Particleboards with Wood in Various Forms

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ABSTRACT

Particleboard, also known as chipboard, is a composite product manufactured from wood chips, sawmill shavings, or even sawdust, and a synthetic resin or other suitable binder. An important aspect of the final price of particleboards is the cost of raw materials, which depends to a large extent on transportation costs. In order to reduce this cost, a solution would be to transfer wood in a compressed form, like for example pellets. In the framework of the EU project MOBILE FLIP, wood material from Scots pine (*Pinus sylvestris*) and Norway spruce (*Picea abies*) in the form of chips, pellets and milled pellets was tested for its suitability to produce particleboards. All forms of wood were subjected to sieving so as to be separated in fractions with similar average particle size (4mm, 6mm and 8mm). The materials were dried and blended with a typical Urea-Formaldehyde resin and formed into mats with dimensions of 35x35cm. Particleboards with a target density of 650 kg/m3 were produced following a simulation of the typical industrial process. It was found that, irrespective of the particle size, only milled pellets can be used in such an application and give particleboards with properties comparable to that of panels prepared from chips.

Key words: Particleboard, Pellets, Wood

1. INTRODUCTION

Typically, particleboards are made from wood particles (chips) that are bonded together using a glue. Particleboards have the largest market share of all types of wood-based panels and find application both indoors and outdoors. After a period of decline in sales, studies predict recovery of their market and increased demand. In particular, the recovery of housing construction in the U.S., the strong growth of this sector in the rapidly developing countries in Eastern Europe and Russia, and the expanding furniture industry globaly, is expected to lead to a boom in particleboard production by 2017 [FDMC 2014]. Furniture will continue to be their prominent application while windows, doors, subflooring, and roofing will be the fastest growing uses (Freedonia 2013).

The cost of particleboards, although low compared to other types of wood-based panel like OSB, MDF or plywood, plays a significant role to their marketability. Various attempts have been made so far in order to decrease costs, which concern mainly the reduction of the final product cost. They are related to the changes in the production line, using less resin during their manufacturing or produce lightweight panels from special types of wood or agricultural materials in order to minimize their transportation cost and at the same time facilitate the do-it-yourself applications.

However, the transportation cost of the particles themselves, from wood or other lignocellulosic materials play also a significant role in the formation of the final price of the panels. Wood is transported both as logs and as particles, i.e. chips, sawdust, or shavings. Biomass particles is a relatively light material that generally weighs between 120-300 kg/m^3 (make it wood). It means that its transportation is expensive and energy consuming. Consequently, a reduction in the transportation routes will bring environmental benefits while the decrease of the transportation cost will create economic benefits to wholesalers, retailers and end users like the particleboard manufacturers.

In this study, the authors have evaluated the ability to make particleboards from compressed wood particles (pellets) in order to propose a solution to reduction of the transportation cost of raw materials that has also environmental benefits.

2. EXPERIMENTAL PART

2.1. Preparation and analysis of lignocellulosic materials and resins

Sawdust made from a mixture of Scots Pine (*Pinus sylvestris*) and Norway spruce (*Picea abies*) was obtained from the fuel pellet company Neova (Främlingshem, Sweden) and processed further at the Biomass Technology Centre, Umeå, Sweden. The sawdust was made into three different particle size assortments by hammer milling (Vertica DFZK-1, Bühler AG, Switzerland) using 4, 6 and 8 mm screen size. The assortments were pelletized in a Bühler DPCB pelletizer (Bühler AG, Uzwil, Switzerland). Milled pellets were produced from all three assortments by cutting milling (Retsch SM200, Haan, Germany) with a screen size of 6 mm. Hence, the following feedstock assortments were produced :

- Sieved particles (S4, S6, S8) – the material before pelletization
- Pellets (P4, P6, P8) – the pelletized material and
- Milled Pellets (MP4, MP6, MP8) – the material resulted from the milling of pellets.

