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A feasibility study on boards from wood and plastic waste: bending properties, dimensional stability and recycling of the board

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The increasing obligation to manage and to recycle industrial and municipal solid waste leads to the developing of new recycled products. In this paper, the possibility to make boards from wood residues and plastic waste (weight-to-weight ratio: 3:1), has been studied. They are obtained by simply heating and compressing. The mechanical tests show that the resistance to static bending are close to those of commercial particleboards. The dimensional stability of recycled wood-plastic composites appears to be particularly encouraging compared to traditional boards. Furthermore, the thermoplastic nature of the waste materials used allows the recycling of the resultant waste, or of the products once at the end of their useful life: tests of runs of successive recycling without any additional supply show a slight decrease in the mechanical properties of the boards obtained, when compared to the original boards.

Untersuchungen zur Herstellung von Platten aus Holz- und Kunststoffabfällen: Biegefestigkeit, Dimensionsstabilität und Wiederverwertung der Platten

Die steigende Verpflichtung, industrielle und kommunale Abfälle wiederzuverwerten führt zur Entwicklung neuer Produkte. In dieser Studie wird die Möglichkeit untersucht, Platten aus Holz- und Kunststoffresten im Verhältnis 3:1 herzustellen. Die Platten wurden einfach durch Erhitzen und Verpressen hergestellt. Ihre statische Biegefestigkeit lag nahe der von kommerziellen Spanplatten. Die Dimensionsstabilität erscheint vielversprechend im Vergleich mit traditionellen Platten. Darüberhinaus erlaubt das thermoplastische Verhalten der Abfälle sowohl eine Wiederverwendung der Reste bei der Herstellung als auch der produzierten Platten nach ihrem Gebrauch. Nach mehrmaliger Wiederwertung solcher Platten ohne sonstige Zusätze ergab sich eine nur geringfügige Abnahme der mechanischen Eigenschaften.

1 Introduction

The management of industrial and municipal solid waste is one of the major objectives of sustainable development. All the industrial nations are thus looking for new solutions to reuse and recycle their waste. Beyond legislation and declarations of intention, it is also necessary to find some technical and practical applications for our most common waste materials. At first, the actions which needs to be taken are only demonstrative: it is necessary to show that recycled materials, made of waste, can have good enough characteristics to allow their use in non technical applications. Then, sooner or later, the finished products should allow us to decrease the surge of discorded waste, and also to save the first materials coming from non renewable and imported resources (those resources of which we don't control the price : e.g. petrochemical products). This article was written to help developing such solutions and to study the possibilities and the characteristics of materials made from wood and plastic waste (municipal or industry refuse).

Many investigations have been made in the recycling field by manufacturing thermoplastic-wood composites : the general idea is to use a virgin component and a recycled one. Yam et al. (1990) have worked on the incorporation of virgin fibres of wood in some recovered PEhd (high density polyethylene of milk bottles).

Ramirez et al. (1984) have used henequen fibres and recovery PEhd from plastic bags and sand to form a composite whose advantages are a good resistance to photodegradation and exceptional thermal insulation. The mixed plastic having very often poor mechanical resistance, Hon et al. (1992) have proposed to add to mixtures of melted plastics (PS, PE, PP) some newspaper fiber (up to 50 % of the plastic weight). After a strong mixing, the mixture is heat-pressed, and then cooled in the press : these composites show much improved rigidity than those obtained without adding fibre. The same team showed that there aren't any chemical interactions between the different components.

As early as 1971, Mitsubishi Corp developed the Papia®, a composite made of old newspapers and of PP (Polypropylene) (1:1), destined to the making of car components, by injection or by thermoshaping. In the field of the paper fibre, Krysyk et al. (1993) partially substitute fibres of recycled newspaper to the virgin wood fibre used to build fibre boards. Using phenol-formaldehyde resins and fibers (half of these recycled), they obtained 3 mm thick products, whose characteristics are inferior to classical fibre boards, but anyway satisfying American norms requirements.

