Colour alterations in hydrothermally recycled particleboards [1]

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ABSTRACT

The particleboard waste constitutes in our days an important part of urban waste stream. The management of such waste already troubles the modern societies. Nevertheless, via recycling it is possible for this material to constitute a valuable resource for the production of new wood based panels thus helping on one part in the partial satisfaction of increased needs for wood and on the other part in the restriction of problems caused by these materials when they are landfilled. The modern particleboard recycling processes include hydrothermal treatments which besides their advantages could involve colour alteration of the recycled boards compared to the original ones. The aim of the present paper was to study the effect of hydrothermal recycling parameters and the effect of various mixing proportions of old particleboard recovered and fresh material on the colour of the produced boards.

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The results showed that different combinations of recycling parameters (temperature, water impregnation and duration) induced significant differences to the colour of the hydrothermally recycled boards. Hydrothermal recycling of particleboards made of fresh material as well as particleboards made of old particleboard recovered material resulted in statistically significant reduction of lightness (colour coordinate L*) as well as statistically significant increase of redness (colour coordinate a*) and yellowness (colour coordinate b*) of the produced boards. In both cases the colour differences (ΔE*) were perceptible by the human eye. Moreover, the substitution of fresh wood particles at rates between 50 and 100% by hydrothermally recovered ones caused statistically significant reduction of lightness (L* colour coordinate) as well as statistically significant increase of redness (colour coordinate a*) and yellowness (colour coordinate b*) of the produced boards but at rates up to 50% did not cause perceptible by the human eye colour differences (ΔE*).

Keywords: colour, hydrothermal treatment, recycling, particleboard

1 INTRODUCTION

The particleboard waste constitutes in our days an important part of urban waste stream. The management of such waste already troubles the modern societies. Nevertheless, via recycling it is possible for this material to constitute a valuable resource for the production of new wood based panels thus helping on one part in the partial satisfaction of increased needs for wood and on the other part in the restriction of problems caused by these materials when they are landfilled.

The wood based panel industries are continuously trying to improve their efforts to use recovered wood in the construction of new wood products (EPF 2002). A few years ago, particleboard recycling which did not involve major economical and technical disadvantages seemed impossible. Nowadays there are some new particleboard recycling methodologies available, which include hydrothermal treatments (Boehme and Michanickl 1998, Roffael 2002, Riddiough and Kearley 2001, Alpar *et al.* 2007, Lykidis and Grigoriou 2008). The development of such methods is based on the susceptibility of particleboards. when they are exposed to water and heat. The recovery methods which involve hydrothermal treatments present the advantage that the recovered wood particles carry residual resin which could be partly reactivated resulting in better mechanical properties and/or lower binder consumption in the recycled boards (Nakos and Roffael 1998). The recycled boards also show reduced hygroscopicity and reduced free formaldehyde content (Roffael and Franke 1995, Michanickl 1996A, Lykidis and Grigoriou 2008).

On the other hand, one of the main drawbacks of the hydrothermal recycling of particleboards is the colour alteration of the wood. Among other properties, wood colour is altered when exposed to heat. This has been found by many researchers (McGinnes and Rosen 1984, Tolvaj and Faix 1996, Voulgaridis *et al.* 1997, Mitsui *et al.* 2001, Sundqvist *et al.* 2006, Tolvaj *et al.* 2008). Some researchers have suggested the use wood colour changes as an indication of its thermal modification. (Bekhta and Niemz 2003).

Lightness, or coordinate L* according to CIE Lab colour system, seems to describe better the degree of thermal modification because it is reduced after hydrothermal treatments of wood (Tolvaj and Faix 1996, Sundqvist *et al.* 2006). In particular, lightness is affected by temperature, the initial water content and the duration of the treatment. (Chen and Workman 1980). Additionally it has been noted that lightness changes are more intense during the first 60min of treatment, thus they are milder in the next hours of the treatment.

Aim of the present paper was the colour determination of hydrothermally recycled particleboards using various recovery parameters. Also investigated was the effect that the percentage of the recovered particles (derived from old particleboards) has on the colour of particleboards made of fresh raw materials.

