ASSESMENT OF HYDROTHERMAL RECOVERY PARAMETERS ON THE QUALITY OF RECOVERED PARTICLES AND RECYCLED PARTICLEBOARDS

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Abstract

The growing need for wood combined with the global uprising of wood and petroleum prices as well as the need to protect forests are factors which -among others- are applying pressure on the sector of wood based panel industries in their pursuit of raw materials. Recycling of particleboards and fiberboards contained in municipal waste could contribute to face the above as well as the environmental problems occurring due to landfilling of such waste. Hydrothermal recovery processes currently represent a group of the most efficient methods to re-gain wood from particleboards and fiberboards. Nevertheless, the use of hydrothermal treatments without any impregnation of waste particleboards, leads to the production of recycled boards with significantly inferior quality compared with that of original ones.

This paper deals with the results of research that has been carried out in order to investigate the impact of various hydrothermal recovery processes on the quality of the recovered wood particles as well as the recycled boards.

The results showed that the water uptake of the particleboards prior to hydrothermal treatment could affect the quality of the recovered particles as well as the recycled particleboards. The internal bond and other technical properties of the recycled boards could be significantly improved when water impregnation of the used boards prior to the hydrothermal treatment is introduced and also when the uptake is increased to values higher than 30%. This improvement obviously derives from the reduction of the particle clustering effect. The optimum (among those tested in this investigation) hydrothermal recovery parameters were 45% water retention, 150°C temperature, 10min duration. A significant reduction of free formaldehyde content of the recycled boards was also noted.

Key words: particleboards, recycling, hydrothermal treatments, water impregnation.

Introduction

It has been broadly acknowledged that over the last years the global need for wood is rising, following the trends of population, while on the same time contributing to an accelerated pace of forest clearance (FAO 2010, FAO 2011). At the same time, the interest in bioenergy is also increasing partly due to the potential of reducing greenhouse gas emissions (Gielen et al. 2001) but also due to growing oil prices as well as the finiteness of fossil energy sources, thus contributing to higher wood consumption rates and consequently to higher wood prices. Given the constant increase of population, the growing need for wood products is probably going to provoke further price uprising as well as increasing pressure on the forest ecosystems for harvesting of wood.

The above circumstances currently constitute a challenge for wood based panel industries in their pursuit of raw materials which could be faced by utilizing used wood based panels. Such waste is not recommended to be used as fuel, due to the presence of adhesives, coatings and other additives which could emit hazardous substances if incomplete combustion occurs (Risholm-Sundman and Vestin 2005). At the same time, utilizing of such waste could also contribute to reducing the volume of landfilled waste and the implications which are connected to such practices.

Recycling of used wood composites has been carried out for some years (Sandberg 1965). Improved recycling methods usually involve hydrothermal treatments, which contribute to the decomposing of the cured resin of the particleboards, thus facilitating the efficient detachment of the wood particles. There are some researchers who have already developed such recycling methods, some of which are currently used by industries (Michanickl 1996, Riddiough and Kearley 2001, Roffael 2002).

Our first attempts to hydrothermally recover wood particles from used particleboards were carried out using saturated steam at temperatures in the range of 120-170°C and durations of 20 to 480min (Lykidis and Grigoriou 2008). All treatments were carried out without involving any impregnation step throughout the process. In most cases, the recovered material contained clustered particles which influenced the quality of recycled boards negatively with regard to most technical properties.

This paper presents the results of research carried out in order to face the clustering effect of the hydrothermally recovered particles using and evaluating combinations of new recovery parameters along with milder hydrothermal treatments in the range of 110 to 150°C.

Materials and Methods

This research consisted of an initial rough assessment that was carried out in order to evaluate the effect of various recovery parameters such as the application of vacuum and water impregnation as well as repeated treatment cycles combined with hydrothermal treatments at temperatures of 110 to 150°C.

