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O EFEITO DO PÓS-FABRICO NAS PROPRIEDADES DOS PAINÉIS DE FIBRA DE ALTA DENSIDADE DO PINHO RETARDADO

THE EFFECT OF POST-MANUFACTURE ON THE PROPERTIES OF HIGHT DENSITY FIRE-RETARDANT TREATED FIBERBOARD PANELS

EFECTO DE LA FRABRICACIÓN DE POSTES EN LAS PROPRIEDADES DE LOS PANELES DE FIBERBOARD DE PINO TRATADO

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RESUMO

Introdução: As placas de aglomerado de fibras apresentam grandes vantagens na fabricação de móveis, apesar da sua inerente inflamabilidade. Este problema pode ser melhorado tratando os painéis com os corretos aditivos retardadores de fogo.

Objetivos: Um conjunto de painéis de fibra de alta densidade passou por várias operações de prensagem a quente, a fim de estudar a influência deste procedimento nas propriedades do substrato.

Métodos: O plano experimental foi desenvolvido para três temperaturas diferentes de 95 °C, 180 °C e 210 °C e dois tempos diferentes de prensagem (22 segundos e 35 segundos) para cada uma. Os painéis foram feitos de fibras de pinho (Pinus pinaster) e tinham uma densidade média de 930 kg / m^3 e espessura de 6,7 mm.

Resultados: Os resultados indicaram que a prensagem a quente pós-fabricação dos painéis de alta densidade tratados com agentes ignifugantes conduziu a uma ligeira melhoria no módulo de elasticidade (MOE) e na resistência à flexão dos painéis utilizados como substratos. Uma diminuição no teor de humidade e na espessura das placas de fibra e um aumento da sua densidade e inchamento foram observados quando temperaturas mais altas e tempos de prensagem mais longos foram aplicados aos painéis.

Houve também uma ligeira diminuição da resistência interna dos painéis devido à presença do agente ignifugante que levou a uma diminuição na capacidade de ligação da resina.

Conclusões: Houve uma ligeira melhoria nas propriedades do substrato, exceto na resistência interna dos painéis, que apresentou uma ligeira diminuição devido à interferência do agente ignifugante.

Palavras-chave: painéis de fibra de alta densidade, modificação térmica, agente ignifugante

ABSTRACT

Introduction*:* Fiberboard panels present great advantages in furniture manufacturing despite their inherent flammability. This problem will be solved by treating those panels with the right fire retardant (FR) additives.

Objectives: A set of high density fiberboard went through several hot pressing operations in order to study the influence of this procedure on the substrate properties.

Methods: The experimental plan was developed for three different temperatures of 95 °C, 180 °C and 210 °C and two different pressing times (22 seconds and 35 seconds) for each. The panels were made out of pine fibers (*Pinus pinaster*) and had an average density of 930 kg/m^3 and were 6.7 mm thick.

Results: The results indicated that the post-manufacture hot-pressing of the FR-treated HDF panels led to a slight improvement in the modulus of elasticity (MOE) and in the bending strength of the panels used as substrates. A decrease in the moisture content and in the fiberboards' thickness and an increase in their density and in their thickness swelling was observed as higher temperatures and longer pressing times were applied to the panels.

There was also a slight decrease in the internal bonding strength of the panels due to the presence of the flame retardant which leads to a decrease in the bonding capacity of the resin.

Conclusions: There was a slight improvement in the properties of the substrate except in the fiberboards' internal bonding strength which experienced a slight decrease due to the interference of the fire retardant.

Keywords: high density fiberboards, thermal modification, fire retardant

RESUMEN

Introducción: Las placas de aglomerado de fibras presentan grandes ventajas en la fabricación de muebles, a pesar de su inherente inflamabilidad. Este problema puede solventarse tratando los paneles con los correctos aditivos retardadores del fuego.

