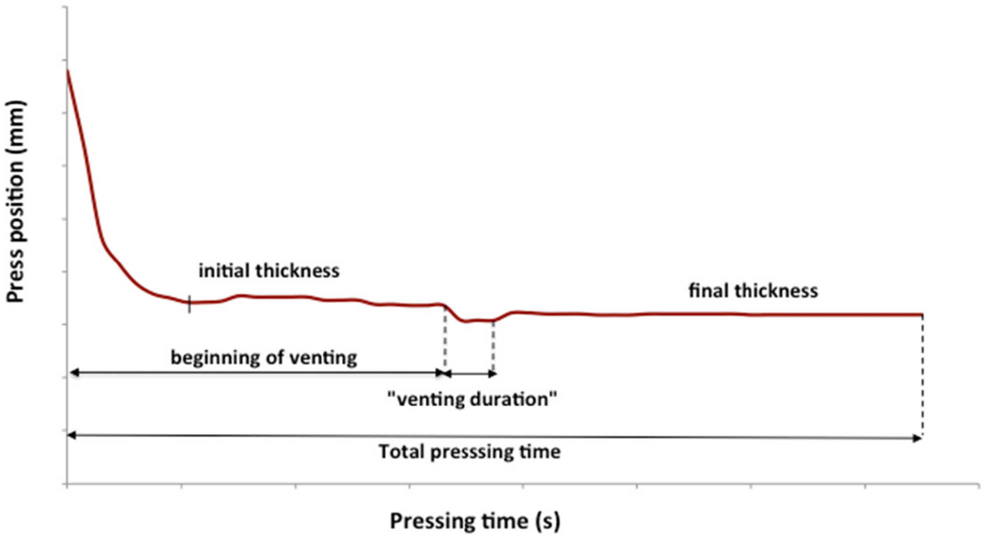

Figure 1: Pressing scheduling with a venting procedure (additional compression and expansion)

Three pressing programs were studied: P1 - fixed number of stages (176 position set-points); P2 - decrease of position set-points to 4; P3 - equivalent to P2 with a slow press closure rate.

Board testing

After pressing, boards were stored in a conditioned room (20 ºC, 65 % relative humidity) and then tested accordingly to the European standards. The boards were tested according to the European standards for density (D) (EN 323), internal bond (IB) (EN 319), moisture content (MC) (EN 322) and thickness swelling (TS) (EN 317). The formaldehyde emission was determined using the gas analysis method (EN 717-2).

ABES testing

The veneers (with a thickness of 0.7 mm), stored at 25 ºC and 65%RH were cut into 117 mm x 20 mm strips using a pneumatically driven sample cutting device for standardized ABES sample preparation (supplied by Adhesive Evaluation Systems, Corvallis, Oregon) and stored in our laboratory at 25 ºC and 65% RH. The glue mix was applied manually with a spatula (10 mg) and the spread rate (100 g/m^2) was controlled in a precision balance. After the desired temperature was reached, adherent pairs of strips were mounted in the system with an overlapping area of 20 mm x 5 mm and pressed together at 1.2 N/mm^2. After the pressing time was elapsed, bonds were pulled at pressing temperature (no cooling). The standard loading rate was used (1 kN/s). The bond strength was tested almost instantaneously in shear mode (the system is digitally controlled and pneumatically driven) (Ferra et al., 2011).

Table 2: ABES test parameters

Parameter	**Values**
Press temperature (ºC)	85, 95 and 105
Press times (s)	15 to 120
Spread rate (g/m^2)	100
hardener content, wt% (solids/oven dry weight of resin)	3.0

Design of Experiments

Table 3 summarises the factors and levels considered in first pressing trial. Due to the great number of parameters to be studied, a statistical experimental design tool (JMP) was used.

Table 3: Factors and levels studied

Factors	**Levels**		
	1	**2**	**3**
Beginning of venting (s)	53	90	
Gluing factor (g resin solids/g oven dry wood)	5	7	
Moisture content in face layer (%)	11	15	
Total pressing time (s)	100	150	
Pressing scheduling	P1	P2	P3
Venting duration (s)	0	20	

In order to evaluate the significance level of the effects of the different factors in the internal bond strength, an analysis of variance (ANOVA) was performed. Taking into account the results obtained in the first trial, the following factors were tested in a second pressing trial: beginning of venting (45, 65 e 85 s), total pressing time (75, 95, 115 e 135 s), Moisture content in face layer (11 e 15 %) and gluing factor (g resin solids/g oven dry wood) (5 e 7 %).

4. Results and discussion

An ANOVA was performed in order to evaluate the significance level of the effects different factors related with the pressing operation on particleboard properties. Table 4 presents the statistical significance level of the six factors on internal bond strength. All factors are statistically very significant except the venting duration. The most significant factors are the beginning of venting, the moisture content of the face layer and the total pressing time.