CHIMAR HELLAS received samples of all of the above fractions and types of materials in order to test them in the production of particleboards. The materials were characterized for their pH and buffer capacity and next were dried in oven until their moisture content was reduced to below 5%.

A typical Urea-Formaldehyde (UF) resin for the production of particleboards was prepared (Minopoulou 2003, Zorba 2008). The physicochemical characteristics of the resin were determined with typical lab analysis while its thermal properties were determined with TGA-DTA analysis in dynamic heating conditions. This analysis was carried out with a Setaram Setsys TG-DTA 1750°C device. For the measurement, a quantity of 5±0.2mg of resin was placed in alumina crucibles and the sample was heated from room temperature to 500°C in a 50mL/min flow of N2. The heating rate was 5°C/min while the sample temperature, sample mass, its first derivative and heat flow were recorded continuously. Together, a TGA study was carried out for the correlation between the mass of the resin and the % mass loss of water contained in it, while the % mass loss of the resin at two different heating rates of 2.5°C/min and 5°C/min was also studied.

2.2 Production of particleboards

According to the typical process for the production of particleboards (particleboard manufaturing process 2010, Wilson 2008), the wood particles (chips) are first dried in an oven to a targeted moisture content of about 3-5%. An adhesive mixture (glue) is prepared by mixing together resin, water, a hardener (necessary for the final curing of the resin) and paraffin emulsion which gives some hydrophobicity to the panel. The glue is distributed onto the wood particles in the form of discrete droplets. For this purpose, the wood particles are loaded into a blender and the adhesive mixture is sprayed via suitable nozzles. The resin most commonly used is the Urea-Formaldehyde (UF) type. However, some products are made either with

Melamine-Urea-Formaldehyde (MUF) or polymeric isocyanate resins (pMDI) when high moisture resistance is requested. The blended particles are distributed into a flat mat. The size of particles, their moisture and resin content are controlled in order to obtain the desired panel properties. The formed mats are initially cold pressed and next hot pressed under pressures of between 2 and 3 MPa and temperatures between 140°C and 220°C. This process sets and hardens the glue. Initially, hot panels are conditioned so that their temperature is lowered to room temperature, and then trimmed and sanded on both major surfaces to a targeted thickness and smoothness. Next, they are stacked and prepared for shipping.

The above-described production process of particleboards is better illustrated on the following diagram (Figure 1).

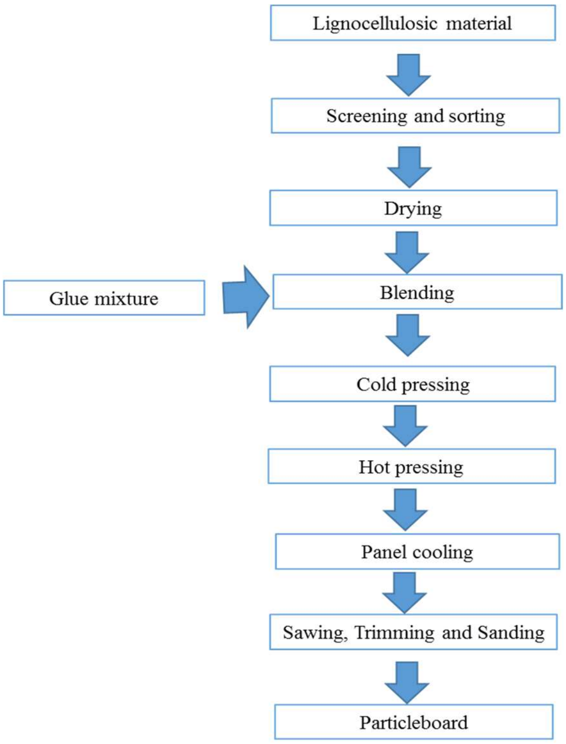

Figure 1. On-site process flow for the production of particleboard

A similar particleboard manufacturing process was followed in this study. In particular, the various samples were tested in the production of particleboards at lab scale at the premises of CHIMAR. All types of material were blended with the adhesive mixture prepared with the UF resin, water, paraffin emulsion and ammonium chloride (hardener). A mat was formed in each case, which was first cold pressed and then hot pressed at the temperature of 200°C for two pressing cycles each. The panels had a target density of 650 kg/m^3 and dimensions 35x35x1.0cm.