Objetivos: Un conjunto de paneles de fibra de alta densidad pasaron por varias operaciones de prensado en caliente con el fin de estudiar la influencia de este procedimiento en las propiedades del sustrato.

Métodos: El plan experimental se desarrolló para tres temperaturas distintas de 95 °C, 180 °C y 210 °C y dos tiempos de prensado diferentes (22 segundos y 35 segundos) para cada una. Los paneles estaban hechos de fibra de pino (Pinus pinaster), tenían una densidad media de 930 kg/m^3 y un grosor de 6,7 mm.

Resultados: Los resultados indicaron que el prensado en caliente post-fabricación de los paneles de alta densidad tratados con agente ignifugante llevó a una ligera mejora en el módulo de elasticidad (MOE) y en la resistencia a la flexión de los paneles utilizados como sustrato. Se observó una disminución en el contenido de humedad y en el grosor de las placas de fibra, así como un aumento de su densidad e hinchazón cuando se aplicaron a los paneles temperaturas más altas y tiempos de presión más largos

De igual forma hubo también una ligera disminución de la resistencia interna de los paneles debido a la presencia del agente ignifugante que ocasionó una disminución de la capacidad de unión de la resina.
Conclusiones: Se observó una ligera mejora en las propiedades del sustrato, excepto en la resistencia interna de los paneles que presentó una ligera disminución debido a la interferencia del agente ignifugante.

Palabras-clave: paneles de fibra de alta densidad, modificación térmica, agente ignifugante

INTRODUCTION

Fiberboard panels offer great advantages for the furniture industry where easy surface finishing and the existence of good and modern machinery are aspects that have become increasingly important over the years. However, and since these composite materials are made of natural fibers, panels' inherent flammability has to be improved with the addition of fire retardant additives.
In most manufacturing processes the addition of fire retardant aqueous solutions happens between the use of the refiner and of the dryer where the wet fibers are mixed with the chemical reagents. This kind of procedure doesn't require major changes in the overall process.
Several authors have studied the effects of fire retardant additives on the physical and mechanical properties of wood and wood-based composites (Hashim et al. 2009, Ayrilmis et al. 2007, Akhtary et al. 2006, LeVan and Winandy 1990, Ayrilmis 2007). However there is no information whatsoever about the effect that these additives have on the properties of the fiberboard panels when they are used as substrates and exposed to heat and pressure during the final finishing operations.
The purpose of this study is to determine the influence of a solution made of polyphosphates and nitrogen that will be used as a flame retardant agent in high density pine fiberboards, when these panels are exposed to post-manufacturing heat pressing during coating film procedures.

