WASTE AGGLOMERATED WOOD MATERIALS AS A SECONDARY RAW MATERIAL FOR CHIPBOARDS AND FIBREBOARDS
PART II. PREPARATION AND CHARACTERISATION OF WOOD FIBRES IN TERMS OF THEIR REUSE

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ABSTRACT

The paper describes a process for the preparation of fibre from waste wood particleboards (PB), oriented strand chipboards (OSB) and middle density fibreboards (MDF). The purpose of recycling of agglomerated wood materials is to reuse them for the production of fibrous materials. The agglomerated materials disintegrated after the initial destruction were further processed under the specified conditions with respect to the moisture content, their type, adhesive used, and properties of final particles - wood chips. The obtained wood particles were characterized by the fractional composition of chips. The resulting chips were mechanically defibred with subsequent characterization of fiber obtained for its reuse in the manufacture of MDF. A quantity of formaldehyde released into the water when cooking waste MDFs and PBs was set up depending on the cooking time. Residual level of formaldehyde is the main chemical load that determines the amount of waste material that can be reused for production of new panels based on urea-formaldehyde adhesives.

KEY WORDS: Pulp, waste particleboards, oriented strand boards, middle density fibreboards, fraction of particles, formaldehyde.

INTRODUCTION

Waste wood-based materials from products at the end of their service life represent a significant amount of material to be valued in accordance with EC Waste Directive 2008/98. The construction, demolition and old furniture waste which contains a lot of wood based agglomerates (Boehme 2003, Lykidis and Grigoriou 2005) is one of the largest waste streams in the EU. New solutions must be found to achieve an efficient material recovery from wooden waste. Generally, the recycling of chemically modified wood waste must take into account a content of harmful obtained in wooden mass (Risholm-Sundman and Vestin 2005, Erbreich 2004).

Waste wood-based materials can be a secondary source of raw material for the production of fibre (Ihnat et al. 2017) similarly to other lignocellulosic materials (Mo et al. 2003, Ihnat et al., 2015a, b, Lubke et al. 2014, Wang and Sun 2002). In terms of their reuse, they can be used in the production of agglomerated materials and in the paper and packaging industry as well. However, the fibre of recycled wood materials has reduced functional properties (Wan et al. 2014). Major problem appears in urea-formaldehyde and melamine-urea-formaldehyde resins that make a wood particles' availability more difficult (Ihnat et al., 2017) and they are also the source of free formaldehyde release (Matyasovsky et al. 2017). Several studies have been carried out to recover wood from waste wood-based materials (Michanickl 1996, Riddiough 2002, Sandison 2002). From view of the initial destruction of waste materials, fibreboards are the easiest to re-defibre (Sandison 2002), and the simplest way, with regard to the chemical load involved, is to reuse them for wood-plastic materials (Chaharmahali 2008).
Thermo-mechanical fibre preparation is performed without chemicals. This method utilizes the lignin- saccharides complex property, that wood can be mechanically defibred under sufficient wood temperature and humidity. This so-called thermomechanical method according Asplund in the case of coniferous woods uses temperature of 175 °C and in case of deciduous woods temperature of 165 °C. When pulping under the conditions described the plastification of middle lamella of cell walls results in reduced energy consumption for the fibre preparation. Thus prepared fibres are used for a fibreboard production. Compared with the production of chemical pulp, the thermo-mechanical production brings considerable savings resulting from significantly better utilization of basic raw materials (95% yield) and lower operating costs. Another advantage is the fact that no exhalations are created and the production has a minimal environmental impact.

On the other hand chemically obtained fibre is characterized by higher quality (Illikainen 2008) as a fiber obtained mechanically. Kraft pulp from industrial wood waste was evaluated and compared with softwood (loblolly pine, Douglas-fir) and hardwood (aspen) pulp. The chemical method for obtaining the so-called semi-chemical pulp by the neutral sulphite cooking process is the best in terms of the quality of pulp obtained. The main components of the boiling solution are Na_2SO_3 and Na_2CO_3 (Keskin 1994, Lovelady 1991, Bierman 1996, Balbercak 1998). Using a mildly alkaline sulphur-free cooking technology, Na_2SO_3 is replaced with NaOH in the boiling solution (Balbercak 2002a, b, Lindström 2002).