Always concerning recycled paper fibre, Ellis et al. (1993) studied the possibility to make sandwich composites from recycled telephone directories and powdered plastic (PE coming from recycled grocery shopping bags) (2:1) and obtained, after heat pressing, boards with mechanical characteristics similar to those of a common particleboard, but with a greater sensitivity to water.

In a very different field of recycling, Gil (1993) worked on powder, coming from industrial transformations of cork, and proposed to agglomerate it with thermoplastics rather than burning it. He made agglomerated boards made of cork powder and PEhd (4:1) remarkable for their

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low thermal conductivity and their resistance to static bending, close to those of classical particleboards.

Thus, generally, when the recycled material is lignocellulosic, it has been used as paper fibre or woodflour. In the present work instead, materials that are all coming from waste are used, as an extreme case of simplification of the preparation process of recycled boards. Heterogeneous wood and plastic waste is used, and boards are obtained by simple heating compression, starting from dry mixtures.

2 Recovery materials and method

All the composite boards presented are made 75 % of wood and 25 % of thermoplastics (reported to the dry weight of the board).

2.1 Wood waste

Oak sawdust and chipped heterogeneous softwoods residues that are not really used in the wood industry to make value-added products, were used:

Particle size analysis (w/w) of the wood residues:

Mesh :	Chipped softwoods :	Mesh :	Oak sawdust :
0 < X < 0.5 mm	6.3 %	0 < X < 0.25 mm	14.1 %
0.5 < X < 1.25 mm	52.6 %	0.25 < X < 0.5 mm	29.2 %
1.25 < X < 3.15 mm	36.2 %	0.5 < X < 1.25 mm	49.1 %
3.15 < X	4.8 %	1.25 < X	7.6 %

2.2 Plastic waste

The thermoplastic waste used has an industrial or post-consumer origin. Industrial waste is used as powder (between 0.08 and 0.25 mm) or chipped material (particles of about 0.5 cm^2 of surface). The post-consumer plastic waste, coming from selective collections, is under the shape of chipped material. The mixed plastic, composed mostly of polyolefins, has the shape of machining off-cuts.

2.3 Preparation of the composites

The difference in density, shape and chemical nature makes it difficult to obtain a homogeneous wood-plastic mixture. Two ways have been used to make the mix homogeneous :

- Mixing at high moisture content : the wood waste used has a moisture content higher than 50 %.
- Mixing with the addition of a surfactant : Triton X 100 (Rhöm and Hass Company) is used in the proportion of about one %, reported to the ovendry weight of the board. In this case, wood residues are first dried to a moisture of 2 to 4 %.

2.4 Mixing of the components

The mixing of wood, plastic, and sometimes of the diluted surfactant, is carried in a rotary blender for three minutes at 250 RPM.

2.5 Board manufacture

Coming out of the mixer, the mats are hot pressed in a Dolouet 100 tons press. The mixture is pressed at 30 bar. The pressing time is function of the moisture content of the mixture : dry mixtures must remain for 15 minutes in the hot press, while those obtained from wet wood waste must remain for 40 minutes in the press, with several degassing cycles. The temperature of pressing is between 180 and 200 °C, which means higher or equal to the melting point of the thermoplastics used.

The boards are taken then out of the press or cooled to 75 °C in the press itself.

2.6 Testing methods

Each board (450 × 450 × 8–11 mm) is cut into 10 bending specimens (250 × 40 × (8–11) mm). Mechanical measurements were made on an Instron universal testing machine (Model 4206) : the samples were tested in three points bending.

3 Experimental results and discussion

3.1 Results of the bending test

For boards made of oak sawdust and PEhd recovery powder, the average MOR in bending of the boards cooled in press were found to be superior to those of the boards cooled without pressure : 14.73 against 12.41 MPa (Figure 1). The homogeneity of the boards is increased by cooling them in the press : the variation coefficient, from 15 % (out of the press), go to less than 10 % (cooled in the press). The cooling in the press allows to obtain MOR in bending (14.73 MPa) and MOE (2295 MPa) close to those of a 16 mm particleboard (respectively 16.94 and 2316 MPa). Other types of mixtures have been tested (with a few examples in Table 1). These results aren't complete, but show that, whatever plastic waste is used, it can produce boards with characteristics from moderate to good, as compared to those of commercial particleboards. The worst of them has a MOR in bending of about 60 % of that of a commercial particleboard of the same thickness. The better result for MOR in bending (18.30 MPa) is obtained with a PVC/softwood board, but the high moisture content of the wood (50 %) makes difficult the manufacturing of

