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Management of Recovered Wood

Strategies Towards a Higher Technical, Economical and Environmental Standard in Europe

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MEDIUM DENSITY FIBREBOARDS (MDF) FROM RECYCLED FIBRES

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1. ABSTRACT

Nowadays, more than 90 % of all furniture produced in Europe is made of wood-based panels, especially particleboards and medium density fibreboards (MDF), which are mainly bonded with urea-formaldehyde resins (UF-resins). The life span of furniture is currently less than 30 years and landfilling has already been forbidden in many European countries due to environmental reasons. Therefore, increasing attention has been given to the issue of recycling in the particleboard and fibreboard industry.

Many methods have been developed for recycling of UF-bonded particleboards. In Germany e.g., the thermo-hydrolytic pulping of mechanically disintegrated chip-boards has attracted industrial interest. However, no systematic research work has been reported on the use of recycled fibres in the production of MDF.

This work reports on a new recycling technology for processing of waste composite boards (particleboards, medium density fibreboards and waste low-grade paper), to obtain fibres suitable for the production of MDF. The patented technology is based on the application of the twin-screw extruder technique and also targeted at reactivating the aminoplastic resin used for bonding in the waste boards, so as to

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enable reduction of the resin level needed to rebond the fibres obtained through recycling. According to the new technology, the material to be recycled is subjected to thermohydrolysis under the action of high shear in a twin-screw extruder. Due to such shear action, the material is defibrated and the morphological structure of the lignocellulosics is disrupted. The extrusion conditions (screw elements, screw speed, temperature profile) can be optimised to obtain the best quality of extruded fibres. Also chemicals can be added during the extrusion process.

Laboratory trials have proved that fibres produced from waste particle- and fibreboards using the extruder technique can effectively replace wood fibres obtained by the refiner technique in the production of MDF. The physical-mechanical properties of MDF made from extruded fibres were equal or even better than those made from virgin fibres. Furthermore, industrial-scale production of MDF using extruded fibres was implemented. As there was a limited amount of extruded fibres, a substitution level up to 15 % was chosen to work with. The results revealed that MDF produced partially from recycled fibres had similar mechanical-technical properties to MDF made from virgin fibres. No deterioration of the surface quality was observed. Moreover, the formaldehyde emission of MDF with extruded fibres was lower than that of the boards from virgin fibres. What is more promising from this industrial test, is the result that when using recycled fibres, a lower resin consumption may be needed due to the activation of the resin present in the boards.

It can be concluded that the addition of recycled fibres obtained by the extruder technique has no negative impact on the properties of the boards, as evaluated by standard methods used in the wood-based panels industry. In this sense, extruded fibres from waste boards can be employed as raw material in making new MDF, by partially replacing the virgin fibres.

2. GENERAL INTRODUCTION

The wood composite industry is mainly a world-wide creation of the last century. The pace of development has been rapid and a continued high speed development is also expected for this century. Technological breakthroughs with new processing machines, quality control devices, better adhesives and use of other lignocellulosics than wood as a raw material will possibly play a great role in the future of this industry. The production of particleboards in 2004 in Europe was about 35 Mio. m^3 and that of fibreboards was higher than 11 Mio. m^3. Particle- and fibreboards are used in furniture and buildings.

In Europe, particleboards and medium density fibreboards (MDF) became the back-bone of furniture and displaced to a very high extent solid wood from this area. Therefore, it was logical that the development of the furniture industry has been dramatically affected by that of the fibre- and particleboard industry.

Pieces of furniture have a life span of 30 to 40 years in Europe. According to environmental regulations in some European countries deploying used furniture on the landfill has been forbidden since the beginning of 2005, as the interaction between organic materials and the environment is of a very complex nature. Leached binders from wood-based panels may influence the groundwater; biological degradation of particle- and fibreboards on the landfill leads, moreover, to the formation of methane which contributes to the „Green-House-Effect“ about 80 times more than carbon dioxide. *Figure 1* summarises the reasons against dumping of organic waste materials.

5 Reasons Against Deploying Organic Materials On Landfills

1. Conventionally increasing costs of landfilling due to reduced landfill capacity.
2. Legislative measures prohibiting the dumping of organic matter.
3. Gerneration of methane and corbondioxide in dumps, which can be considered as anaerobic reactor. Methane contributes to the green house effect eighty times more than carbondioxide (1 t methane is equivalent to 88 t of carbondioxide in global warming of the atmosphere).
4. Polluted leaching water from dumps may penetrate in the earth crust and contaminate surface and underground water.
5. In the dumps energy content of wood and wood-based panels is wasted and no utilization is made of the organic biomass.

