Effect of Bio-Based Additives on Physico-Mechanical Properties of Medium Density Fibreboards

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ABSTRACT

Dimensional stability of wood-based panels is generally improved with application of suitable additives. Most of these additives, such as paraffin wax, are petroleum-based and with relatively high cost, and therefore, it is desirable to develop low-cost and effective substitutes from renewable resources. This work studied the potential of using a renewable water-repellent additive, such as tall oil fatty acid, for lab-scale manufacturing of medium density fibreboards (MDF). Tall oil fatty acid (TOFA) was used at 1 and 3% w/w of urea formaldehyde (UF) resin. MDF panels with similar concentrations of paraffin wax (wax) and panels without adding a water-repellent agent were served as controls. It was assessed the dimensional stability of the panels in terms of thickness swelling and water uptake after 4 and 24h immersion in water, and their mechanical performance in terms of modulus of elasticity, modulus of rupture and internal bonding. Results showed no obvious differences in the strength behaviour of the panels by addition of water-repellent agents. Dimensional stability, however, considerably improved by addition of TOFA, but it was still inferior when compared to that provided by wax.

Key words: Dimensional stability, wood-based panels, paraffin wax, tall oil fatty acid, water-repellent additives, strength properties

1. INTRODUCTION

Wood-based panel is a general term for a wide range of different wood-derived products composed of strands, particles, fibres, or veneers of wood, and bonded with synthetic adhesives, mainly urea-formaldehyde (UF), phenol-formaldehyde (PF), melamine-urea formaldehyde (MUF), and polymeric diphenylmethane diisocyanate (PMDI), under heat and pressure to form composite materials. These panels show reversible and irreversible swelling when they are exposed to high relative humidity or immersed in water. Reversible swelling of the panels is related to the annealing of amorphous wood polymers (Hosseinpourpia *et al.,* 2017), while irreversible swelling is attributed to the springback of densified materials, such as wood particles or fibres, and the breakage of inter- or intra-adhesive bonds (Hsu *et al.* 1988).

A traditional approach to overcome this problem is to improve the dimensional stability of wood-based panels with application of small amount of water repellents agents, such as emulsified paraffin wax (wax). This is because micro-particles of wax emulsions can penetrate deep into the capillary structure of wood, and the strongly hydrophobic nature of the wax prevents the uptake of water through the capillaries (Borgin and Corbett, 1970). However, addition of wax in higher amounts adversely affects the bond quality and the strength of the panel (Hundhausen *et al*., 2009). Moreover, wax is a relatively high cost substance as a by-product of the petroleum distillation process.

Hyvönen *et al*. (2007) revealed that the bio-based oil such as tall oil, a by-product from kraft pulping process, is capable to improve the dimensional stability of wood. Crude tall oil is characterized as viscous and sticky dark brown liquid that is ill-smelling prior to refining (Marda, 2006). The refined tall oil is less brown and viscous but oily (Baumassy, 2014). Tall oil fatty acid (TOFA) is refined from crude tall oil and consists predominantly of free-fatty acids e.g. oleic acid and linoleic acid. TOFA has the largest market for end-uses compared to the other tall oil distillation products and produced at 90–98% purity, which may deviate depending on the end-use application (Panda, 2013). The main uses for fatty acids include protective coatings and inks, chemical intermediates, soaps and detergents and ore flotation (Panda 2013).

The present study aimed at investigating the effect of a bio-based additive, this case tall oil fatty acid (TOFA), on the physical and mechanical properties of medium density fibreboards. For comparison, panels made with conventional wax and without a water-repellent agent were used.

2. EXPERIMENTAL

MDF panels were manufactured by standardized procedures that simulated industrial production in the laboratory. Dry wood fibres (Steico Steinmann & Co. GmbH, Germany), with moisture content below 5%, were mixed with UF resin for 3 min using a rotary drum adhesive blender fitted with a pneumatic spray gun. UF adhesive was mixed with ammonium sulphate as a hardener just before its application to the fibres. The water repellent agents (TOFA, wax) were then added, according to *Table 1*, and further mixed with fibres for another 3 min.

Following the blending treatment, the mixture was weighed and then formed into a mat on an aluminium caul plate, in a 450 × 450 mm^2 forming box. To reduce the mat height, cold pressing was applied first. The hot pressing was performed in a manually controlled electrical-heated press. The maximum pressure, temperature and total press time were 20 N mm^{-2}, 190°C and 10 min, respectively. The panels were then trimmed to a final size of 400 × 400 × 10 mm^3 after cooling. Three experimental panels were manufactured for each treatment. The density of the panels after trim was 750-771 kg m^{-3}. The samples with similar density levels were selected for mechanical and dimensional stability tests.

