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INFLUENCE OF ISOCYANATE ADDITIVE UPON SOME SELECTED PROPERTIES OF PARTICLEBOARDS

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Abstract:
The outcome of the present research was to the evaluate the possibility of simultaneous reduction of the density and formaldehyde emission of particleboards without affecting their other important properties, such as the swelling in thickness, the surface absorption, the bending strength, the modulus of elasticity in bending and the internal bond. The envisaged solution involves the production of panels with reduced density and the addition of a isocyanate-based additive into their composition recipe. The effects of two different amounts of additive were tested on panels with three different thicknesses (8mm, 18mm and 28mm). The best found variant (with 0,25% isocyanate-based additive) allowed a decrease by 4,04-7,39% of the density and by 12,08-21,99% of the formaldehyde emission. Additionally, the swelling in thickness decreased by 7,78-22,61% compared to normal density particleboards.

Key words: *particleboards; density; formaldehyde emission; mechanical properties; isocyanate.*

INTRODUCTION

Wooden particleboards (PB) made of wood chips bonded with synthetic resins are the main material used in wood-based furniture industry. Compared to solid wood, they offer several material advantages, especially in terms of homogeneity, lack of cracks and knots, better thermal and acoustic insulation properties, more uniform physical-mechanical properties, more diverse finishing possibilities.

In the construction industry, PB have become a basic material during the last decades, especially in the light construction area, floors etc. Major advantages are given by the better thermal and acoustic insulation properties than those of concrete, but also by the lower price than that of other wooden materials, such as solid wood or plywood. When talking about large construction projects where thousands of plates are used, the cost difference can be an important factor.

Contrary to the general perception, PB are environment-friendly products. Probably this also places them at a leading position when choosing raw materials in different large projects. Being produced from secondary wood resources, low quality wood, processing wood wastes, or even re-used, recovered, recirculated materials (such as from old furniture, demolition elements etc.), PB are actually a modality to harness wood efficiently, to its smallest fraction.

It is assumed that the notion of PB is linked in a negative way to formaldehyde emission, which in the past was somewhat justified, but nowadays, wood-based panels with extremely low formaldehyde emission, similar to that of natural wood, can be produced particularly by means of special melamine-urea-formaldehyde adhesives (Mantanis *et al.* 2017).

Considerable efforts have been made to ensure that wood-based panels have no adverse effects on the human health. In particular, the formaldehyde emissions of these panels have been greatly reduced over the last decades by adopting formaldehyde-free resins or additives with blocking properties in the new developed recipes.

Following-up the general eco-trend, we can state that the main task of the particleboard industry today is to produce boards with as low as possible amount of wooden raw material, with low density (weight) and very low formaldehyde emission, without increasing the production costs and by maintaining at least standard-according physical and mechanical properties of these boards.

OBJECTIVE

The main objective of the present research was to test the cumulative effect of reducing the PB density and adding an isocyanate-based additive into their composition recipe, upon the most important properties of PB. Panels with three different thicknesses (8mm, 18mm and 28mm) and two different amounts of additive (0,25% and 0,4%) were tested.

The selected properties to be determined were: the formaldehyde emission, the swelling in thickness, the surface absorption, the bending strength, the modulus of elasticity in bending and the internal bond.

MATERIAL, METHOD, EQUIPMENT

The material used within the present research consisted in low-emission P2 raw particleboards with thickness of 8mm, 18mm and 28mm, respectively, produced by KASTAMONU Romania.

The composition recipes of the tested boards (standard recipes by Kastamonu) are presented in Table 1.

First, particleboards with normal density (Table 2) were tested, then particleboards with the density reduced by 7% (Table 2). These two tests were called „base tests" because the boards contained no additive, thus serving as reference. For the manufacturing of the PB with reduced density, the same press factor was applied, but a different (7% lower) quantity (mass) of particles.

The third set of tests was meant to improve the properties of the boards with reduced density by using an isocyanate additive into the adhesive's recipe. The additive was mixed with the UF resin in a static mixer before being injected. Two percentages of additive were tested: 0,25% and 0,4% in order to establish the optimum value which leads to a significant improvement of the main physical and mechanical properties of the boards, but without increasing too much the formaldehyde emission. The two values (0,25% and 0,4%) represent percentages from the weight of the dry wood in the core layer.