1. THEORETICAL FRAMEWORK

The most commonly used fire retardant additives for wood treatment are phosphoric acid, diammonium and monoammonium phosphate, ammonium sulfate, zinc chloride, nitrogen and borates such as: boric acid and borax (Wang et al. 2004; Ayrilmis et al. 2007)
Several studies have shown that the addition of the fire retardant agent during the manufacturing process causes some problems as it reduces the agglomerating capacity of the resin which will, in turn, influence negatively the structural properties of the treated panels. According to Winandy et al. 2008, the first problem relates to interference of chemical reagents with resin curing development when the addition of fire retardant is attempted prior to hot-pressing. This interference seems to either inhibit or alter the chemical mechanism required for the adhesives to bond together the fibers of the panel. The second problem relates to the mechanical interference resulting from the addition of the fire retardant agent that affects the internal bonding which is critical to the structural performance of the panels.
The most important fire retardant solutions used in the treatment of wood-based products contain phosphorus, mainly phosphoric acid and its diammonium and monoammonium phosphate salts. Tests carried out using 21 different types of compounds showed that phosphoric acid was the most effective in increasing the amount of residual coal. Monoammonium phosphate, diammonium phosphate and zinc chloride came right after (LeVan and Winandy, 1990).
According to Özdemir and Tutus 2013, the retardant effect of ammonium polyphosphates is due to the creation of a carbon film during combustion. Such a film blocks access to oxygen and heat which inhibits combustion and reduces the amount of smoke. These fire retardant chemicals do not completely stop the combustion of the wood, but they create a slowing effect by releasing phosphoric acid esters, wood polysaccharides and water. These releases influence the dehydration reactions of wood (Grexa et al. 1999).
Acids in wood, especially when accelerated by acidic fire retardant treatments and/or exposure to high temperatures, hydrolyze the cellulose chains. As cellulose and hemicellulose chains are often thought to be primary responsible for the resistance and strength of wood fibers, reducing the length of these chains would cause a reduction in the resistance of the panels (Sweet and Winandy 1999). The same acid hydrolysis mechanism that is useful in the slowing of the fire may be harmful as it reduces the resistance of the panels under certain conditions, particularly when the panels are exposed to high temperatures and pressures during the coating process using melamine resin-impregnated papers or wood sheets.
Coating MDF panels with decorative surface films allows reducing the absorption of water and humidity, eliminating formaldehyde emissions and panels will exhibit improved physical and mechanical properties (Chow et al. 1996). During hot pressing procedures, the effects on physical and mechanical properties are deeper in high density fiberboard panels, (800-1,100 kg/m3), as seen in the current study, than in medium density panels, (600-800 kg/m3).

As the characteristics of this composite can be altered by temperature and pressure, it is important to know to what extent these dimensions are affected during the coating procedures. This knowledge will allow researchers to map the initial specifications that the product should offer in order to withstand further coating conditions. This will allow the preservation of the natural characteristics of the product that will make it suitable enough to be used in the final applications for which it has been designed and will, thus, reduce possible flaws in that final product.

2 METHODS

2.1 Manufacturing of fibreboard panels

In the dry manufacturing of high density fiberboard panels tested in this study, one uses a melamine-urea-formaldehyde resin which must be dissolved in water prior to use and that has the following characteristics: a 15% percentage of melamine, a molar ratio (urea-formaldehyde) of 1.7; 63% of solid contents, a viscosity of (170 ± 50) mPa.s, a density of 1.275 ± 0.010, a reactivity of 70 ± 20 S, a pH of 9.0 ± 1, a sizing rate between 15 and 21 g of resin solids/ 100 g of dry fiber).

The sizing/bonding rate was increased by about 3% in relation to the panels which weren't treated with fire resistant agents to compensate for the reduction of the resin's agglomerating capacity. As a catalyst, we used a diluted ammonium nitrate solution with a mass percent of 25% and a diluted urea solution with a mass percent of 30% was used as formaldehyde capture agent.

A paraffin solution with a solid content of 60% was also used as a hydrophobic agent and the quantity used ranged between 0.5 and 2% (g of paraffin/ 100g of dry fiber). An aqueous solution of polyphosphate compounds and 50%-50% dilute nitrogen was used as a fire retardant agent.

After mixing, the fibers were dried up to a moisture content of (9-12%) and pressed into a 25 m Siempelkamp Contiroll press to produce the test specimens. Pine wood (Pinus pinaster)was the raw material used in that process.

2.2 Experimental Plan

The experimental plan was developed for two different post-pressing times (22 s and 35 s) and three different temperatures were tested for each of them: 95 °c, 180 °c and 210 °c. A pressure of 25 N/cm2 was applied to promote a light but uniform contact between both plates of a Burkle hydraulic lab press and the surface of the panels.

Two panels measuring 2440mmx2080mmx6.7 mm each, with a density of 930 kg/m3 and an average thickness of 6.7 mm, were cut down into small 45x45 cm panels to carry out the tests. After hot pressing, the panels were cut into smaller test pieces and placed in a climate chamber with a temperature of (20 ± 2) °c and a relative humidity (RH) of 65 ± 5% for two weeks before performing the tests.