***Figure 1.** Five reasons against deploying organic materials on landfills.*

Due to the above mentioned reasons, increasing attention has been given to the issue of recycling in the fibre- and particleboard industry. Many methods have been developed for recycling of particleboards (Roffael 1997). In Germany, the discontinuous thermohydrolytic pulping of mechanically disintegrated chipboards has found industrial application since nearly five years (Boehme and Wittke 2002, Kirchner and Kharazipour 2002).

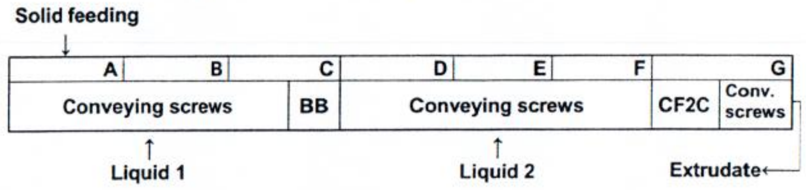
3. OBJECTIVES OF THE WORK

Our presentation today relates to a new recycling technology for processing of waste composite panels (particleboard, fibreboard) and waste low-grade paper, either alone or in mixtures, to obtain fibres suitable for the production of medium density fibreboard (MDF), a valuable commodity. The patented technology

is based on application of the extrusion technique and targets also at reactivating the aminoplastic resin used for bonding of waste panels, so as to enable reduction of the resin level needed to rebond the fibres obtained through recycling. For comparative studies, waste particleboard, fibreboard, and mixtures therefrom, are defibrated in a conventional refiner as commonly used in the MDF industry.

The twin extruder machine contains 7 different compartments (modules). In the first part of the twin extruder the solid material to be extruded is fed and transported within the extruder through the so called conveying screws. Thereafter, the material to be extruded is subjected to thermohydrolysis under the action of high shear. The high shear is exerted by the so called twin flight reverse pitch self wiping devices. Due to such shear action the material is defibrated and the morphological structure of the lignocellulosics is highly disrupted. The profile of the extruder can be changed according to the material to be extruded. The defibration process can be done at a temperature as low as 40°C, but it is usually carried out at a temperature of 90°C to 110°C. In extruders working at high pressure the temperature can be much higher. *Figure 2a* shows the profile of the twin-extruder. *Figure 2b* shows a temperature gradient during

Configuration and the profile of the extruder



BB: bicam kneading discs
CF2C: screw elements with reverse pitch
Liquid 1 is either water or soda and liquid 2 is always water
The screw rotation speed is 200 rpm

Temperaturprofile in the twin-screw extruder

A	B	C	D	E	F	G
70°C	80°C	110°C	100°C	100°C	100°C	60°C

***Figure 2a, 2b.** Configuration and profile of the twin-screw extruder (2a); temperature profile in the twin-screw extruder (2b).*

the extrusion process. *Figure 2c* shows the different devices used in the extruder. The devices can be combined in different manners.

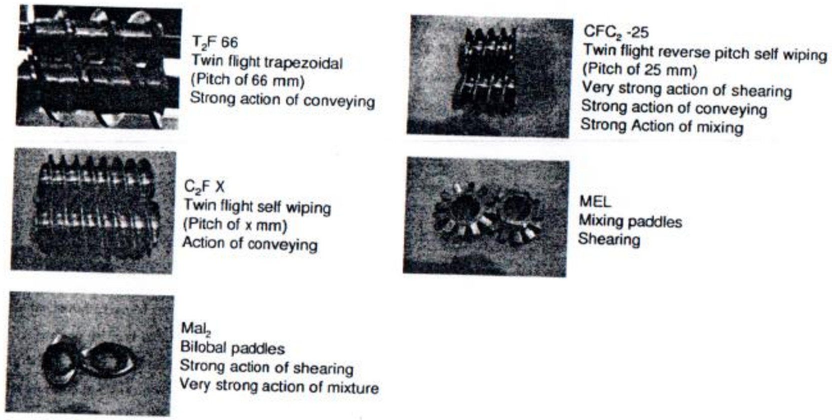


Figure 2c. *Description of the devices (screws) used for the twin-screw profile in the extruder.*