A number of 200 particleboards from each recipe were produced, at a moisture content of 5-7%.

Table 1

Composition recipe of the tested particleboards (CL = core layer; SL = surface layer)

Percentual participation of hardwood / softwood chips	Percentual participation of the isocyanate additive, %	CL adhesive, %	SL adhesive, %	CL urea, %	SL urea, %	CL hardener, %	SL hardener, %
25/75	No additive	8,0	11,0	0,00	0,17	0,22	0,18
25/75	0,25	8,0	11,0	0,00	0,17	0,18	0,22
25/75	0,4	8,0	11,0	0,00	0,17	0,22	0,18

The ratio between core and surface layers was: 52% / 48% for the 8mm thick panels; 70% / 30% for the 18mm thick panels and 72% / 28% for the 28mm thick panels.

Table 2

Moisture content (MC) and density (ρ) of the tested particleboards (mean values and standard deviations)

PB type	Panel thickness					
	8mm		18mm		28mm	
	MC, %	ρ, kg/m^3	MC, %	ρ, kg/m^3	MC, %	ρ, kg/m^3
PB with normal density, no additive	5,43 (0,18)	716,55 (15,89)	5,72 (0,19)	656,71 (12,04)	5,25 (0,04)	618,14 (7,51)
PB with reduced density, no additive	3,28 (0,10)	656,29 (12,84)	4,68 (0,15)	597,45 (13,06)	5,41 (0,11)	592,86 (10,93)
PB with reduced density, pMDI additive 0.25%	5,06 (0,24)	666,30 (13,56)	5,46 (0,16)	608,16 (12,49)	4,80 (0,07)	593,17 (10,66)
PB with reduced density, pMDI additive 0.4%	5,42 (0,33)	669,12 (13,44)	5,63 (0,46)	607,21 (13,44)	4,93 (0,07)	592,35 (10,90)

The following pressing parameters were applied:

- feed speed of the press: 230mm/s;
- press factor: 5,95s/mm;
- maximum temperature: 245°C;
- maximum pressure: 3,12N/mm^2.

After pressing, the boards were conditioned for 30 minutes at ambiental temperature and then, specific test pieces were cut out of eight randomly selected boards, according to EN 326-1:1994 (confirmed 2014), in order to determine the selected properties of the particleboards.

The density, formaldehyde emission (flask method), swelling, surface absorption, bending strength & modulus of elasticity, and the internal bond were determined according to EN 323:1993, EN 717-3:1996, EN 317:1993, EN 382-1:1993, EN 310:1993 and EN 319:1993, respectively, and as described in detail by Lengyel *et al.* (2018).

The main pieces of equipment used in these tests are presented in Figs.1-4.

Fig. 1.
Spectrophotometer for the determination of the formaldehyde emission by the flask method.

Fig. 2.
NUVE-BS402 equipment used for the determination of the swelling in thickness after water immersion of the tested particleboards.

Fig. 3.
Experimental set-up with inclined support and dropping pipette, for the determination of the surface absorption.

Fig. 4.
IMAL IB600 equipment used for the determination of the mechanical properties of the tested particleboards.

RESULTS AND DISCUSSION

The results concerning the influence of the additive amount upon the selected properties of particleboards with different thicknesses, as compared to the reference values obtained for PB with normal density and reduced density without additive, are presented in Table 3.