As control, particleboards from typical chips of pine wood were also produced.

After hot pressing, the successful panels were cooled and conditioned for 24h. Next, they were trimmed and cut in pieces in order to be tested for their mechanical and physical properties according to the European standards in force which are cited in table 1.

Table 1. European standards for the testing of particleboards

a\a	Properties	Unit	Test Method	Remarks
1	Internal Bond (IB)	N/mm^2	EN 319	-
2	Modulus of Rupture (MOR)	N/mm^2	EN 310	-
3	Thickness Swelling (TS)	%	EN 317	24h, 20°C
4	Formaldehyde content	mg/100g atro	EN 120	Perforator method

3. RESULTS AND DISCUSSION

The physicochemical properties of the typical UF resin used in this study are presented in the following table 2.

Table 2. Properties of UF resin

Properties of UF resin	Unit	Value
pH at 25°C	[ ]	8.28
Brookfield viscosity at 25°C	cP	345
Hardening time at 100°C	s	56
Water tolerance (resin/water) at 25°C	mL/mL	1 / 2.5
Dry solids	mass/mass %	65.4
Free Formaldehyde	%	0.06
Buffer Capacity (measured with 0.1N H2SO4)	mL	11.3
Conductivity	μS/cm	96.6
Specific Gravity @ 20°C	[ ]	1.286

The UF resin was also studied for its thermal behaviour with Thermogravimetric Analysis (TGA). The following Figure 2 shows the dependence of the mass loss and the heat flow to the temperature.