In the extrusion process water or pulping chemicals such as dilute sodium hydroxide solution or dilute acids can be added from different positions to enhance defibration. Also, the speed of the screws can be changed over a wide range to meet optimal conditions. In our research project the conditions were in average as follows:

Maximum temperature during extrusion:	90°C
Water rate flow:	5-10 kg/h
Liquid solid ratio:	1:1
Defibrated extrudate:	7-10 kg/h
Dry matter of extrudate:	50-60 %

Using the above mentioned conditions, practically no change in the chemical composition of extruded particle- or fibreboards takes place during the defibration process as long as water is used for the defibration process. However, on using sodium hydroxide as a pulping agent chemical degradation of the resin occurs leading to a decrease in the nitrogen content of extruded fibres compared to that of the original boards. In other words, both the thermo-mechanical (TMP) and the chemo-thermo-mechanical (CTMP) pulping conditions can be applied using the extruder technique. In *table 1* the chemical com-

Table 1. Chemical characterization of industrially produced uncoated particleboards (22 mm thickness) and industrially produced uncoated medium density fibreboards (MDF) (7 mm thickness)

Analysis	PARTICLEBOARDS	MDF
Lignin content [%]	27.51	25.82
Nitrogen content [%]	3.73	6.15
pH value of cold water extract (particle size ≥ 0,5 < 1 mm)	4.89	5.36
Buffering capacity of cold water extract [mmol NaOH/ 100 g o.d. sample]	1.37	0.64
pH value of hot water extract (particle size ≥ 0,5 < 1 mm)	6.96	7.80
Buffering capacity of hot water extract [mmol NaOH/ 100 g o.d. sample]	0.28	Not determinable
Ash content [%]	0.81	0.30
Silica content [%]	0.058	0.00
Formaldehyde emission (Flask method, according to EN 717-3, after 24 h) [mg / 1000 g o.d. board]	93.4	37.3

position of the fibre- and particleboards to be extruded are compiled. *Table 2* presents data on the change of chemical composition of particle- and fibreboards due to extrusion using water and sodium hydroxide as pulping chemicals. In trials no. 1 and 2 using water for the thermohydrolysis the main difference was in the rate of extrusion, in experiment no. 1 the rate was 16.2 kg/h, whereas in experiment no. 2 the rate was 27.2 kg/h. In experiment 3 and 4 particleboards were extruded at a rate of 27.4 kg/h and 14.9 kg/h respectively. In all trials the energy consumption was nearly 400 (Wh/kg). The moisture content of the extruded fibres was nearly 60 %.

In one experiment the properties of the extruded fibres obtained from the extruder technique was compared with those obtained from the refiner technique. According to the results, the degradation of the resin in the refiner is much more pronounced than in the extruder as the values of the nitrogen content clearly show (*table 3*).

The fibres produced from particle- and fibreboards by the extruder tech-

Table 2. Chemical characterization of fibres produced from waste particleboards, waste medium density fibreboards (MDF) and pine wood using the twin-screw extruder technology (n.d. = not detectable)

Sample No.	1	2	3	4	5	6	7	8	9	10	11
Raw material	PARTICLEBOARD				MEDIUM DENSITY FIBREBOARD				PINE WOOD CHIPS		
Liquid 1 in conveying Screw	Water	Water	NaOH	NaOH	Water	Water	NaOH	NaOH	Water	Water	NaOH
Lignin content [%]	29.49	28.57	28.67	28.65	26.27	26.03	26.01	26.21	30.40	30.57	30.39
Nitrogen content [%]	3.74	3.75	3.66	3.64	6.02	6.00	5.85	5.66	0.2	0.06	0.07
pH value of cold water extract	5.75	5.57	5.73	5.90	6.26	6.38	6.63	6.81	6.55	4.99	5.70
Buffering capacity of Cold water extract [mmol NaOH/ 100 g o.d. sample]	0.80	0.87	0.78	0.81	0.46	0.71	1.5	1.05	1.2	2.4	2.7
Ash content [%] / Silicate content [%]	0.82 / 0.18	0.8 / 0.16	1.03 / 0.19	0.98 / 0.13	0.31 / 0.004-0.028	0.31 / 0.007-0.026	0.57 / 0.01	0.59 / 0.01	0.34 / n.d.	0.32 / 0.05	0.53 / 0.04-0.07
Formaldehyde emission (Flask method, according to EN 717-3, after 24 h) [mg / 1000 g o.d. fibres]	157.3	141.4	129.8	49.2	113.5	96.9	119.6	76.2	Not detectable		