Each combination of treatment parameters of the above preliminary research was replicated for 4 different durations, resulting to a total of 144 combinations. The efficiency of the above tested combinations was assessed measuring the quantity of particle clusters contained in the recovered material. The treatments which resulted to a cluster percentage of lower than 10% were finally accepted and a more detailed assessment was carried out in the next phase utilizing them for the production and quality assessment of recycled boards. From the above assessment, 7 combinations of recovery parameters resulted to particle clustering of less than 10%. These parameters were subsequently used in order to recover wood particles from commercially produced particleboards and use them in the laboratory production of recycled ones. The laboratory produced boards comprised of three layers with surface to core layer weight ratio of 40:60, nominal thickness of 12mm and density of 0.68 g/cm^3. The adhesive used was a E2 class commercial urea-formaldehyde resin sprayed at a rate of 8% per dry particle mass for the core and 12% for the surface layers. The hardener used was ammonium chloride at a dry weight ratio of 2% (per dry resin weight). The hot pressing temperature was 185°C and the total pressing duration was 240s.

For each of the seven groups of recovery parameters applied, the moisture content and the proportions of clustered particles present in the recovered material were determined according to the formula: $C_p = m_c/m_p$, where C_p is the percentage of dry particle agglomerations present in the dry mass of hydrothermally treated particleboards (%), m_c is the dry mass of particle agglomerations present in the recovered material (g) and m_p is the dry mass of hydrothermally treated particleboards (g). In addition to the above, mechanical (internal bond, surface soundness, modulus of rupture and modulus of elasticity in static bending), hygroscopic (thickness swelling and water adsorption) properties as well as free formaldehyde content of the recycled particleboards were determined according to the related European Norms.

Results

From the above assessment, it was found that the use of vacuum treatment and 2nd treatment cycles did not have a beneficial effect in terms of clustering of the recovered particles. The impregnation of boards with water prior to hydrothermal treatment significantly improved the efficiency of the recovery process. In more detail, it was found that seven groups of the tested recovery parameters resulted to clustering of less than 10% and were as follows (water gain / temperature / time): 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). The moisture content and clustering effect for each of the 7 types of recovered materials is presented in Table 1. As can be seen in the above Table, the increase of hydrothermal treatment temperature within the tested range contributes to the reduction of clustering of the recovered particles. The same effect appears by the water gain increase of the specimens prior to the hydrothermal treatment. Among all tested parameters, the lowest clustering effect was measured for the recovery parameters 45%/ 130°C/ 20min, 45%/ 150°C/ 10min and 60%/ 150°C/ 8min.

Tab.1: *Moisture content and clustering effect of the recovered particles*

Recovery Parameter*		**Moisture content of the recovered material**	**Cluster ratio in the recovered material**
		(%)	(%)
1	30%/ 150°C/ 20min	37.5	9.14%
2	45%/ 110°C/ 75min	69.4	4.97%
3	45%/ 130°C/ 20min	68.8	1.45%
4	45%/ 150°C/ 10min	70.3	0.57%
5	60%/ 110°C/ 30min	85.6	3.34%
6	60%/ 130°C/ 10min	83.8	1.84%
7	60%/ 150°C/ 8min	83.6	1.46%

*: Water gain/temperature/duration

The properties of the recycled boards produced with the recovered particles using the above 7 recovery parameters are presented in Table 2. It is obvious that the water uptake of the particleboards prior to hydrothermal treatment affects, along with the quality of the recovered particles, also the quality of recycled particleboards. The internal bond (IB) of the recycled boards presented significant improvement when the water uptake prior to the hydrothermal treatment was increased to values higher than 30%. This improvement obviously derived from the reduction of the particle clustering effect. This assumption is also based upon the high correlation coefficient (R^2=0.70) between cluster percentage and IB values of the recycled boards. On the contrary, the other determined properties did not show significant correlations to the cluster percentage. The improvement of IB in boards produced after recovery of particles utilizing water impregnation of used boards has also been reported in other works (Michanickl and Boehme 1996).

The comparison of the 7 types of recycled boards showed that those produced utilising recovery parameters no. 4 along with those of recovery parameters no. 3, no. 5 and no. 7 showed the highest IB values. With regard to the surface soundness (SS), recovery parameters no. 4 along with no. 3 and no. 7 resulted in the highest values of recycled boards. Regarding the modulus of elasticity (MOR) and the modulus of rupture (MOE) in bending, the boards that were produced utilising the recovery parameters no. 4 together with no. 1, and no. 7 showed the highest values. Concerning the thickness swelling (TS) and water absorption (WA) of the recycled boards, parameters no. 4 as well as no. 3, no. 6 and no. 7 showed the best quality.