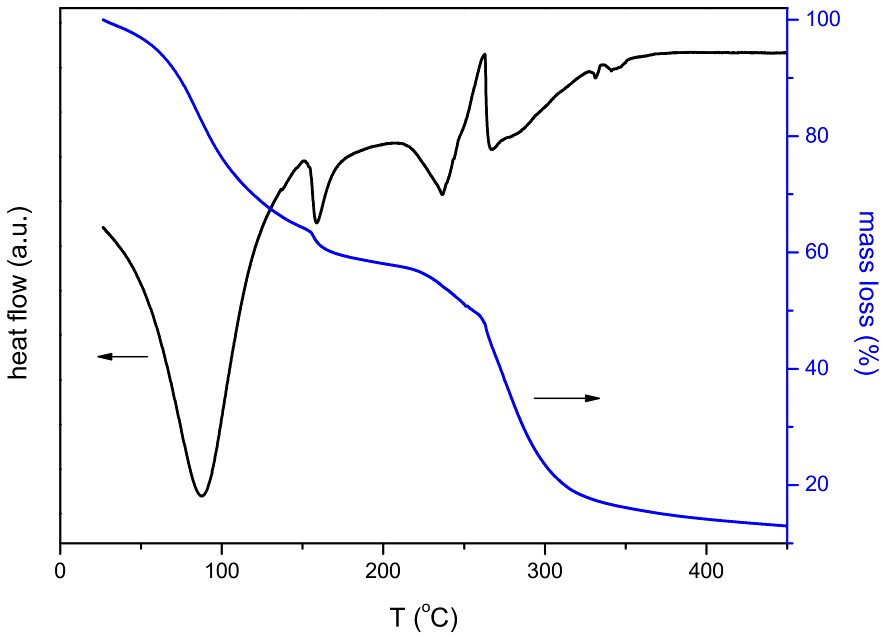

Figure 2. Mass loss % and heat flow vs temperature

During the raising of the temperature the polycondensation takes place preferably over formation of methylene linkages between the linear resin fragments. The solidification of the glue is extended over a wide range of temperatures and exothermic peaks are fully covered by the large endothermic peak of water evaporation (water exists already in the reaction mixture and results from the condensation reaction). The small mass loss between 100°C and 200°C is associated with the slow evaporation of free formaldehyde. After 200°C the destruction of the resin begins. First the scission of the di-methylene–ether groups takes place (Samarzija-Jovanovic S. et. al. 2011) while the maximum degradation rates happen when the stable methylene-ether linkages deconstruct (Siimer K. et. al. 2003, Roumeli E. et. al. 2012).

During the implementation of the above measurements it was observed that the loss of water begins already from the start of the measurement, while a very small amount escapes already when preparing the sample for the measurement. It was also noticed that the rate of the initial water loss was greater the smaller the mass of the sample being measured was. For this reason, the water loss was studied at two samples of the resin with different weight (m1=38.8mg and m2=13.5mg). Figure 3 shows the mass loss and heat flow vs temperature for these two samples.

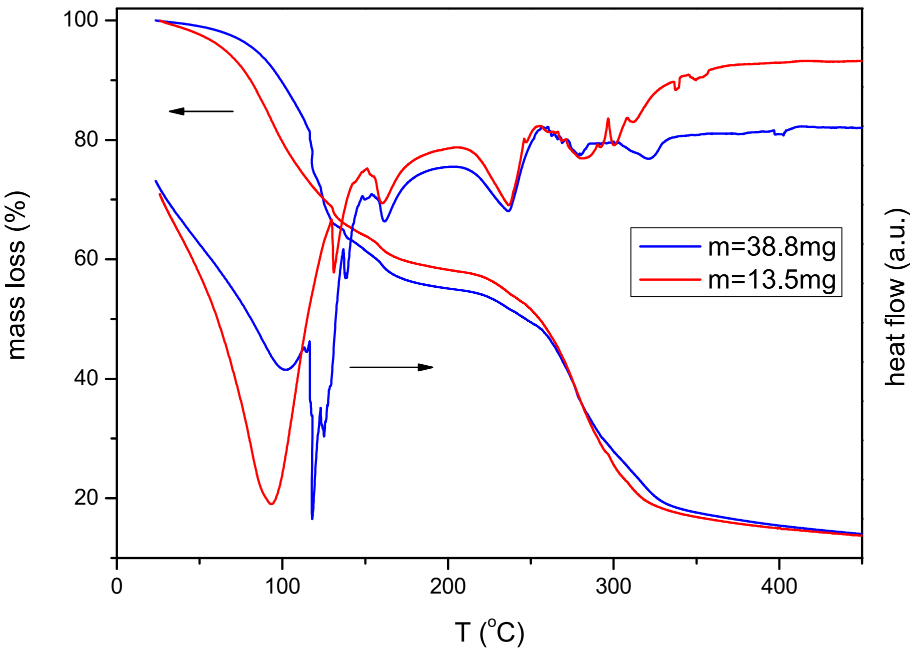

Figure 3. Mass loss (%) and heat flow vs temperature for two samples with different mass of UF resin

It was observed that the rate at which water evaporates is significantly higher in the case of the sample with the lowest mass.

The water loss was also studied with isothermal measurements at the temperature of 25°C (Figure 4). In this case the mass of sample was 15mg.