The following tests were carried out for each of the samples: modulus of elasticity and bending strength according to NP 310:2002; density according to EN 323:2002; tensile strength perpendicular to the plane of the board according to NP EN 319:2002; thickness swelling after immersion in water according to NP EN 317:2002 and water content according to NP 322:2002.

3 RESULTS and DISCUSSION

3.1. Effect on residual moisture content

The variation of the water content in comparison to standard values (without any kind of pressing) can be seen in Figure 1. It becomes clear that hot pressing causes a decrease in the balance moisture content and presents a maximum value of 7% (in comparison to standard values) at a temperature of 210 °c and a pressing time of 35 s. A temperature of 95 °c does not seem to have much influence on the balance moisture content.

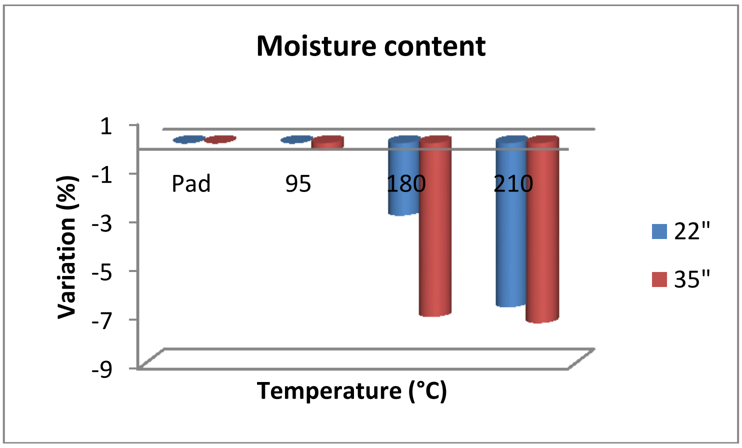

Fig.1 - Effects of pressing temperature and hot-pressing time on moisture content in comparison to standard values.

The hot pressing of MDF panels normally leads to lower moisture levels than the cold pressing method. Grigsby et al. (2012) have come to the conclusion that MDF panels glued with urea-based formaldehyde resins present a residual moisture content around 6.7%. They also found out that the resin affects the hydrophobicity of the fibers, but does not prevent water retention.

3.2 Effects on density and thickness swelling

According to Chow (1976), the mechanical properties of the panels are linearly correlated with their density. However, dimensional stability and water absorption do not follow this kind of behavior.

Density is the feature of the panel that most directly influences the other properties. Densification is an easy way to improve the properties of the panel leading to better contact between fibers and consequently to a reduction in the amount of resin that is lost in the empty spaces (Maloney, 1989).

In Figure 2 we can observe the values of the density variation in relation to standard values. In general terms, evidence shows that pressing promotes an increase in density, resulting in a maximum variation of 9% whenever certain temperature and pressing time conditions are met (210 °c and 35 s). However, a temperature of 95 °c does not seem to have a clear influence on the density, regardless of the pressing time.

As far as thickness swelling is concerned, the results presented indicate a progressive increase in swelling caused by the increase in temperature and pressing time. In general terms, it is clear that hot pressing causes a large increase in the thickness swelling of the panels, resulting in a maximum value of 72% of variation when compared to standard values when temperature and pressing time conditions are 210 °c and 35 s respectively.

In fiberboard panels the thickness swelling/shrinkage increases with the increase of the density of the panel especially above 850 Kg/m3 (Ayrilmis, 2007). According to this author, the increase in thickness swelling is usually caused by a decrease in shrinkage, as well as by the degradation of the bonding between particles, which prevent the fibers from sticking together.