MATERIAL AND METHODS

1) Preparation of wood fibre from waste PBs

Experimental investigation on waste PBs was provided for two different glue basis urea-formaldehyde (UF) and melamine-urea-formaldehyde (MUF).

a) based on UF resins

Waste PBs were cut into blocks sized 100 x 100 mm and were cooked in boiling water for 30 min to achieve at least 40 % relative humidity (Ihnat et al. 2017). Samples were disintegrated into chips using a Palmann drum chipper with oval-shaped longitudinal holes (5.5 mm x 54.1 mm). PBs were crushed with a surface foil. The distribution of the prepared chips was determined by laboratory screening after drying at 105 °C. The chips were dried and screened at semi-production facilities. Particles smaller than 2 mm were removed using a sieving. It can be stated that the surface film particles were removed in this step as well. The chips above 2 mm were heated in water at 80°C before grinding to achieve at least 45% relative humidity. The chips were defibred by a single pass through Sprout-Waldron. The fiber obtained was refined on the Valley holander gradually for 18, 40, 50, 70 min with an increasing degree of Schopper-Riegler at 13, 24, 28, 40 (°SR).

b) based on MUF resins

Waste PBs sized to 100 x 100 mm were cooked in water for 180 min. The cooked PBs were pressed using a pressure machine for an initial destruction and chipped on Palmann as in the previous case. The chipping was carried out with a surface foil and particles smaller than 2 mm were removed. Fiber was defibred on Sprout-Waldron and refined on the Valley holander as well.

2) Preparation of wood fibre from waste OSBs based on MUF resins

Pieces of OSB were cooked in water for 180 minutes. The cooked OSBs were then pressed for the initial destruction and then chipped and defibered similar as in the previous cases. The same devices were used.

3) Preparation of wood fibre from waste MDFs

Experimental investigation on waste MDFs was provided for both UF and MUF glue bases.

a) based on UF resins

Waste MDF was obtained from an old furniture. It was destructed on parts with edges not more than 5 cm. Parts of MDF were cooked with constant stirring in water for 3 min until achieved relative humidity at least 45%. The parts are defibred on the Sprout-Waldron at minimum temperature of 80°C.

b) based on MUF resins

Waste MDFs were cut into parts of 100 x 100 mm and cooked in water for 180 min. They were pressed for an initial destruction and chipped on Palmann. The chipping was carried out with a surface foil and particles smaller than 2 mm were removed. Fiber was defibred on Sprout-Waldron at min 80°C and refined on the Valley holander.

4) Preparation of comparative samples

Comparative fiber samples were obtained from the production of soft fiber-insulating panels with a bulk density of 250 $kg \cdot m^{-3}$ in a wet manner and also from overcooked old furniture

board from MDF. Overcooked board was centrifuged in a laboratory centrifuge and subsequently dried in a laboratory drier.

Fibre prepared according point 1-4 was characterized by Schopper-Riegler (°SR), fiber distribution, WRW (amount of water contained in wood), pH and dewaterability.

5) Determination of formaldehyde by HPLC

The HPLC (High Performance Liquid Chromatography) was used for wasted MDFs and PBs boiled in water before a chipping.

Waste MDFs were cut to samples of 10 x 20 mm and 50 x 50 mm. Samples were cooked separately for 3, 10, 30, 60, 120 and 180 minutes in 100 g and 200 g of water. Waste PBs were cut into samples of 10 x 20 mm, 50 x 50 mm and 100 x 100 mm. Samples were cooked separately for 30, 60, 120 and 180 minutes in 100 g and 200 g of water.

The HPLC system (CHROMSERVIS SK, Slovakia) with column H^+ (0.005N H_2SO_4 at 30^oC) was used to determine formaldehyde. Values of formaldehyde in individual samples were determined using the internal standard method.

RESULTS AND DISCUSSION

Characterisation of wood fibre obtained from waste PBs based on UF resins

The amount of 41.9 % of fine particles (1 mm and less) and a relatively large proportion of chips above 8 mm is included in the total composition after chipping on the chipper with oval-shaped longitudinal holes (5.5 mm x 54.1 mm) (Tab.1, sample 1). The amount of usable particles (2 mm and more) for the further fiber preparation is 58.1%. Surface film enhances the presence of fine particles.

Tab. 1: Composition of chips obtained from waste PB and OSB by cooking and subsequent chipping

Sieve / Sample	8 mm	4 mm	2 mm	1 mm	0,2 mm	Residue	Total
	(%)						
1	12.40	30.30	15.40	22.40	17.60	1.90	100 %
2	2.36	31.08	20.09	23.29	21.93	1.25	100 %
3	1.68	28.8	23.11	22.64	17.42	6.35	100 %
4	0.00	34.09	21.45	18.71	19.12	6.63	100 %

Notes:

Sample 1 - waste PB based on UF resin - 30 min cooking

Sample 2 - waste PB based on MUF resin - 180 min cooking

Sample 3 - waste OSB based on MUF resin - 180 min cooking

Sample 4 - waste MDF based on MUF resin - 180 min cooking

The obtained chips were defibred on Sprout-Waldron. Fiber obtained with 5°SR is insufficient for the preparation of MDFs (Tab. 2, sample 1) for a high proportion of fraction 16 (40 mesh) compared to the comparative sample.

