THERMO-MECHANICAL TREATMENT TO MODIFY WOOD-BASED COMPOSITES

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Abstract
This paper aims to present some results about the utilization of thermo-mechanical process to densify the following wood-based composites (WBC): medium density particleboard (MDP), medium density fiberboard (MDF) and oriented strand board (OSB). The paper focus on variables regarding the thermo-mechanical process: densification rate (DR, %), compression rate (CR, %) and mass loss (ML, %). Commercial MDP, OSB and MDF boards were obtained and cut in small pieces measuring 400 mm x 400 mm (w x l). The thermo-mechanical process was performed using a single opening hydraulic hot press with pressure and temperature control. A combination of two temperatures, 150°C/170°C (MDP), 150°C/170°C (MDF), 170°C/190°C (OSB) with two pressures, 25 and 50% of the perpendicular compression strength ($f_{c,90°}$) was used. The results showed that the proposed process can be used to densify the WBC tested, although the MDF showed to be more easily densified. It was found that the higher the pressure and the temperature the higher the densification.

1. Introduction

The modification of wood is the subject matter that has been extensively research since early 20th century. There are several chemical and thermal processes that can be applied to modify the wood and thus enhancing its properties. The processes based on thermal treatment of wood have the main goal to reduce the hygroscopicity and to improve durability. Usually, a certain level of degradation of the wood polymers have to happen to achieve these improvements. As being the less-thermally stable wood polymer, hemicelluloses are easily degraded even under mild thermal treatments which reduces the hydroxyl sites for water molecules bond and eliminates the primary source of fungi feeding. However, as the temperature of the treatment is raised and the conditions get longer, celluloses are also degraded which led to a severe loss of wood strength. Severe loss of the wood mechanical strength is the main drawback of practically any kind of thermal treatment. Usually bending strength loss is associated to hemicellulose degradation, whereas bending loss is associated to degradation of cellulose [1].

There is a type of thermal treatment that combines heat and mechanical pressure: thermo-mechanical treatment. This term has been used to describe modifications processes that comprise the application of heat along with pressure in order to reduce the voids and eventually improve the density of the wood. The research has been focused on the application of this process mainly on solid wood [2-3], but more recently the process has been tested on wood-based composites [4-5].

In this context, this paper aims to present some results about the utilization of thermo-mechanical process to densify the following wood-based composites (WBC): medium density particleboard (MDP), medium density fiberboard (MDF) and oriented strand board (OSB). The paper focus on variables regarding the thermo-mechanical process: densification rate (DR, %), compression rate (CR, %) and mass loss (ML, %).

2. Materials and Method

2.1. Wood Based Composites

Sixty commercial boards of medium density particleboards (MDP), medium density fiberboards (MDF) and oriented strand boards (OSB) with the dimensions of 400 mm x 400 mm x 15 mm were obtained and then measured and weighted (M_i) to determine the initial density (ρ_i). According to the manufacturers the MDP and MDF are single-layer wood-based composites (WBC) produced using urea-formaldehyde (UF) for bonding particles/fiber from eucalypt species while the OSB is a three-layer composite produced using phenol-formaldehyde (PF) in the face layers and isocyanate (PMDI) in the core layer for bonding strands from Pinus species. For each kind of WBC five samples were cut to assess the perpendicular compression strength ($f_{c,90°}$) following [6] with adaptions.

2.2. Thermo-Mechanical Treatment

The thermo-mechanical process was performed using a single opening hydraulic hot press (INDUMEC 1000 kN) with pressure and temperature control. During the treatment the inner temperature of the WBC was measured every 20 seconds using a type J thermocouple connected to a datalogger. The treatments consisted of placing the board in the press until the treatment temperature was reached inside the board. Thereafter, the pressure (25% or 50% of $f_{c,90°}$) was held constant for 10 minutes, at each press adjustment the temperature and time were recorded. The pressure was then relieved by 50% for 5 minutes. Finally, the pressure was completely relieved and the treatment continued for further 5 minutes. Each WBC was treated under two temperatures and two pressures which led to four different combinations of treatments (Table 1) and for each one five replications were done.