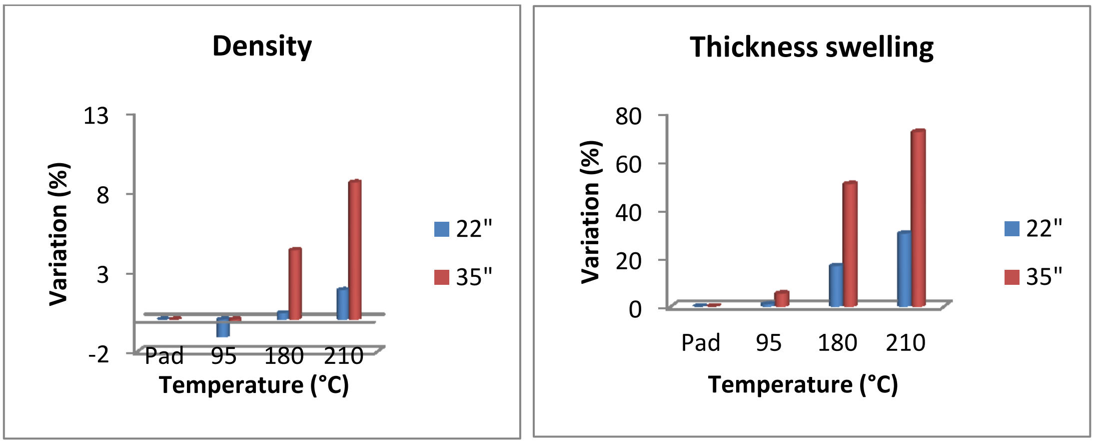

Fig. 2 - Effect of the pressing temperature and hot-pressing time on density and thickness swelling in comparison with standard values.

According to Mackenzie (1989), an increase in the panel density corresponds to a larger quantity of material and consequently to a greater thickness swelling.

Additionally, the swelling caused by the increase in density can also be explained by the swelling of the cell walls. Wu (1999) found out that in hot pressing the lumen of the cells - or the leaf vessels in the case of hardwoods- collapses, causing fractures on the cell wall.

3.3 Effect on static bending strength and modulus of elasticity

Figure 3 shows the influence of the temperature and pressing time on the panels' bending strength and modulus of elasticity when compared to standard values.

As one observes the figure, it becomes clear that the influence of pressing time on the panels' bending strength does not present a linear behavior. However, as the temperature increased there was an improvement of 5% (for a 22 s pressing time) and of 10% (for a 35 s pressing time).

The effect of hot-pressing on the modulus of elasticity is quite limited and exhibits variations under 8% when compared to standard values. The modulus of elasticity observed for a pressing time of 22 s does not present a variation proportional to the increase in the temperature. When the pressing time increased to 35 s, a gradual increase in the modulus of elasticity could be observed and there was an improvement of about 8%.

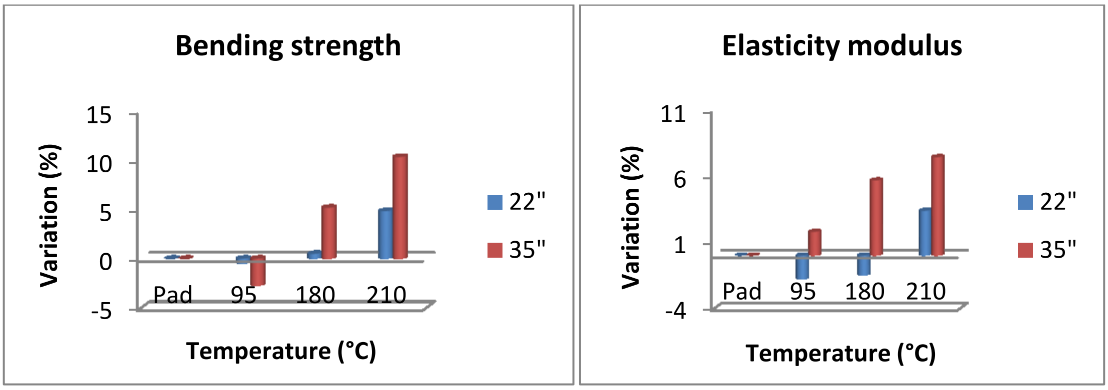

Fig. 3 - Effect of pressing temperature and pressing time on static bending strength and elasticity modulus in relation to standard values.