Table 3. Comparison of chemical data of fibres produced from pine wood, waste particleboards (PB) and waste medium density fibreboards (MDF) using the extruder and refiner technique. Moreover the chemical properties of the original raw materials are listed

Chemical Data	Basic raw material			Defibration by					
				Extruder technique			Refiner technique		
	Pine wood	PB	MDF	Pine wood	PB	MDF	Pine wood	PB	MDF
Lignin content [%]	28.5	27.51	25.82	30.57	28.57	26.03	29.70	28.44	27.24
Nitrogen content [%]	0.07	3.73	6.15	0.06	3.75	6.00	0.14	3.29	4.75
Formaldehyde-emission (Flask method, 24 h) [mg/1000g o.d. fibres]	16.2	93.4	37.3	not detect-able	141.4	96.9	89.2	67.5	99.3

nique can be used as a raw material for fibreboards. In *table 4* the conditions of the production of fibreboards are compiled. As can be seen from the results presented in *table 5* the fibreboards obtained without adding any sizing agent show fairly good internal bond strength and also relatively low thickness swelling. Though, the boards are made out of 100 % waste boards the formaldehyde release is still very low. However, the bending strength is comparatively low. We have always noticed, that boards, made from 100 % recycled boards do have low bending strength compared to those from virgin wood.

Table 4. Parameters of board production

Pressure (N/mm²)	**35**
Press temperature (°C)	**190**
Press time (s/mm)	**15**
Target density (kg/m³)	**800**
Resin types:	**UF110 & UF110+cross linker**
Glue factor (%)	**12**
Hardener (% on dry resin, Ammonium sulfate	**2**
Board dimensions	**43cmx43cmx16mm**

Table 5. Properties of MDF produced from extruded fibres

Sample No.	**1***	**2**	**3***	**4**
Sample mix (waste feedstock)	**PB**	**PB**	**MDF**	**MDF**
%hardener	2	2	2	2
Density, kg/m³	810	803	812	799
MOR, N/mm²	18.6	22.6	17.6	19.7
IB, N/mm²	**0.44**	**0.41**	**0.52**	**0.48**
Thickness, mm	15.7	15.6	15.8	15.7
24h swelling, %	**14.3**	**11.4**	**15.0**	**14.9**
HCHO, mg/100g	6.3	8.5	7.1	9.6
Moisture content, %	6.9	6.5	7.1	6.9

*** with cross linker**

In further work mixtures of wood, particleboards and fibreboards were disintegrated in a hammermill and extruded together. In another set of experiments every material was hammermilled and extruded separately and thereafter mixed together after extrusion. From fibres obtained using the above mentioned two techniques medium density fibreboards were made according to the following conditions.

Conditions used for preparing UF-bonded fibreboards:

Board type:	One layer
Board size:	45 cm x 45 cm x thickness
Board thickness:	20 mm not sanded, 19 mm sanded
Target density:	800 kg/cm³
Resin:	Urea formaldehyde resin (resin 115 from partner no. 3)
Resin level:	12 % (soled resin based on dryed fibres)
Catalyst:	Ammonium sulphate (2 % based on solid resin)
Size agent:	No sizing agent
Gluing:	Blender technique
Press temperature:	190 °C
Press time:	15 or 25 seconds per millimetre

The results of measuring the physical and mechanical properties are presented in *table 6*. As can be seen from the results mixing pure waste particleboards, fibreboards and pine wood in the ratio of 1:1:1 leads to boards with very low thickness swelling and water absorption. However, the bending strength of the boards was lower than that of boards made out of pure pine wood. Besides, the formaldehyde release of the MDF prepared from different mixtures was also assessed. The results are presented in *table 7*. Accordingly, the formaldehyde release measured using the perforator method (EN 120) is low and meets the requirement for boards of the E1-class. Moreover, the results show that there is no significant differences between the formaldehyde release of the boards prepared from fibres extruded before mixing or after mixing the waste boards. This again can be regarded as a positive aspect as no special care is needed in handling the process as far as the formaldehyde release is concerned. The results of measurements according to EN 717.3 are in full agreement with the results obtained by measuring the perforator value according to EN 120.