Table 3

Influence of the isocyanate-based additive amount upon some selected properties of particleboards with different thicknesses (mean values and standard deviations)

Panel thickness	F_v, mg/kg	G_t, %	A_s, mm	f_m, N/mm^2	E_m, N/mm^2	f_{t1}, N/mm^2
Particleboards with normal density, no additive						
8 mm	816,2 (20,2)	6,90 (1,51)	41,67 (4,94)	14,97 (1,20)	2338,23 (132,63)	0,43 (0,07)
18 mm	684,2 (12,8)	8,84 (0,61)	37,22 (1,65)	13,71 (1,03)	2653,94 (154,28)	0,39 (0,03)
28 mm	729,7 (16,3)	9,13 (1,24)	34,62 (2,11)	13,12 (0,32)	2433,58 (29,45)	0,35 (0,02)
Particleboards with reduced density, no additive						
8 mm	1095,1 (32,4)	7,71 (2,21)	46,18 (7,19)	11,68 (0,35)	1995,72 (82,29)	0,28 (0,04)
18 mm	1028,5 (34,2)	10,43 (1,13)	47,75 (3,91)	10,37 (0,90)	2164,10 (81,93)	0,24 (0,03)
28 mm	1061,6 (28,2)	10,83 (0,46)	46,72 (3,36)	8,84 (0,45)	2251,82 (100,52)	0,23 (0,02)
Particleboards with reduced density and 0.25% pMDI additive						
8 mm	684,8 (9,8)	5,34 (0,56)	58,44 (2,39)	13,84 (1,25)	1843,02 (124,86)	0,39 (0,06)
18 mm	601,53 (10,2)	7,57 (1,04)	49,49 (3,78)	12,48 (0,82)	2235,70 (156,22)	0,35 (0,04)
28 mm	569,26 (11,2)	8,42 (0,38)	48,32 (2,11)	12,29 (0,77)	2185,51 (107,87)	0,26 (0,03)
Particleboards with reduced density and 0.4% pMDI additive						
8 mm	701,9 (12,4)	4,35 (0,30)	46,30 (2,73)	14,86 (0,84)	1853,94 (94,07)	0,40 (0,05)
18 mm	626,57 (11,1)	5,56 (0,99)	37,55 (3,53)	12,82 (0,50)	2259,33 (55,56)	0,36 (0,02)
28 mm	612,42 (8,7)	7,85 (1,75)	38,01 (5,65)	12,70 (0,44)	2189,12 (47,79)	0,27 (0,02)

where: *F_v – formaldehyde emission (flask method); G_t – swelling in thickness; A_s – surface absorption; f_m – bending strength; E_m – modulus of elasticity in bending; f_{t1} – internal bond.*

Influence of the panel thickness

As one may notice, with increasing thickness, the formaldehyde emission tends to decrease. This is due to the fact that, with the flask method, the formaldehyde emission is measured in mg per 100g. Thus, 100g of 8mm thick panels involve a much greater surface than 100g of 28mm thick panels (Fig. 5), and implicitely, a higher amount of chips and adhesive. This is why the formaldehyde emission values of the thin panels are higher.

The swelling increases with increasing thickness. The swelling is mainly performed by the core layer (CL), which contains more air (as can be seen in Fig. 5). Considering that the surface layer (SL) has the same thickness for all panel thicknesses, a higher panel thickness actually means a higher core layer thickness, and thus, a higher swelling tendency.

The bending strength decreases with the panel thickness. This is mainly due to the higher density in case of the thinner panels (see Table 2), caused, as previously mentioned, by the lower volume at the same mass.

The internal cohesion is also better (higher) with the thinner panels. Beside the influence of the higher density, this is mainly due to the fact that the panel core reaches in a shorter time the temperature which is necessary for the chemical reaction which leads to the adhesive hardening.

Fig. 5.
Particleboards of 8mm and 28mm: surface difference at the same mass (100g); thicker core layer with thicker panels.

Thus, one may conclude that thick PB (28mm) have lower formaldehyde emission but also weaker physical and mechanical properties than thin (8mm) panels.

Influence of the density reduction by 7%

Particleboards with reduced density have much weaker properties than those with normal density (Fig. 6):

- up to 50.32% higher formaldehyde emission;
- up to 18.62% higher swelling and up to 34.95% higher surface absorption;
- up to 32.62% lower bending strength and up to 18.46% lower modulus of elasticity;
- up to 38.46% lower internal bond.

Consequently, this is not a viable alternative of optimisation. In order to improve the properties of PB with reduced density, the use of an additive in the composition recipe is absolutely necessary.