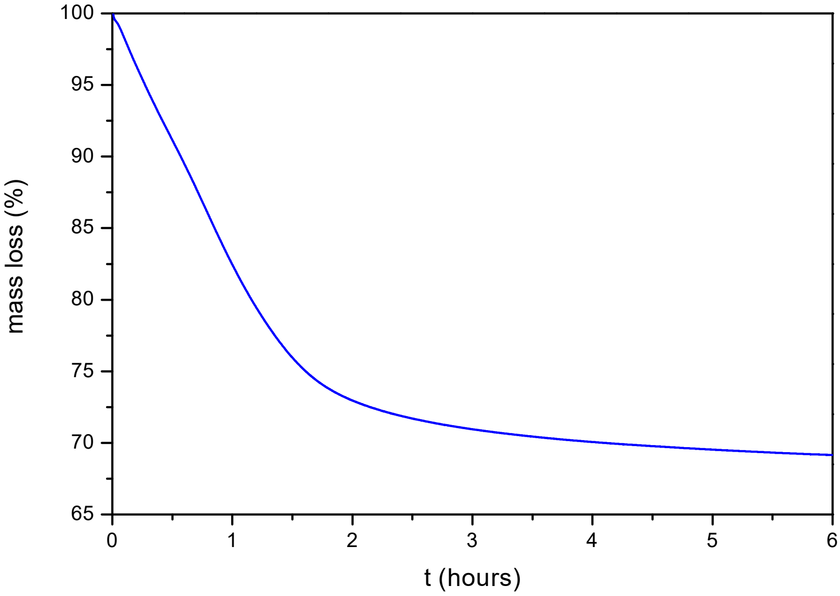

Figure 4. Mass loss (%) of UF resin vs time at the temperature of 25°C.

It was observed that at ambient temperature (25°C) the UF resin loses the higher percentage of its water content within the first three hours.
So, when a specific container is used for the resin, the smaller the quantity of the resin, the higher the rate of the mass loss of water.

The thermal stability of the resin as a function of the heating rate was also studied by carrying out the measurement with two different heating rates of 2.5 and 5°C/min. The following Figure 5 shows the corresponding results.

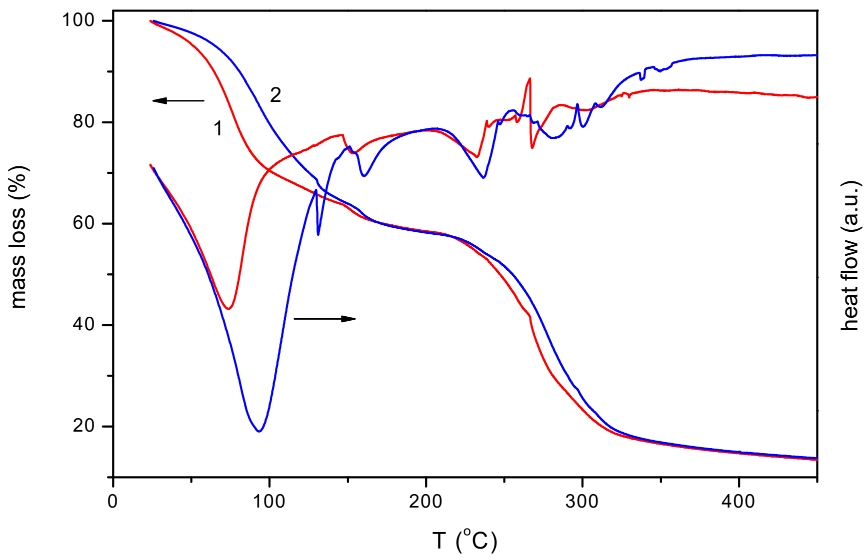

Figure 5. Mass loss (%) and heat flow vs temperature at two different heating rates: 1) 2.5°C/min and 2) 5°C/min.

It was observed that the mass loss regions are shifted to lower temperatures when the heating rate is slowed down. Hence, it can be said that a lower heating rate facilitates the early mass loss of water.

The above observations were taken into consideration to the selection of the parameters for the preparation of panels.

The lignocellulosic materials used in this study were analysed for their pH, buffer capacity and moisture content after drying. The results of these analyses are shown in the following table 3.