Table 1. Experimental design used to treat thermo-mechanically the wood-based composites.

WBC	*Temperature (ºC)*	*Pressure (MPa)*	*# Boards*
MDP	150ºC	1.7 (25%)/3.4 (50%)	20
	170ºC		
MDF	150ºC	2.0 (25%)/4.0 (50%)	20
	170ºC		
OSB	170ºC	1.5 (25%)/3.0 (50%)	20
	190ºC		

After the treatment the thickness (T_f) and mass of the boards were again obtained to calculate the final density (ρ_f) and eventually the densification rate (DR, %), compression rate (CR, %) and mass loss (ML, %) according to the equations 1, 2 and 3, respectively:

$$DR\ (\%) = [(\rho_i/\rho_f)-1]\ x\ 100 \quad (1)$$

$$CR\ (\%) = [1-\ (T_f/T_i)]\ x\ 100 \quad (2)$$

$$ML\ (\%) = [(M_i-M_f)/M_i]\ x\ 100 \quad (3)$$

3. Results and Discussion

Figure 1 shows the inner temperature of the board during the thermo-mechanical treatment. The figure presents only the information about the OSB, but similar behavior was found for MDP and MDF: first stage (around 2-3 minutes), the temperature rises rapidly because the presence of adsorbed water which evaporates and transfers heat to colder regions; second stage (3-6 minutes), the temperate reaches a plateau around 100-104ºC for few minutes which means that WBC is been dried; the third stage, the temperature rises slower, but constantly until reaching nearly the temperature of the hot press plate. The same behavior was found by others [7-8] when applied a thermal post-treatment on OSB boards and wood [2]. The mean duration of the treatment varied according to the WBC being treated: OSB, ±31 minutes; MDF, ± 36 minutes; and MDP, ±39 minutes.

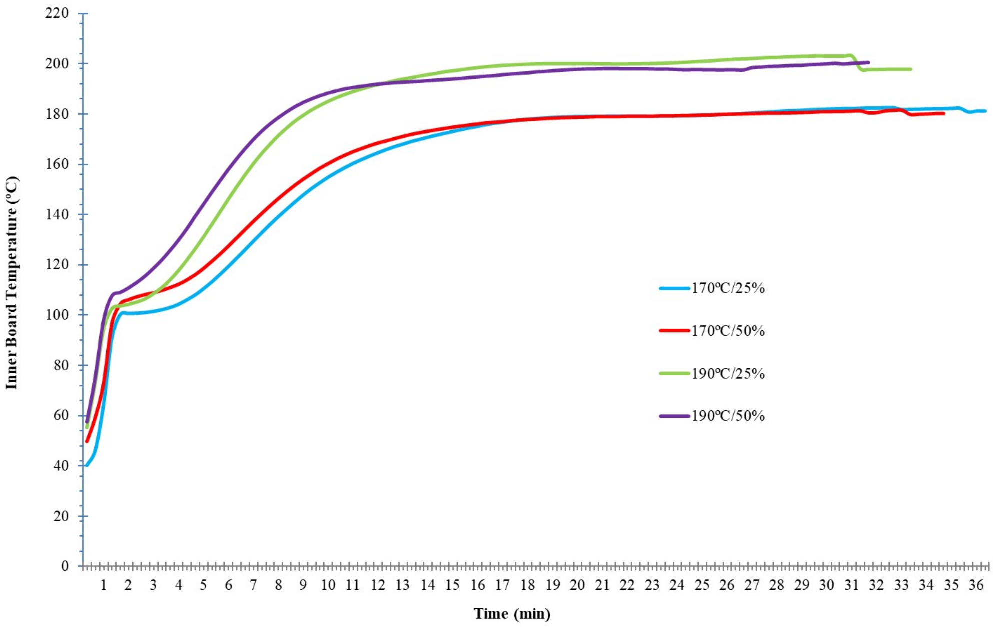

Figure 1. Inner temperature of the OSB board during the thermo-mechanical treatment.