Tab.2: Distribution and properties of the fibre obtained from the waste PBs and OSBs defibred on Sprout-Waldron.

Sample		**1**	**2**	**3**	**Comparative sample**
°SR		5	7	7	10
Dewaterability (sec.)	500ml	1.66	1.75	1.72	2.25
	700ml	2.60	2.71	2.81	3.05
	800ml	3.02	3.1	3.15	3.35
Brecht-Holl (%)	chips	0.000	0.000	0.000	4.243
	16 (mesh 40)	67.180	59.050	41.461	47.207
	50 (mesh 120)	18.820	28.485	41.949	24.295
	100 (mesh 240)	10.760	3.160	4.350	15.970
	above 100 (above mesh 240)	3.230	9.305	12.240	8.285

Notes:

Sample 1 *– waste PB based on UF resin – 30 min cooking*

Sample 2 *- waste PB based on MUF resin – 180 min cooking*

Sample 3 – waste OSB based on MUF resin – *180 min cooking*

Comparative sample *- overcooked MDF*

The obtained fiber characterized by 5 °SR was refined on the Valley holander. The fiber was refined gradually for 18, 40, 50 and 70 min with an increasing degree of °SR 13, 24, 28, 40 (Tab.3).

Tab.3: Distribution and properties of fibre obtained from the waste PBs based on UF resins defibred on Sprout-Waldron and refined on Valley holander

°SR		**40**	**28**	**24**	**13**
Refining time		70 min	50 min	40 min	18 min
Dewaterability (sec.)	500ml	19.47	14.25	12.46	2.47
	700ml	49.19	26.73	21.38	4.70
	800ml	74.92	38.66	28.00	9.50
Brecht-Holl (%)	16 (mesh 40)	4.175	20.150	25.900	42.520
	50 (mesh 120)	49.330	48.040	47.480	40.560
	100 (mesh 240)	19.490	16.120	13.470	10.130
	above 100 (above mesh 240)	26.805	15.730	13.150	6.790

As it is see from tab. 3 the fibre distribution for 13 °SR good matches with the comparative sample (tab. 2) in the amount of fraction 16 (mesh 40) with the higher value of the medium fiber 50 (mesh 120). Fine fractions are also in good compliance. The content of 4.2% of chips obtained by overcooking of the comparative MDF shows that the fibre has not been

completely separated. In the case of fibre obtained by the refining for 40 min, the main fraction representation is transferred from the rough fibre to middle values. The percentage of fine fiber is in good compliance with the comparative sample. Dewaterability rate increases with the loss of the rough fiber fraction. From the above mentioned it seems a possible to utilise in the range of 13 ^{o}SR to 24 ^{o}SR for the MDF production. Using fibre in the range of 28 ^{o}SR to 40 ^{o}SR would require more resins (26.8% of dust particles), therefore it would be uneconomic with worse physic-mechanical and ecological properties.

Characterisation of wood fibre obtained from waste PBs based on MUF resins

The composition of the chip after initial destruction by pressing and chipping (Tab.1, sample 2) has the 46.47 % percentage of fine particles below 2 mm. The amount of particles usable for the fiber preparation (above 2 mm) is approximately 53.53 %. Surface foil increases the presence of fine particles.

Fibre obtained after defibering at the Sprout-Waldron has a high 59 % representation of rough content mesh 40 (Tab.2, sample 2), which is 8% more than the comparative sample and very low the fine fiber content (mesh 240). Even in this case, the fibre is unsuitable for the intended further processing. For this reason, the fiber was further refined on Valley holander as in the previous case.