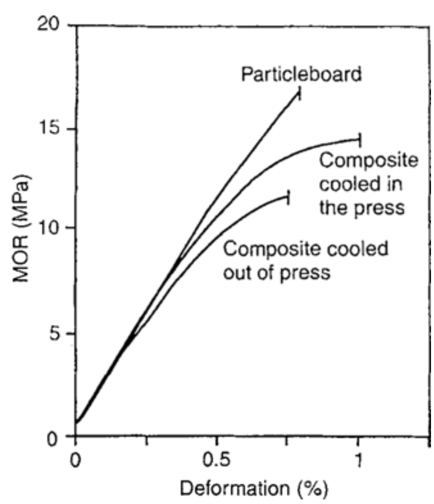

Fig. 1. Average bending test data of softwood-PEhd composites and of a particleboard
Bild 1. Mittlere Biegefestigkeiten von Kunststoffabfällen und einer entsprechenden Platte

Table 1. Average MOR and MOE of different boards based on recovery material: (sample's thickness: approximatively 10 mm)
Tabelle 1. Mittlere Werte für MOR und MOE von Platten aus Abfallmaterial. (Probendicke ca. 10 mm)

Wood residues:	Moisture content:	Thermoplastics:	Surfactant (%W/W)*	MOR (MPa)	Variation coefficient**	MOE (MPa)	Internal bond strength (Mpa)
Softwood	50 %	PVC (industrial power)	0	18.30	25 %	-	0,44
Oak	2 %	PP (industrial power)	0.75	12.65	16 %	1824	-
Softwood	2.5 %	Mixed plastic chips	0.8	14.97	21 %	2891	0,40
Oak	2.5 %	Mixed plastic chips	0.8	10.84	23 %	2204	0,30
Oak	2.5 %	Chipped PVC (bottles)	0.8	9.19	20 %	2104	0,40
Oak	4 %	Chipped PEhd (bottles)	0.8	9.49	5 %	1746	0,31
As a comparison: Commercial Particleboard (thickness: 10 mm)				14.70	12 %	3000	
Commercial particleboard (thickness: 16 mm)				16.94	10 %	2800	0,35

*based on ovendry board weight

**Variation coefficient $= \frac{\text{MOR standard deviation}}{\text{MOR average value}} \times 100$

this kind of material (due to the necessity of using degassing cycles). For all the boards manufactured, the MOE values are between about 60 % and 100 % of those of commercial particleboards. All the measured internal bond strengths (0,31 to 0,44 MPa) are close to that of an industrial particleboard (0,35 MPa).

3.2
Dimensional stability (Norm NFB 51–252)

After stabilisation, some samples (surface 100 × 100 mm) are dipped vertically into water for 24 hours (20°C). Then their thickness swelling and water absorption are measured. Whatever is the nature and the size of the plastic waste, the samples made of waste show greater absorption than classical wood-based panels (Figure 2). However, their thickness swelling is lower than that of particleboards tested undersame conditions (Figure 3). These small thickness variations aren't only due to a lower wood proportion (75 %, while particleboards have 90 % of wood). Actually, if the variations observed are reported to the proportion of wood in the finished materials, the composites based on oak sawdust and plastic waste appear to be more stable than traditional particleboards.