2 EXPERIMENTAL METHODS

The research was carried out in 3 phases, the first two of which aimed at finding out the optimal conditions for the recovery of wood particles from industrial particleboards. The 1st phase of research was carried out in order to roughly estimate the efficiency of various recovery conditions (temperatures, water impregnation and duration) using as criterion the quality of the recovered material. From the 1st phase, 7 groups of recovery conditions were distinguished: 1) 30%/ 150°C/ 20min, 2) 45%/ 110°C/ 75min, 3) 45%/ 130°C/ 20min, 4)

45%/ 150°C/ 10min, 5) 60%/ 110°C/ 30min, 6) 60%/ 130°C/ 10min and 7) 60%/ 150°C/ 8min. These conditions were applied in the 2nd phase, in which 7 types of recycled particleboards were produced from the recovered materials and their colour was determined. All 7 types of laboratory boards were produced with a commercial urea-formaldehyde resin (E2 class) at a rate of 12% (per dry wood weight) for the surface and 8% (per dry wood weight) for the core layers. A commercial ammonium chloride hardener was also used at a rate of 2% (per dry resin weight). The mean density of each of the produced boards was 0,68g/cm^3 and their thickness was 12mm. The hot pressing conditions were: temperature of 185°C, maximum pressure of 25Kp/cm^2 and total hot pressing duration of 240s. The surface layers were produced by particles that passed through a 1,5mm sieve while the core layers were produced by the particles that did not pass through the same sieve.

Moreover, based on the mechanical and hydroscopic properties as well as the formaldehyde content of the recycled laboratory boards, the optimal of the 7 different recycling methodologies was assessed. The optimal recovery conditions that finally resulted included particleboard impregnation with water (45% retention) followed by 10min of hydrothermal treatment with saturated steam at a temperature of 150°C. These conditions were applied in the 3rd research phase for the recovery of raw materials from particleboards derived from old wooden constructions (Fig. 1) and their utilization in the production of new (recycled) particleboards. The recovered laminates were crushed and mixed in the core layers of the laboratory boards.

Figure 1: Particleboard samples after the hydrothermal treatment

Using the above raw materials as well as fresh wood particles supplied by a particleboard industry, 5 types of laboratory boards were produced as shown in Table 1. The production methodology of the laboratory boards was the same used in the 2nd phase.

Table 1: Types of laboratory particleboards produced in the 3rd research phase

Board Type	Description
100	Particleboards made of 100% recovered particles
50	Particleboards made of 50% recovered and 50% fresh wood particles
0	Particleboards made of 100% fresh wood particles
0A	Recycling of type 0 boards
100A	Recycling of type100 boards

The colour of the board surfaces was determined using a MiniScan XE Plus spectrophotometer based on a D65 light source. Colour coordinates L*, a* and b* were determined according to CIE Lab colour system. Coordinate L* values range between 0 and 100 and represent the colour lightness of the examined particleboard. Lightness values equal to 0 correspond to absolute black while values equal to 100 correspond to absolute white colour. Colour coordinate a* values range between -100 and +100 and represent the redness (positive values) or the greenness (negative values) of the colour. Finally, colour coordinate b* values range between -100 and +100 and represent the yellowness (positive values) or blueness (negative values) of the colour.

The total colour differences (ΔE^*) were calculated using the following equation:

$$\Delta E^* = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{1/2} \quad (1)$$

Where ΔL^*, Δa^* and Δb^*: The changes of the colour coordinates L*, a* and b* respectively. According to the above equation, low ΔE^* values correspond to low colour differences (Oltean *et al.* 2008).

3 RESULTS AND DISCUSSION

Table 2 shows the values of the three colour coordinates (L*, a* and b*) of the laboratory particleboards produced in the 2nd research phase. According to the referred Table it was found that, among the 7 types of recycled particleboards, the milder hydrothermal treatment parameters (group 5) showed the highest lightness (L*= 60,72) as well as the lowest redness (a*= 6,189) and yellowness (b*= 20,705) values compared to the other recovery parameters. The above mentioned differences were found to be statistically significant.

Table 2: Colour coordinate values (L*, a* and b*) of the laboratory particleboards produced in the 2nd research phase

Board Type (recovery parameters)		L* (Lightness)	a* (Redness)	b* (Yellowness)
1 (30%/ 150°C/ 20min)	**mean**	52,388	8,348	24,094
	min	50,140	7,540	22,280
	max	55,270	9,220	25,610
	(s)	1,17922	0,36974	0,77257
	n[a]	48	48	48
2 (45%/ 110°C/ 75min)	**mean**	57,293	7,041	22,525
	min	52,680	6,240	20,450
	max	59,900	7,950	24,110
	(s)	1,36537	0,37661	0,90875
	n	48	48	48
3 (45%/ 130°C/ 20min)	**mean**	58,247	6,741	22,270
	min	55,680	6,060	20,640
	max	61,010	7,770	24,120
	(s)	1,35182	0,39015	0,93381
	n	48	48	48
4 (45%/ 150°C/ 10min)	**mean**	56,399	7,076	22,725
	min	52,920	6,080	21,040
	max	58,870	8,400	24,640
	(s)	1,38250	0,43609	0,74042
	n	48	48	48
5 (60%/ 110°C/ 30min)	**mean**	60,720	6,189	20,705
	min	58,490	5,120	19,100
	max	65,830	7,200	23,220
	(s)	1,66620	0,50926	0,91922
	n	48	48	48
6 (60%/ 130°C/ 10min)	**mean**	59,250	6,480	21,349
	min	57,010	5,840	19,810
	max	61,930	7,480	22,830
	(s)	1,37898	0,38354	0,77742
	n	48	48	48
7 (60%/ 150°C/ 8min)	**mean**	56,466	7,160	22,172
	min	53,240	6,450	20,810
	max	59,490	7,880	23,700
	(s)	1,38767	0,35976	0,70902
	n	48	48	48