Tab.4: Distribution and properties of fibre obtained from the waste PBs based on MUF resins defibred on Sprout-Waldron and refined on Valley holander

^{o} SR		**40**	**28**	**24**	**13**
Refining time		70 min	50 min	40 min	18 min
Dewaterability (sec.)	500ml	25.97	12.17	10.29	2.40
	700ml	55.69	34.89	30.05	8.59
	800ml	81.42	57.25	50.80	13.76
Brecht-Holl (%)	16 (mesh 40)	3.533	13.590	16.850	46.235
	50 (mesh 120)	48.530	46.540	45.785	31.090
	100 (mesh 240)	15.180	12.200	14.520	12.325
	above 100 (above mesh 240)	32.757	27.670	22.845	10.350

The distribution of fiber produced at 13 ^{o}SR is in good compliance with the comparative sample. Growth ^{o}SR (increasing of the fineness) causes the 40 mesh decreases and increase of mesh 240 and above. Compared to fiber obtained from waste PBs bonded with UF resins, this fiber has the higher fine fiber content (above mesh 240) and lower fiber content of the rough fibre (mesh 40). This is apparently due to the greater brittleness of MUF resins compared to UF resins and a smaller swelling of chips coated with MUF resins. Only fiber refined at 13 ^{o}SR is suitable for the MDF preparation, refining quality at 24, 28 and 40 ^{o}SR is not suitable. This means that all chips from MUF-bonded waste PBs over 2mm will be defibred and subsequently refined to 13 ^{o}SR.

Characterisation of wood fibre obtained from waste OSBs based on MUF resins

The composition of the chip after initial destruction by pressing and chipping (Tab. 1, sample 3) shows the 46.41% representation of fine particle sized less than 2 mm. The amount of usable particles above 2 mm for the fiber preparation is represented by 53.59%. As in the previous cases, defibering on Sprout-Waldron (Tab. 2, sample 3) appears too rough, unsuitable for new MDFs with a low representation of fine fibres (mesh 240). For this reason, the fibre was further refined on Valley holander as well.

Tab.5: Distribution and properties of fibre obtained from the waste OSBs based on MUF resins defibred on Sprout-Waldron and refined on Valley holander

°SR		**40**	**28**	**24**	**13**
Refining time		70 min	50 min	40 min	18 min
Dewaterability (sec.)	500ml	27.12	13.22	8.17	2.51
	700ml	58.18	35.94	32.65	8.10
	800ml	83.15	59.15	45.86	12.26
Brecht-Holl (%)	16 (mesh 40)	3.156	12.435	18.160	48.617
	50 (mesh 120)	42.706	45.938	45.080	26.859
	100 (mesh 240)	16.862	12.086	13.610	12.114
	above 100 (above mesh 240)	34.276	29.541	23.150	12.410

By comparing the fibre from OSBs (Tab. 5) and the fibre from PBs based on MUF resins (Tab.4) it can be found just small differences in fibres obtained by defibering and refining. The fibre is fragile with a high representation of particles sized above mesh 240. For this reason, waste OSBs can be treated together with PBs both based on MUF. Such obtained fibre refined on 13 °SR can be used for a MDF production.

Characterisation of wood fibre obtained from waste MDFs based on UF resins

Waste MDFs were cooked in boiling water just for 3 min. This time is adequate to obtain the minimum 45 % relative humidity. Properties of fibre obtained by defibering on Sprout Waldron from such cooked MDFs are shown in Tab. 6. As seen the quality of such fibre is suitable without further refining for the new MDF production.

Characterisation of wood fibre obtained from waste MDFs based on MUF resins

Waste MDFs were after very long boiling initially destructed by pressing and then chipped. The composition of the chips is shown in Tab.1, sample 4. Representation of usable particles above 2 mm for fibre preparation was just 55.54%. Distribution of the fibre obtained by defibering on Sprout Waldron is suitable (Tab. 6) without further refining on Valley holander.

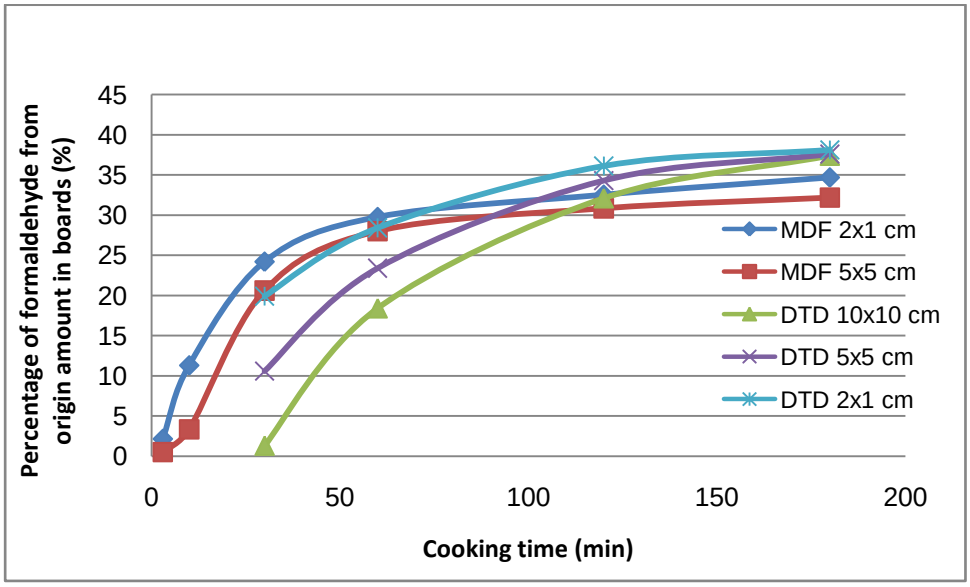
Tab.6: Distribution and properties of fibre obtained from waste MDFs