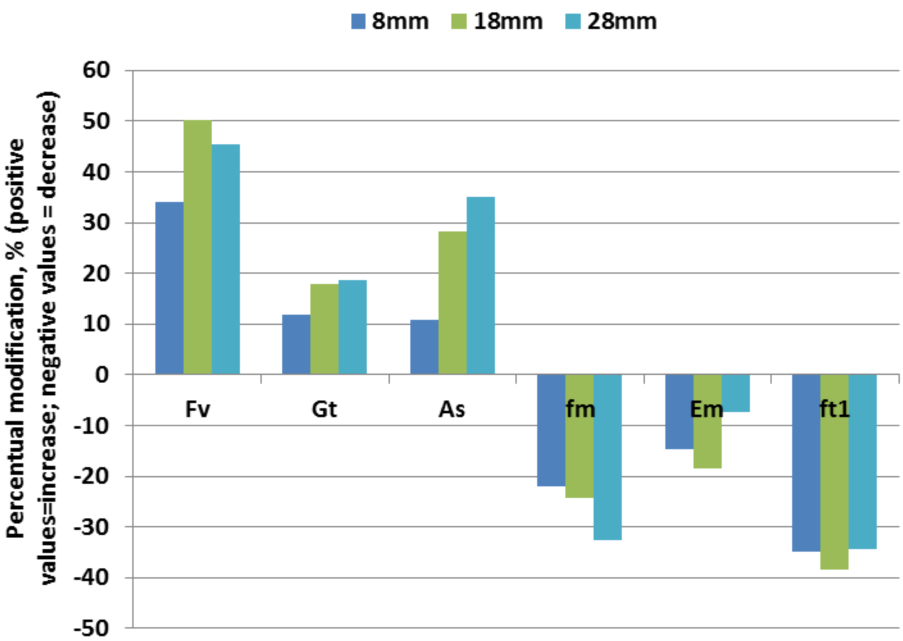

Fig. 6.
Percentual modification of physical and mechanical properties of PB with reduced density compared to PB with normal density.

Influence of the isocyanate-based additive

Indeed, by adding 0.25% pMDI into the recipe of PB with reduced density, the following property modifications were achieved compared to the particleboards with reduced density without additive (Fig. 7):

- the formaldehyde emission decreased by 37,47-46,38%;
- the swelling in thickness decreased by 22,25-30,74%;
- the surface absorption decreased by 3,42-4,89%;
- the bending strength increased by 18,49-39,03%;
- the modulus in elasticity decreased by 1,31-7,65%;
- the internal bond increased by 13,04-45,83%.

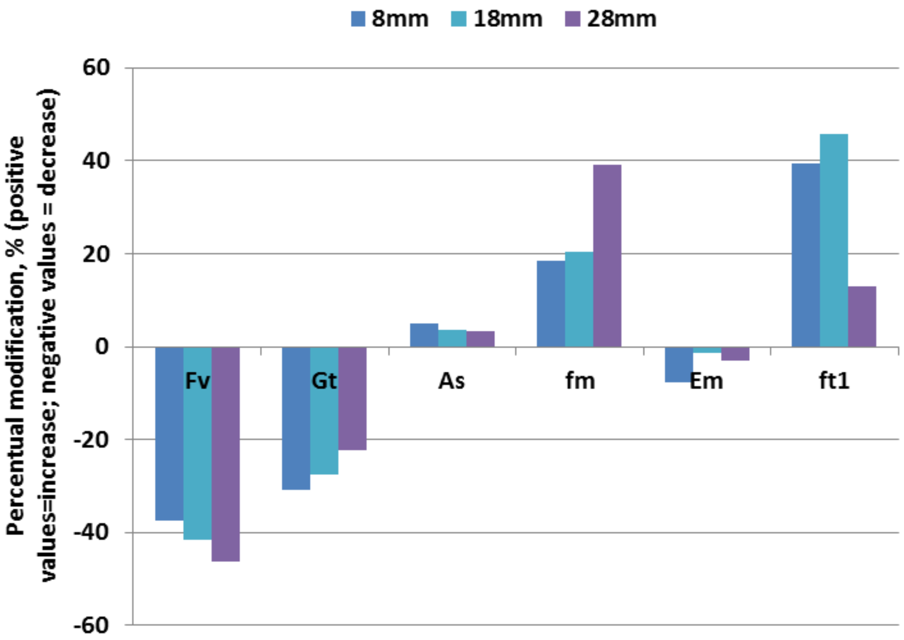

Fig. 7.
Percentual modification of physical and mechanical properties of PB with reduced density and 0,25% pMDI compared to PB with reduced density and no additive.