[a]*Number of measurements*

In contrast to the above, the lowest lightness as well as the highest redness and yellowness values was shown by the boards of type 1 (30%/ 150°C/ 20min). Types 4 and 7 showed (after type 5) the highest lightness without any statistically significant differences among them. Additionally, hydrothermal treatments of rising temperatures resulted (except type 2) in reduced lightness of the recycled boards, a finding which agrees with the results reported by Roffael and Schaller (1971).

Table 3 presents the values of the colour coordinates L*, a*, και b* of the board produced in the 3rd research phase.

Table 3: Colour coordinate values of the laboratory particleboards produced in the 3rd research phase

		100	**50**	**0**	**0A**	**100A**
L* (Lightness)	**mean**	55,89	57,23	58,88	51,11	51,45
	max	57,04	57,97	60,76	51,77	52,48
	min	54,92	55,30	55,97	49,99	50,01
	(s)	0,5465	0,6548	1,1028	0,4754	0,4925
	n	24	24	24	24	24
a* (Redness)	**mean**	7,62	7,61	7,21	8,98	9,09
	max	8,36	8,56	8,30	9,93	9,81
	min	4,46	7,03	6,39	8,45	8,51
	(s)	0,7758	0,3888	0,5005	0,3929	0,3353
	n	24	24	24	24	24
b* (Yellowness)	**mean**	25,29	24,99	24,49	26,15	26,15
	max	26,24	25,77	26,02	27,41	27,21
	min	24,17	23,97	23,51	25,07	24,81
	(s)	0,6089	0,5238	0,5735	0,5780	0,5675
	n	24	24	24	24	24

As can be seen in Fig. 3, replacement of fresh wood particles at rates of 50% and 100% by particles recovered from old particleboards resulted to statistically significant reduction of lightness (colour coordinate L*) from 58,88 (control value) to 57,23 and 55,89 respectively.

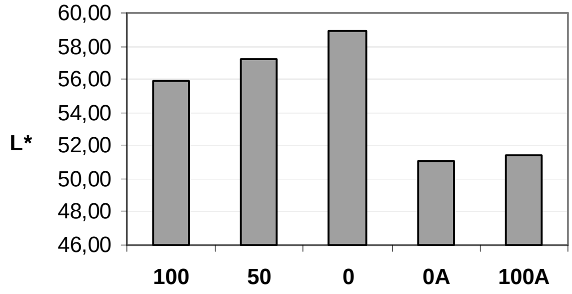

Figure 3: Effect of the recovered wood percentage and of the recycling on the lightness of the laboratory boards

In addition, the recycling of boards made of fresh wood particles (comparison between 0 and 0A) as well as the recycling of boards made of particles recovered from old particleboards (comparison between 100 and 100A) resulted in lightness reduction since the L* values decreased in the case of fresh particles from 58,88 to 51,11 and in the case of recovered particles from 55,89 to 51,45. The above differences were all statistically significant. The above results are in accordance with findings reported by Chen and Workman (1980), Tolvaj and Faix (1996) and Sundqvist *et al.* (2006).

Comparison of particleboard types 0A and 100A showed no statistically significant differences concerning colour coordinate L*.

According to the results shown in Fig. 4 the substitution of fresh wood particles at rates of 50% and 100% by particles recovered from old particleboards, resulted in a statistically significant increase of redness (colour coordinate a*) from 7,12 (control value) to 7,61 and 7,62 respectively. The above mentioned differences were found to be statistically significant. Comparison of the laboratory board types 50 and 100 showed no statistically significant difference in redness.

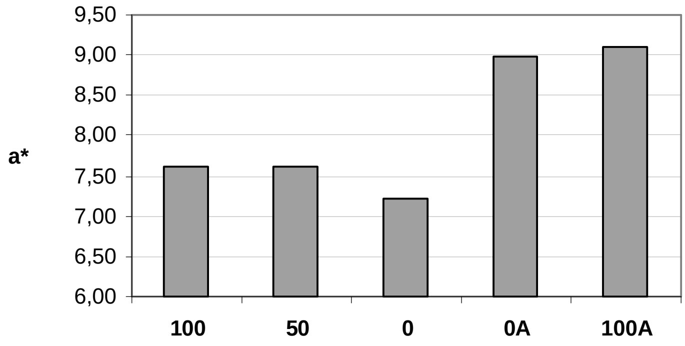

Figure 4: Effect of the recovered wood percentage and of the recycling on the values of redness of the laboratory boards

Moreover, the recycling of particleboards made of fresh wood particles (comparison between 0 and 0A) as well as of particles recovered from old particleboards (comparison between 100 and 100A) resulted in an increase of colour coordinate a* in the case of particleboards made by fresh wood particles from 7,21 to 8,98 (types 0 and 0A) and in the case of particleboards made by wood particles recovered from old particleboards from 7,62 to 9,09 (types 100 and 100A). All of the referred differences were found to be statistically significant.