		based on UF resins	based on MUF resins	Comparative sample
°SR		12	16	10
Dewaterability (sec.)	500ml	2.12	7.15	2.25
	700ml	6.21	24.15	3.05
	800ml	10.18	32.81	3.35
Brecht-Holl (%)	chips	0.000	0.000	4.243
	16 (mesh 40)	42.110	37.110	47.207
	50 (mesh 120)	34.780	39.780	24.295
	100 (mesh 240)	12.130	10.250	15.970
	above 100 (above mesh 240)	10.980	12.860	8.285

Determination of formaldehyde release during resin hydrolysis

The origin value of formaldehyde contained in waste PBs is gradually reduced by boiling in water due to the hydrolysis of UF resins. In generally at the 10 % content of UF resin to absolutely dry chips, amount of 3548 mg of formaldehyde and 6452 mg of urea is counted on 100 g of absolutely dry chips. For 1 mole of urea the amount of 1.1 mole of formaldehyde is added. The amount of formaldehyde released depends on the cooking time and on the sample size (Fig.1).

Fig.1: Resin hydrolysis of waste MDFs and PBs depending on sample size and cooking time



Formaldehyde release due to the hydrolysis of resins of larger samples cooked occurs slower than of smaller samples. Samples of waste PBs and MDFs will be cooked so long as they reach the relative humidity at which they can be crushed without the risk of particle burning. The required relative humidity is about 40%, this moisture when cooking a sample of 2 x 1 cm is achieved in less than 3 minutes and in the case of dimensions of 5 x 5 cm in about

30 min. Cooking of the 5 x 5 cm samples for 30 min causes resin hydrolysis of 10 to 20% adhesive, i.e. about 354mg to 708 mg of formaldehyde per 100 g dry wood will be in the solution. In the case of the 180 min cooking will be amount of resins reduced the amount by 30 – 40 % of the original amount due to progressing hydrolysis. It is assumed that the amount of formaldehyde from waste materials after boiling water treatment will be minimally reduced by the values shown in fig. 1. According to the results of hydrolysis in the samples examined by further cooking, the amount of formaldehyde in the samples of MDFs and PBs will no longer be more pronounced.

Amount of formaldehyde in the solution is an indicative parameter, the amount of formaldehyde released from the prepared MDFs or PBs is important.

CONCLUSIONS

On the basis of the experiments carried out, it can be stated that:

- fraction of chips 2 mm and more was used for fibre preparation
- insufficient (too rough) fraction at level 5 ^{o}SR to 7 ^{o}SR has been achieved after defibering on sprout Waldron
- fibre obtained from waste PBs and OSBs based on UF and MUF was refined on Valley holander at 13 ^{o} SR, 24 ^{o} SR, 28 ^{o} SR and 40 ^{o} SR. Fibre properties in range of 13 ^{o} SR to 24 ^{o} SR values are sufficient for the MDF production
- dewaterability of fibre obtained from waste PBs based on UF resins is better than that based on MUF
- fibre obtained from waste PBs based on UF resins has a higher proportion of long fiber, while fibre obtained from PBs and OSBs based on MUF resins has a greater proportion of fine fiber over mash 240. This is due to the greater brittleness of chips covered with MUF resins. Less swollen chips released during the cooking reduced amount of formaldehyde. This fact is also explained by higher dewatering times.
- fibre obtained from waste MDF based on UF resins cooked 3 minutes and defibred on Sprout Waldron is suitable for the MDF production
- fibre obtained from waste MDF based on MUF resins is suitable for the MDF production directly after defibering on Sprout-Waldron
- amount of formaldehyde contained in resins is reduced by 30 – 40 % of the original amount by the 180 min cooking due to hydrolysis for all samples. It is assumed that the amount of formaldehyde in fibre prepared from waste PBs and MDFs after the boiling water will be minimally reduced as shown at Fig.1

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