By increasing the percentage of isocyanate additive furthermore to 0,4%, the following property modifications were achieved compared to the particleboards with 0,25% additive (Fig. 8):
- the formaldehyde emission increased further by 2,50-7,58%;
- the swelling in thickness decreased further by 6,77-26,55%;
- the surface absorption decreased further by 4,42-24,13%;
- the bending strength increased further by 2,72-7,37%;
- the modulus of elasticity increased further by 0,16-5,79%;
- the internal bond increased further by 2,56-3,84%.

As one may notice, the property improvements when increasing the pMDI amount from 0,25% to 0,4% are significant only in the case of swelling and surface absorption. For the mechanical properties, the increases are modest, while the formaldehyde emission increases by more than 7%. The fact that no other significant benefits (especially in bending) are brought by the additional additive amount, the variant with 0,4% additive is considered to be less efficient than the one with 0,25%.

CONCLUSIONS

The conclusions of the present research can be formulated as follows:
1. The swelling of PB increases with increasing thickness.
2. The bending strength and internal cohesion of PB decreases with increasing thickness.
3. The simple density reduction of particleboards is not a viable alternative because all properties are seriously affected; an additive is compulsorily required.
4. The addition of a pMDI isocyanate additive in the composition recipe of particleboards with reduced density leads to a significant improvement of all physical and mechanical properties.
5. Compared to normal density boards, the variant with 0,25% pMDI brings simultaneous decrease by 4,04-7,39% of the density and by 12,08-21,99% of the formaldehyde emission, An other advantage is the decrease by 7,78-22,61% of the swelling in thickness. The mechanical properties decrease (by ca. 7% the bending strength, by ca. 15% the modulus of elasticity and by ca. 15% the internal bond), but they still remain above the standard limits.

6. The increase of the pMDI additive amount up to 0,4% does not bring any further significant improvements, but it increases the product costs. Therefore, the addition of 0,25% pMDI has been found as being the optimum one.

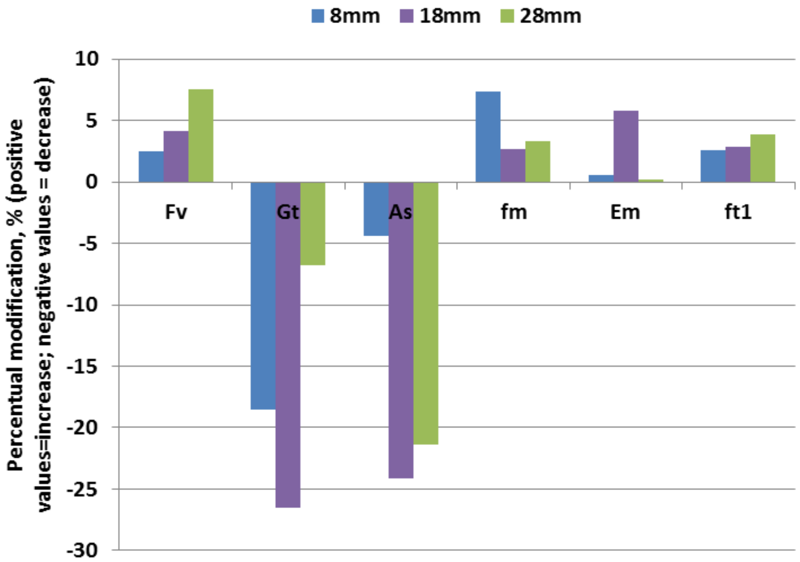

Fig. 8.
Percentual modification of physical and mechanical properties of PB with reduced density and 0,4% pMDI compared to PB with reduced density and 0,25% pMDI.

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