The results obtained in the laboratory scale were confirmed by industrial trials carried out using one single opening press. In the experimental trials 15 % of the fibres obtained from virgin wood were replaced by recycling fibres obtained from UF-bonded fibre boards by the extruder technique. As the results

Table 6. Physical-mechanical properties of UF-bonded MDF prepared from pine fibres and panel residues

Board No.	Press time s/mm	Fibres from	Board properties Density kg/m³	Bending strength N/mm²	Internal bond strength N/mm²	Thickness swelling 2h %	24h %	Water absorption 2h %	24h %	Moisture content %
1a/1	15	Pine wood (33%) / Particleboard (33%) / MDF (33%) Mixed during hammermilling before extruded	805	21.67	0.54	5,0	17,5	18,7	67,5	7.7
1b/1	15	Pine wood (33%) / Particleboard (33%) / MDF (33%) Each material is extruded before being mixed together	837	21.09	0.41	7,7	22,2	37,7	72,9	7.7

Table 7. Formaldehyde release of UF-bonded MDF prepared from pine fibres and panel residues

Press time s/min	Fibres from	Formaldehyde release [1]) (flask method) EN 717.3 mg/1000 g d. board 3h	24h	Formaldehyde content [2]) (perforator method) EN 120 mg/100 g d. board A	B	Moisture content %
15	Pine wood (33%) / Particleboard (33%) / MDF (33%) Mixed during hammermilling	5.9	52.8	7.0	7.0	6.5
15	Pine wood (33%) / Particleboard (33%) / MDF (33%) Each material is extruded before being mixed together	4.6	49.1	5.4	5.8	5.9

1) EN 717 – 3
2) EN 120, A: perforator value determined based on the moisture content of the board
B: perforator value determined and corrected to a moisture content of 6.5%

are compiled in *table 8* reveal, substitution of 15 % of the virgin fibres by recycling fibres has no detrimental effect on the mechanical properties of the boards. Moreover, the formaldehyde release doesn't experience any change due to the substitution of 15 % of virgin fibres by recycling fibres.

Table 8. Internal bond strength of 16 mm medium density fibreboards (MDF) with and without extruded fibres as a function of the resin level

Resin level %	Internal bond strength N/mm²	Density g/cm³	Thickness swelling %		Remarks
			2 h	24 h	
7.0	1.17 1.02	0.774 0.760	4.18 4.16	16.98 16.34	Board **without** extruded fibres
6.6	0.71 0.98	0.739 0.749	no data was available		Board **without** extruded fibres
6.6	0.75 0.74	0.830 0,780	4.30 4.80	16.00 17.06	Board **with** extruded fibres

Also the formaldehyde release according to the flask method (EN 717-3) was determined (*table 9*). The formaldehyde release of the normal boards (without recycling fibres) using the flask method was 35.6 mg/100 g o.d. board after 24 h reaction time. That of the boards including recycling fibres was 30.9 mg/100 g o.d. board after the same reaction period indicating a decrease in the fomaldehyde release of more than 10 %. Moreover, the formaldehyde release of the fibres after gluing but before pressing was also assessed. The resinated fibres from the production line without any recycled fibres showed a formaldehyde release of 233.6 mg/100 g o.d. fibres, whereas those containing recycling fibres showed only 210.4 mg/100 g o.d. fibres, this also indicates a decrease in the formaldehyde release of about 10 % due to the addition of recycling material. Insofar, it seems that recycling fibres do have a positive effect on the formaldehyde emission of the boards. They act as a week formaldehyde scavenger. The experiments were done deliberately using a resin of high molar ratio 1:1.3 in order to be able to assess the influence of recycling fibres on the formaldehyde release.

Table 9. Formaldehyde release (mg HCHO / 100 g o.d. sample) and nitrogen content (%) of 16 mm medium density fibreboards (MDF) with and without extruded fibres as a function of the resin level

Resin level %	Formaldehyde release mg HCHO /100 g o.d. sample		Nitrogen content %	
	3 h	24 h	glued fibres	MDF
7.0 without extruded fibres	4.45	35.6 (233.6)*	2.90	2.90
6.6 with extruded fibres	4.00	30.9 (210.4)*	2.91	2.90

*) Formaldehyde release of the glued fibres prior to pressing according to the flask method after 24 h reaction time

4. SUMMARY

The extrusion technique can be used to recycle particle- and fibreboards separately or in mixture. The fibres obtained can be used as a raw material for medium density fibreboard. The fibreboards obtained under conventional gluing and pressing conditions show satisfactory results as far as the internal bond strength and the thickness swelling are concerned. Also, the formaldehyde release of the fibreboards meets the E1-requirements.

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