Table 1. Dosage of adhesive, hardener and water-repellent agents in MDF panels

UF[1] (%)	Hardener[2] (%)	wax[2] (%)	TOFA[2] (%)
14	3	-	-
14	3	1	-
14	3	3	-
14	3	-	1
14	3	-	3

[1]) The concentrations represent percentage resin based on dry fibre
[2]) The concentrations represent percentage additive based on dry resin

2.1. Determination of dimensional stability and mechanical properties

Determinations of thickness swelling and water uptake were done according to a modified version of EN 317 (1993) using 5 samples (50 × 50 mm^2) per board (n= 15). The length, width and thickness of samples were measured before and after immersion in the water bath at 20±2°C for 4 and 24 hours. Percentage thickness swelling and water absorption of samples were calculated.

A three-point bending test was performed according to EN 310 (1993) to determine the modulus of elasticity (MOE) and modulus of rupture (MOR) using a Zwick machine (model 010). Four samples (50 × 350 mm^2) per MDF board (n= 12, per treatment) were tested. The span of the supports was 200 mm, and the loading speed was 8 mm min^{-1}. The internal bond strength test was performed following EN 319 (1993) using Zwick machine (model 010). Five samples (50 × 50 mm^2) per MDF board (n= 15, per treatment) were tested. Metal plates were glued to both sides of the specimens with hot melt glue (CM ultra 250, Henkel Technologies France SAS). The samples were pulled in the direction of thickness or across the surface of the panel until they failed. Tests were performed with a loading speed of 8 mm. min^{-1}.

3. RESULT AND DISCUSSION

Results of bending testing of the MDF categories are presented in *Figure 1*. Based on standard EN 622-5 (2009), the minimum requirements for MOR and MOE of MDF panels for indoor application are 22 N mm^{-2} and 2500 N mm^{-2}, respectively. All the MDF categories, regardless of their bio- or petroleum-based hydrophobic agents, fulfilled the minimum requirement of the standard for bending strength and stiffness (*Figure 1a, b*).

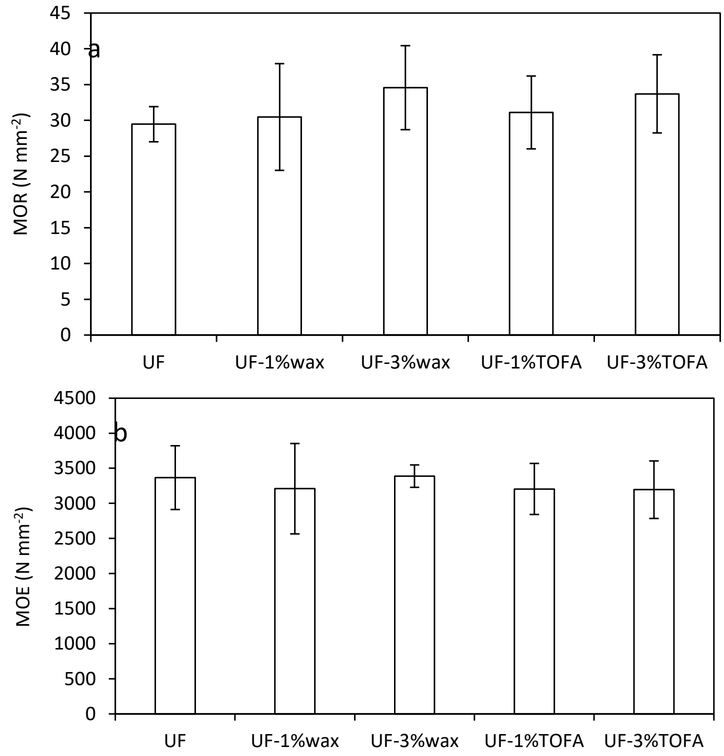

Figure 1. Mean moduli of rupture (MOR, a) and elasticity (MOE, b) of MDF categories manufactured by using bio- or petroleum-based additives (TOFA and wax). The bars show standard deviation.

The results of internal bond (IB) strength also showed that the MDF categories were able to meet marginally the minimum requirement of EN 622-5 (2009) of 0.6 N mm^{-2} (*Figure 2*). In general, application of bio- or petroleum-based water repellent agents had no negative effect on mechanical strength of the MDF categories. As explained previously, the mechanical properties of wood-based panels are directly and linearly related to their density (Jarusombuti *et al.*, 2012; Amini *et al.*, 2013), and thus the similar mechanical behaviour of the MDF categories can be explained by similarities in their density.