Table 4: ANOVA by factor for internal bonding strength - mean
(NS-not significant, *5%, **1%, ***0.1%)

Factor	Sum of squares	F_{obs}	p-value	Significance level
Beginning of venting (s)	$4.55\ \ 10^{-2}$	28.25	$7.53\ \ 10^{-7}$	****
Gluing factor (g resin solids/g oven dry wood)	$4.80\ \ 10^{-2}$	29.76	$4.18\ \ 10^{-7}$	****
Moisture content in face layer (%)	$7.31\ \ 10^{-2}$	45.36	$1.44\ \ 10^{-9}$	****
Total pressing time (s)	$9.85\ \ 10^{-2}$	61.13	$9.05\ \ 10^{-12}$	****
Pressing scheduling	$2.05\ \ 10^{-2}$	6.36	$2.60\ \ 10^{-3}$	****
Venting duration (s)	$1.52\ \ 10^{-4}$	0.09	$7.60\ \ 10^{-1}$	NS

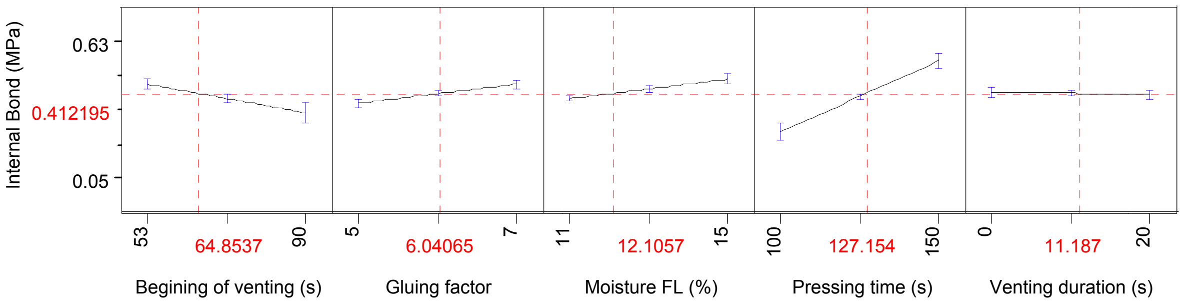

Figure 2: Effects of factors levels on internal bond (mean)

Figure 2 presents the effects of factors levels on internal bond. This figure shows that increasing the beginning of venting, the internal bond decreases. The internal bond increases slightly with the moisture content of the face layer, probably due to a better heat transfer to the interior of the mat. As expected, the internal bond increases strongly with the pressing time, due longer resin reaction time.

Figure 3 presents the ratio of internal bond and formaldehyde emission (EN 717-2). The greater values are obtained for the beginning of venting of 45 and 65 s, which means that for the same level of internal resistance, the formaldehyde emission is lower.

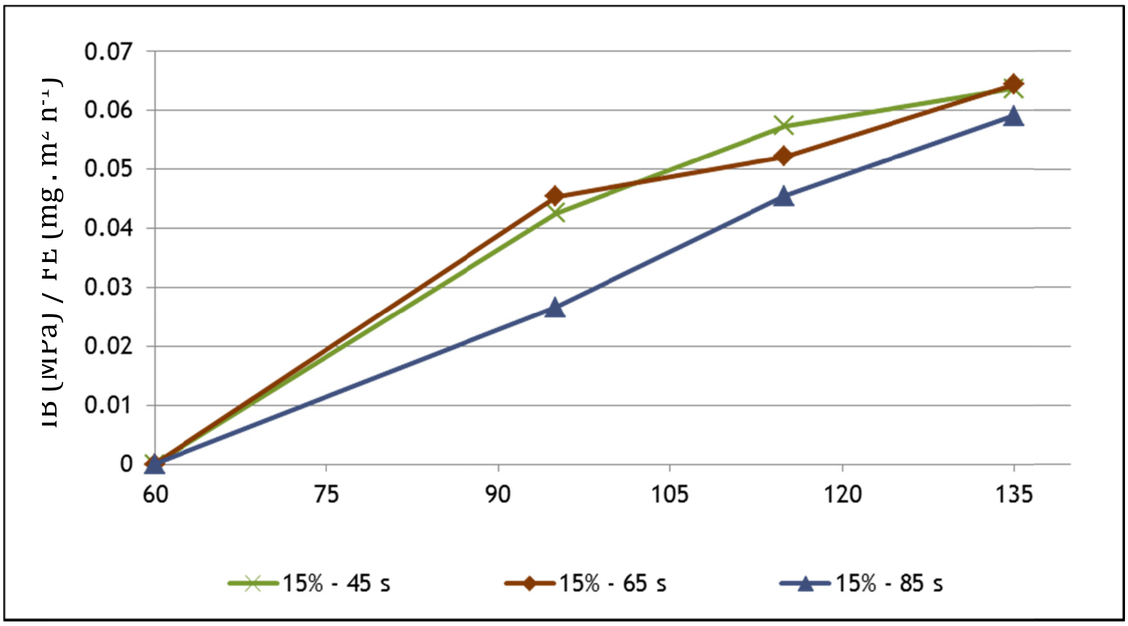

Figure 3: Ratio of internal bond and formaldehyde emission (gas analysis) in function of pressing time

Figure 4 shows the evolution of the internal mat temperature along the press cycle. These results, combined with the ABES results (bond strength development as a function of pressing time) permitted to estimate the expected internal bond strength of the panel. In this figure, it can be also observed that the internal bond depends on moisture content, pressing time and the beginning of venting. The effect of venting is more notorious for 15 % of moisture content. In these conditions, the venting should be initiated between 45 and 70 s (grey zone in figure 4).