It was also observed that during the treatment the hot press automatically adjusted several times the pressure. As a viscoelastic material, the wood experiences the relaxation phenomena, which means the pressure required to keep the deformation of the board is reduced with the time. It happens because the lignin, which holds wood fiber microstructure, goes from a glassy to a rubbery state when the temperature is raised and this way leading to a temporary wood stiffness reduction. That is the well-known glass transition temperature (*Tg*). In this situation, as long as the temperature is kept the wood can be easily compressed. Indeed, every hot press adjustment reduces the voids and improves the wood density. The number of press adjustment was different within the WBC treated here: from 6 to 9, for MDP and OSB; and 5 to 10 for MDF.

Figure 2 shows the thickness profile view of the MDF subjected to the thermo-mechanical treatment. It can be observed that the higher the temperature and pressure the higher the densification. The process led to a compression of the whole board through its thickness which reduced significantly the natural voids usually found in this kind of wood-based composite.

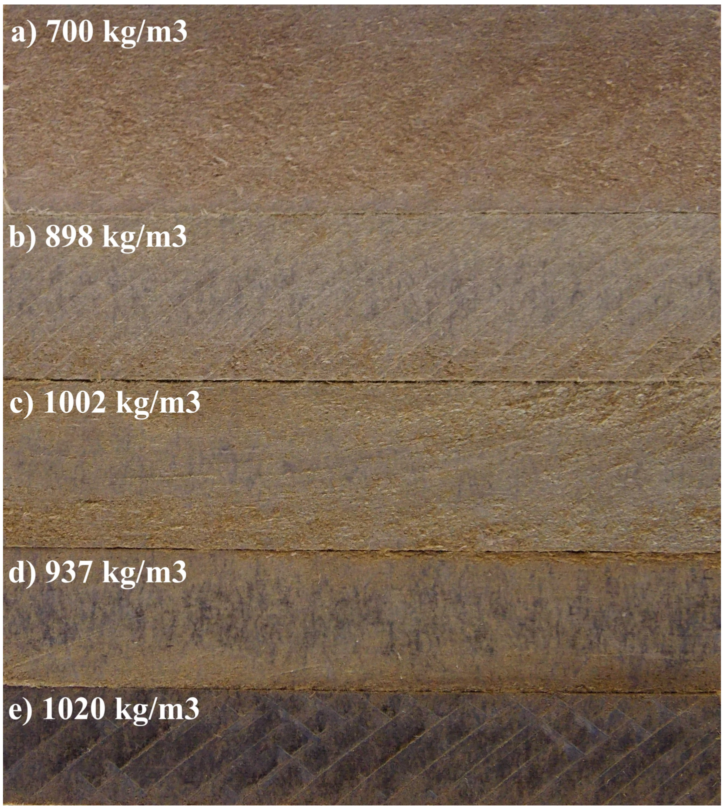

Figure 2. Thickness profile view of the MDF thermo-mechanically treated: a) untreated; b) 150ºC/2 MPa; c) 150ºC/4 MPa; d) 170ºC/2 MPa; and e) 170ºC/4 MPa.

Figure 3 shows the results of the mean value of DR, CR and ML of the WBC subjected to the thermo-mechanical treatment. studied. The boards presented the following density prior the treatment: MDP, 650 kg/m^3; MDF, 700 kg/m^3 and OSB, 600 kg/m^3. It can be observed that MDP and OSB presented similar behavior regarding the three variables analyzed. For these WBC the compression rate was higher than densification rate, probably because the CR measures only the reduction in thickness while DR measures the density which must take in account the mass of the WBC. As the WBC loses mass due the polymer thermal degradation it has an important role on the global density of the WBC after the treatment. A different behavior was observed for MDF, where CR was lower than DR. It is also clear that the ML was very low, less than 10%, which means the wood-based composites were basically dried during the process.

The comparison between the wood-based composites was not the aim of this paper, but the differences observed here can be attributed to the type of the wood used, whose geometry and dimensions are strongly different. MDP is manufactured using wood particles not longer than 3 mm and width about 1-2 mm, while fiber is used to manufacture MDF and they are much smaller: 0.7 to 1.2 mm longer. On the other hand, the strand used in OSB presented a geometry quite different: 100 mm x 25 mm x 0.6 mm (l x w x t).