Table 3. Types and Properties of lignocellulosic materials

Sample No	**Description of sample**	**Moisture content after drying, %**	**Buffer Capacity, %**	**pH @ 25°C, [ ]**
1	Sieved particles (S) - 4mm	2.45	4.7	4.47
2	Sieve particles (S) - 6mm	2.37	-	-
3	Sieve particles (S) - 8mm	2.13	-	-

4	Pellets (P) - 4mm	2.45	4.9	4.38
5	Pellets (P) - 6mm	3.12	-	-
6	Pellets (P) - 8mm	3.44	-	-
7	Milled pellets (MP) - 4mm	2.95	4.9	4.4
8	Milled pellets (MP) - 6mm	3.02	-	-
9	Milled pellets (MP) - 8mm	2.79	-	-
10	Control wood	3.47	5.0	5.46

The panels made of sieved particles (S) and milled pellets (MP) were produced without any problems. However, MP had higher density than S particles and hence more dense panels of about 20-25% were produced.

The material in the form of pellets was not able to yield particleboards because the pellets had a film on their outer surface created during the palletization process which did not allow their proper wetting by the glue mixture. Moreover the geometry of the pellets irrespectively of their particle size, did not allow their good contact. The large empty spaces created between them interrupted the continuity of the panel and made their production unsuccessful.

The particleboards that were successfully produced were tested according to the European standards of table 1. The testing results are cited in the following table 4.

Table 4. Properties of particleboards

Formula			1	2	3	4	5	6	7
Substrate			**control**	S	S	S	MP	MP	MP
Particle size, mm			**-**	8	6	4	8	6	4
	Unit	**Value**				**Short press Time, s/mm**			
IB	N/mm^2	Ave	0.43	0.36	0.42	0.40	0.36	0.59	0.52
		STD	0.04	0.07	0.07	0.10	0.08	0.13	0.13
Density	Kg/m^3	Ave	619	604	629	653	770	852	822
		STD	38.27	19.85	47.81	49.02	49.44	46.76	63.58
TS 24h, 20°C	%	Ave	49.18	42.04	40.99	42.57	45.65	47.39	49.00
		STD	4.34	2.18	60.3	5.30	2.55	2.92	1.86
MOR	N/mm^2	Ave	12.75	8.53	6.36	6.06	3.11	2.22	3.59
Formaldehyde content 6.5% MC	mg/100g	Ave	5.94	8.43	8.20	8.22	9.29	7.33	8.75
						Long press Time, s/mm			

IB	N/mm^2	Ave	0.45	0.40	0.39	0.37	0.39	0.49	0.57
		STD	0.04	0.07	0.06	0.11	0.10	0.08	0.19
Density	Kg/m^3	Ave	642	629	621	632	823	806	862
		STD	14.66	19.85	51.40	65.51	91.23	31.65	118.68
TS 24h, 20°C	%	Ave	52.88	40.24	40.72	40.22	52.87	49.28	49.02
		STD	2.98	2.09	5.62	4.95	3.17	2.72	2.13
MOR	N/mm^2	Ave	12.28	6.55	6.74	6.63	2.72	3.83	2.64

The testing results show that:

- Pellets are unsuitable material for the production of conventional particleboards no matter of their particle size.
- Milled pellets, as raw-material had higher density than chips (S and control) and hence resulted in somewhat densier particleboards. These panels had noticeable improved IB, somewhat worse TS and slightly higher formaldehyde content. The property that was affected more was MOR that was at a quite low level compared to that of the panels produced with chips.
- Among the various fractions, it seems that the ones with average particle size of 6mm and 4mm are the best overall performed.

4. CONCLUSIONS

The conclusions that can be drawn from this work is that pellets as such, cannot be used in the conventional production of particleboards. However, the lignocellulosic material can be transported as pellets in order to save routes and cost and be milled on site. The milled pellets may be used at applications where heavy panels are needed but high MOR values are not necessary. The preferred average particle size of material is that of 4-6mm.

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