Comparison of particleboard types 0A and 100A showed no statistically significant differences concerning colour coordinate a*.

According to the results shown in Fig. 5 the substitution of fresh wood particles at rates of 50% and 100% by particles recovered from old particleboards resulted in an increase of yellowness (colour coordinate b*) from 24,49 (control value) to 24,99 and 25,29 respectively. The above mentioned differences were found to be statistically significant. Comparison of the laboratory board types 50 and 100 showed no statistically significant difference in yellowness.

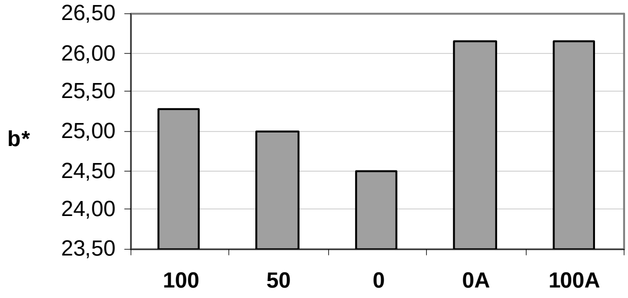

Figure 5: Effect of the recovered wood percentage and of the recycling on the values of yellowness of the laboratory boards

Moreover, the recycling of particleboards made of fresh wood particles (comparison between 0 and 0A) as well as of particles recovered from old particleboards (comparison between 100 and 100A) resulted in an increase of colour coordinate b* in the case of particleboards made of fresh wood particles from 24,49 to 26,15 (types 0 and 0A) and in the case of particleboards made of wood particles recovered from old particleboards from 25,29 to 26,15 (types 100 and 100A). Both of the referred differences were found to be statistically significant.

Comparison of particleboard types 0A and 100A showed no statistically significant differences concerning colour coordinate b*.

Table 4 presents the colour differences among the laboratory boards compared to type 0 (control board) and Table 5 shows the colour differences between board types 100 and 100A.

Table 4: Colour differences of laboratory boards compared to control board (type 0)

		0	**50**	**100**	**0A**
ΔE*	**mean**	0,00	1,87	3,28	8,16
	n	24	24	24	24

Table 5: Colour differences between the laboratory boards of type 100 and 100A

		100	**100A**
ΔE*	**mean**	0,00	4,81
	n	24	24

As can be seen from Table 4 the substitution of fresh wood particles (control boards) at rates of 50% (type 50) and 100% (type 100) by particles recovered from old particleboards resulted in colour alteration (ΔE* value) of 1,87 and 3,28 respectively. The same Table shows that the recycling of particleboards made of fresh wood particleboards resulted in colour difference (ΔE* value) of 8,16. From Table 5 it is obvious that the recycling of particleboards made of material recovered from old particleboards resulted in colour difference (ΔE* value) of 4,81.

According to Sundqvist and Moren (2002), colour differences (ΔE* values) greater than 2-3 units are perceptible by the human eye. Based on this statement, the substitution of fresh wood particles at a rate of 50% by particles recovered from old particleboards (comparison of control board to board type 50) resulted in colour differences (ΔE* values) not perceptible by the human eye. On the other hand, perceptible by the human eye colour differences occur when fresh wood particles are fully substituted by particles recovered from old particleboards (comparison of control board to board type 100), as well as in the case of recycling board type 0 (comparison of 0 and 0A) and board type 100 (comparison of types 100 and 100A).

4 CONCLUSIONS

Based on this study, the following conclusions can be drawn:

- Among the 7 hydrothermal recovery processes tested, the milder hydrothermal treatment parameters (water retention after impregnation of 60%, temperature of 110°C and duration of 30min) resulted in boards with the highest lightness as well as the lowest redness and yellowness values.

- The application of the recovery parameters of 45%/ 150°C/ 10min, which was found to be the most advantageous regarding the properties of the recycled boards, caused to the boards the following colour alterations:

1) Replacement of fresh wood particles at rates of 50% and 100% by particles recovered from old particleboards resulted in significant alteration of the colour lightness, redness and yellowness, while substitution at rates up to 50% did not cause to the boards colour differences perceptible by the human eye.

2) The recycling of particleboards made of material recovered from old particleboards as well as the recycling of particleboards made of fresh material resulted in perceptible by the human eye colour differences.

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