Thus, it is clear that particles, fibers and strands present compressibility and different bulk density. These wood mat characteristics might affect the heat transfer into the board and thus leading the difference in densification rate found here. We have also to take into account the different parameters used to manufacture each wood-based composite such as resin, pressing time, additives applied and others.

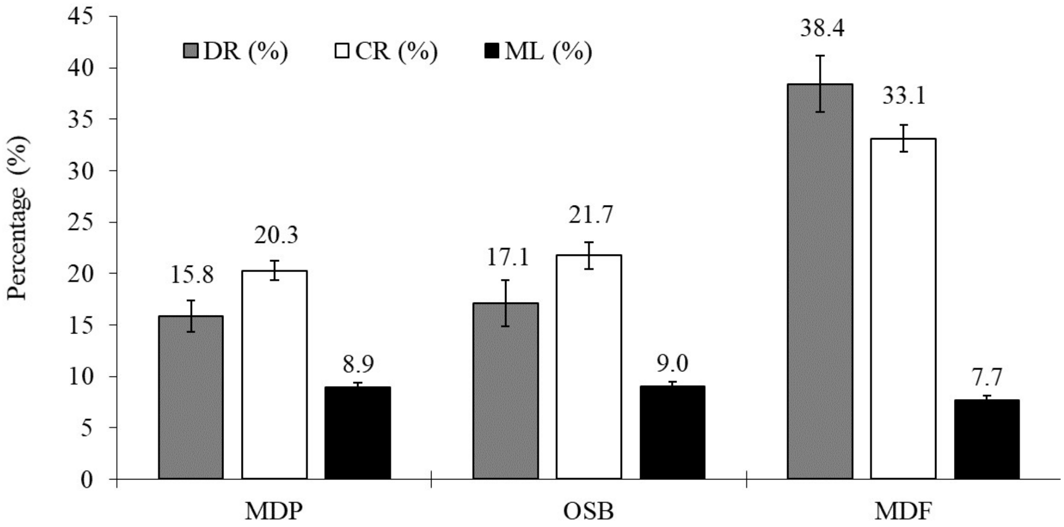

Figure 3. Mean and standard deviation values of densification rate, compression rate and mass loss of wood-based composites subject to thermo-mechanical treatment.

The results presented on Figure 3 can be detailed by isolating the effect of temperature and pressure (Table 2). The temperature improved significantly DR, CR and ML of the MDP and MDF, while for OSB only ML was affected. On the other side, the pressure improved significantly DR, CR and ML of the three wood-based tested, except ML of the MDP. The effect of the temperature on CR has been found by others [5]. The authors densified plywood at two temperatures (120ºC and 150ºC) and observed that compression rate was higher when 150ºC was used. They also found that densification rate was higher at such condition.

Table 2. Isolated effect of the temperature and the pressure of the thermo-mechanical treatment on densification rate (DR), compression rate (CR) and mass loss (ML) of the wood-based composites tested.

WBC	*T* (°C)	*DR* (%)	*CR* (%)	*ML* (%)	*Pressure* (MPa)	*DR* (%)	*CR* (%)	*ML* (%)
MDP	150	14.7*	18.9*	8.1*	1.7	7.6*	14.6*	8.9^{NS}
	170	16.9	21.7	9.8	3.4	24.1	26.0	9.1
MDF	150	36.7*	31.6*	6.7*	2.0	31.9*	29.8*	8.8*
	170	40.1	34.7	8.7	4.0	44.9	36.5	9.2
OSB	170	17.0^{NS}	21.1^{NS}	8.2*	1.5	7.5*	15.2*	7.4*
	190	17.2	22.4	9.9	3.0	26.7	28.3	8.0

*Mean difference within temperature or pressure is statistically significant; NS: non-significant mean difference

4. Conclusions

Three kinds of wood-based composites (MDP, MDF and OSB) were subjected to the thermo-mechanical treatment. The process applied improved significantly the density of the composites, although the MDF was more easily densified. The mass loss due the process was quite low. It was found that the level of densification is affected by the temperature and the pressure used, although the temperature did not affect the OSB. It can be concluded that in general the higher the pressure and temperature, the higher the densification of the wood-based composite.

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