***Tab2**: Values of determined properties of the recycled boards and correlation to the clustering effect of the recovered particles*

Type	Recovery Parameter	DENSITY	IB	SS	MOR	MOE	TS	WA	FC
		(g/cm^3)	(N/mm^2)	(N/mm^2)	(N/mm^2)	(N/mm^2)	(%)	(%)	(mg/100g)
1	30%/150°C/ 20min	0.69[1]	0.38	0.87	13.53	2687	21.80	80.05	3,68
		(0.035)[2]	(0.108)	(0.163)	(1.615)	(251.9)	(0.026)	(0.056)	
2	45%/110°C/ 75min	0.68	0.43	0.90	12.95	2248	20.83	84.39	9,92
		(0.033)	(0.058)	(0.101)	(1.178)	(192.5)	(0.011)	(0.068)	
3	45%/130°C/ 20min	0.70	0.53	0.98	13.46	2340	20.30	81.44	10,75
		(0.028)	(0.044)	(0.104)	(1.532)	(144.3)	(0.012)	(0.040)	
4	45%/150°C/ 10min	0.69	0.54	0.99	14.16	2535	19.64	79.77	6,15
		(0.029)	(0.032)	(0.124)	(1.430)	(281.1)	(0.015)	(0.041)	
5	60%/110°C/ 30min	0.69	0.54	0.70	9.21	1783	23.99	86.32	14,40
		(0.028)	(0.068)	(0.072)	(0.942)	(147.1)	(0.016)	(0.046)	
6	60%/130°C/ 10min	0.69	0.46	0.95	12.83	2344	19.86	83.13	12,64
		(0.025)	(0.051)	(0.093)	(1.325)	(161.6)	(0.013)	(0.045)	
7	60%/150°C/ 8min	0.69	0.54	1.02	13.92	2448	19.37	79.90	7,56
		(0.035)	(0.069)	(0.120)	(1.342)	(164.0)	(0.018)	(0.043)	
	n	60	18	36	15	15	18	18	3
Correlation coefficient (R^2) of property to cluster percentage		-	0.70	-	0.01	0.05	0.24	0.01	-

[1]: Arithmetic mean

[2]: Standard deviation

Concerning free formaldehyde content (FC), laboratory boards corresponding to parameters no. 4 along with parameters no. 1 and 7 showed the lowest values. It is also noteworthy that these formaldehyde content values correspond to E1 class, although the recycled boards were produced using E2 urea–formaldehyde adhesive. Similar findings have also been reported in other studies (Michanickl 1996, Lykidis and Grigoriou 2008) and are attributed to the presence of urea and other derivatives of hardened urea–formaldehyde degradation, such as dimethyl-urea (Roffael and Kraft 2005). It is likely that higher temperature treatments lead to increased adhesive degradation of the recovered boards and therefore promote the production of degradation derivatives which are activated during the production of recycled particleboards and act as scavengers (catchers) of the excess formaldehyde.

Conclusion

From the above discussed results the following conclusions can be drawn: In a previous research it was reported that particleboards produced from steam-recovered wood particles without any added treatment showed a quality inferior to that of particleboards made from original particles.

The introduction of water impregnation of the boards prior to hydrothermal recovery could be beneficial in terms of quality both of the recovered material and the recycled particleboards but also in terms of reduction of treatment duration. In terms of the quality of recycled boards, the optimum (among those tested in this investigation) hydrothermal recovery parameters were 45% water retention/150°C temperature/10 min duration.

The same recovery parameters (45% water retention/150°C temperature/10 min duration) resulted to the lowest clustering effect of the recovered material.

It was also noteworthy that some of the recycled boards performed as E1 class boards, although they were produced using E2 urea–formaldehyde adhesive. This fact can be attributed to the derivatives of resin degradation, which act as formaldehyde scavengers.

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