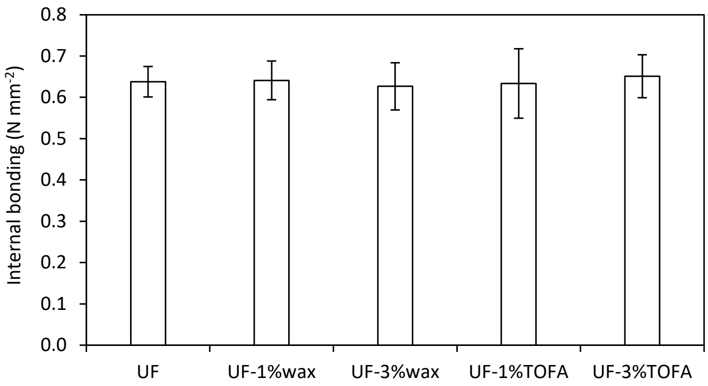

Figure 2. Mean internal bonding (IB) of MDF categories manufactured by using bio- or petroleum-based additives (TOFA, wax). The bars show standard deviation.

The water-related properties of MDF categories demonstrated a different trend than their mechanical performance. As expected, use of water repellent agents could enhance the dimensional stability of the panels as compared to those made without any additive (*Figure 3a, b*). Addition of small amount of the bio-based water-repellent agent (1%), TOFA, caused a similar thickness swelling as control category without a hydrophobic agent after 4h, while it was considerably reduced the thickness swelling of MDF categories after 24h. Addition of 3% TOFA decreased the thickness swelling of MDF categories after both 4h and 24h measuring time. Similar trends have seen in terms of water uptake of the panels, which it was not improved by addition of low dosage of TOFA (1%), but strongly decreased by application of higher concentration of TOFA (3%). The wax additive, however, performed better than TOFA at both 1% and 3% loading levels in terms of thickness swelling and water uptake after 4h and 24h.

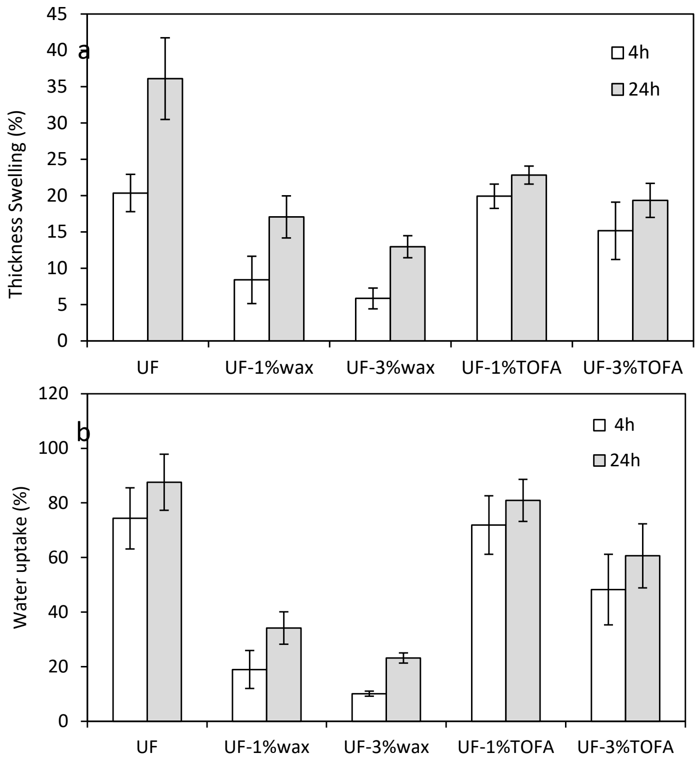

Figure 3. Thickness swelling (a) and water uptake (b) of MDF categories manufactured by using bio- or petroleum-based additives (TOFA, wax). The bars show standard deviation.

In addition, MDF categories that produced with higher concentration of TOFA (3%) and with both loading levels of wax (1% and 3%) fulfilled the minimum requirement of EN 622-5 for thickness swelling after 24h at 20%. The better performance of MDF panels that manufacture with wax addition might be attributed to the better dispersion of emulsified wax at the fibre surfaces during mixing process in comparison with TOFA, which was resulted in higher stability of the samples in terms of water uptake and thickness swelling. Nevertheless, the results of present study indicate the great potential of TOFA to be applied as a water-repellent agent in MDF panels.

4. CONCLUSIONS

The use of bio- or petroleum-based water repellent agents (TOFA, wax) in manufacturing MDF panels bonded with UF did not alter their mechanical properties (MOR, MOE, internal bonding). TOFA could reduce the thickness swelling and water uptake of the MDF panels, especially at the higher loading level (3%). However, wax performed much better than TOFA in this respect and could fulfil the requirements for thickness swelling set by the EN 622-5 (2009) standard. Although TOFA proved to be inferior to wax as regards its hydrophobation effect on MDF panels, it is an interesting bio-based material to study further and optimise its application for a better interaction with the fibre surfaces.

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