The expected values of internal bond were calculated by applying the three parameters model for the bond strength development (ABES) presented by Costa et al. (2012). The evolution of mat internal temperature was used to estimate the evolution of the model parameters (kinetic constant).

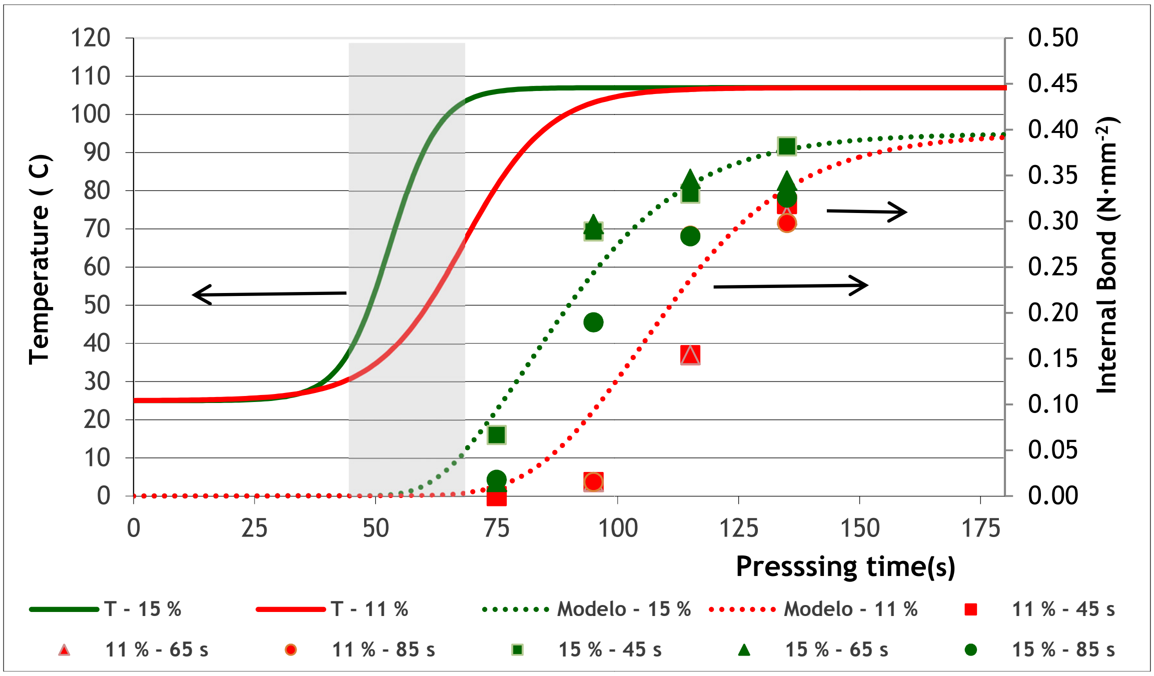

Figure 4: Measured evolution of the internal mat temperature (continuous lines), measured particleboard internal bond strength (markers), predicted internal bond strength from ABES model (dashed lines), as a function of pressing time, for different values of moisture content in the face layer and beginning of venting.

This methodology allowed predicting the minimum pressing time needed to obtain a panel that meets the standard specifications.

5. Conclusions

The aim of this work is to understand the influence of the pressing operating conditions on the performance of particleboards bonded with a Carb II class fortified UF resin. Several trials were carried out on a computer controlled lab scale hot-press, varying the pressing scheduling, namely the venting starting time, the total pressing time and the moisture content on the mat face layer. An ANOVA was performed in order to assess the significance level of all factors studied, as well as the effects of factors levels on particleboard properties (internal bond). In a second trial, the influence of the more significant pressing parameters on physical-mechanical properties and formaldehyde emission were studied.

The main conclusions of this study are:

-The venting has only a significant effect for higher moisture content of the face layer (15 %);

-In these conditions, the venting should start between 45 and 70 s;

-Using the venting in the pressing scheduling, it is possible to gain 20 s in pressing time when the moisture content is increased from 11 to 15 %.
A new methodology has been developed by combining results of mat internal temperature evolution and bond strength development curves obtained using ABES apparatus to estimate the internal bond strength. This methodology allowed predicting the minimum pressing time needed to obtain a panel that meets the standard specifications.

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