In general terms there is an increase in the bending strength and elasticity modulus of the panels as density increases. These results are in agreement with those obtained by (Wu, 1999) who found out that both perpendicular and parallel modulus of elasticity and bending strength increase linearly with increasing density. This fact is usually attributed to the increasing amount of wood material used in a given panel, a situation that usually happens in high density panels.

Generally, higher temperatures cause greater reduction in modulus of elasticity and bending strength or modulus of rupture values compared to untreated specimens. This could be partially attributed to the fact that the heat treated MDF panels had some minor mass loss during heating. Stamm (1956) reported that softwood specimens heated over 30 min in air at 200 °c could lose more than 10% of their original bending strength(or modulus of rupture).

3.4 Effect of tensile strength perpendicular to the panel surface

This study seems to point out that the pressing time and the increase in temperature cause a slight decrease in the internal cohesion of the panels leading to a maximum variation of 5% when 180 °c is the temperature applied and 22 s is the pressing time that was chosen.

When the selected temperature reaches 210 °c this decreasing tendency seems to slow down. As this situation is quite different from what could be expected, further confirmation is required.

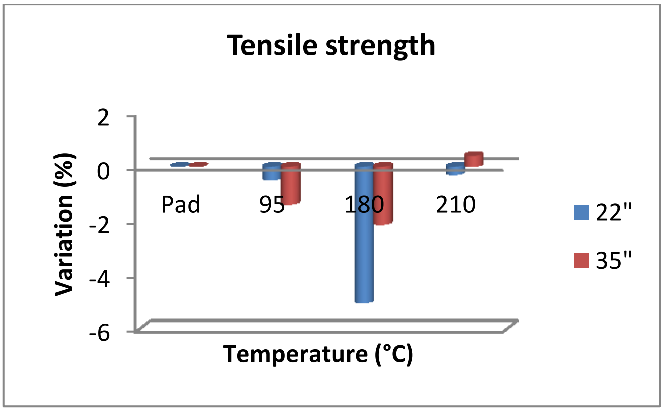

Fig. 4 - Effect of temperature variation and hot-pressing time on tensile strength perpendicular to the panel surface when compared to standard values

Previous studies have shown that both untreated and FR treated fiberboard panels lose internal resistance when they are exposed to high temperatures (LeVan et al., 1990; Winandy, 2001).

Studies by Sweet and Winandy (1999) showed that acids in wood, especially when accelerated by acidic fire retardant agents and/or exposures to high temperatures, hydrolyze the cellulose chains by reducing the length of the cellulose molecules that would cause a reduction in their macro-strength properties. Levan et al. (1990) also noted that cleavage of hemicellulosic side chains within the lignin-hemicellulose matrix may be responsible for the observed strength loss.

The decrease in the internal strength verified in this study seems to be connected to the high temperatures to which the panel is subjected during the post-pressing operations and the acidic character of the fire retardant agent that optimizes the degree of depolymerization of cellulose and the cleavage of hemicellulosic sidechains.

CONCLUSIONS

The results from this study show that there is a slight decrease in equilibrium moisture content and thickness and a slight increase in density when the panels are subjected to heat and pressure in the final finishing operations.

The dimensional stability of the panels with average densities of 930 kg/m3 was adversely affected by the swelling which increased slightly with the increment of the panel density. The thickness swelling of the panels could be related to the swelling of the fiber cell walls and partly caused by deterioration of the inter-particle bonding in the panels.

There was a slight increase in the panels bending strength and modulus of elasticity with the increase of temperature and pressing time duration which improved the final properties of the product.

The decrease in the tension strength perpendicular to the surface of the panel can be explained by the presence of the fire retardant agent that interferes with the inter-particle bonding process, reducing the agglomeration capacity of the resins.

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