The good dimensional stability of wood thermoplastic composite compared to traditional boards can be explained by his internal structure (Figure 4). However in the surface of the board, a coat of glue should decrease the water absorption of the particles of commercial boards, this absorption is very high in the wood thermoplastic boards. But, in depth plastic particles should make a waterproof sheet, protecting the wood particles from water absorption and so, from thickness swelling. In this way,

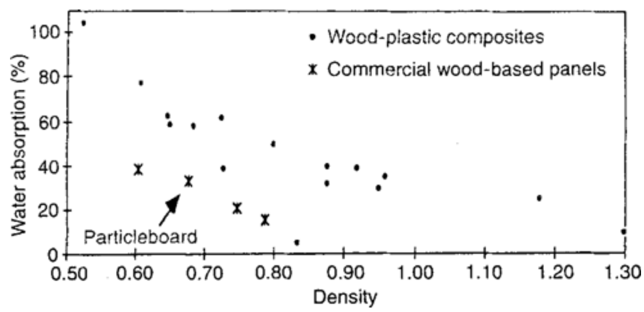

Fig. 2. Water absorption versus density after 24 hours of immersion in 20 °C water
Bild 2. Wasseraufnahme in Abhängigkeit von der Dichte nach 24-stündiger Lagerung in Wasser bei 20 °C

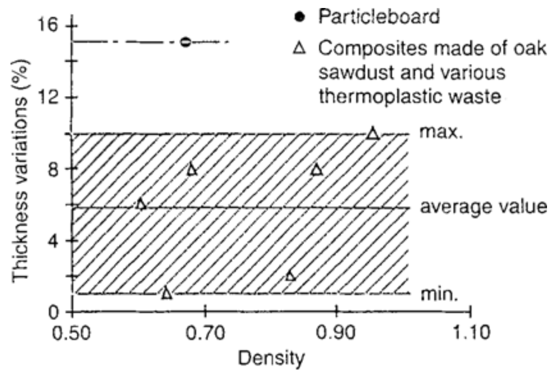

Fig. 3. Dimensional variations after 24 hours of immersion in 20 °C water
Bild 3. Dimensionsänderungen nach 24-stündiger Lagerung in Wasser bei 20 °C

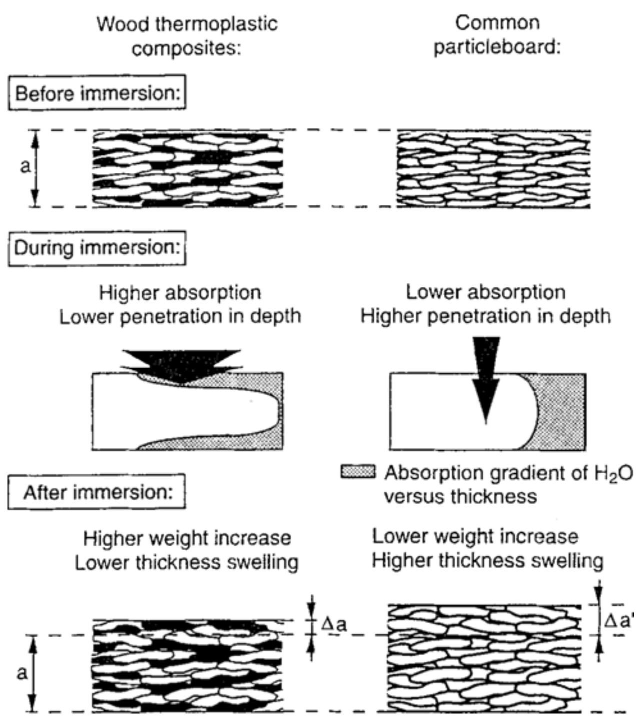

Fig. 4. Dimensional stability: water absorption and thickness swelling
Bild 4. Dimensionsstabilität: Wasseraufnahme und Dickenquellung

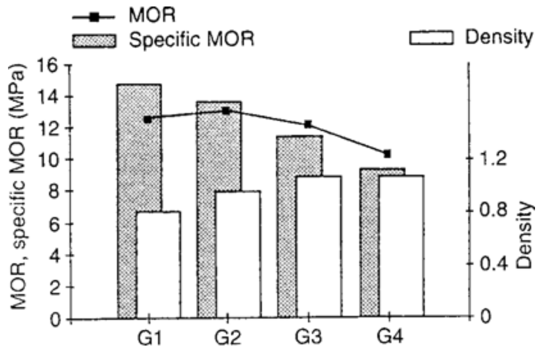

Fig. 5. Static bending test of successive runs of recovery boards on oak sawdust and polypropylene powder
Bild 5. Ergebnisse der statischen Biegeprüfung nach mehrmaliger Wiederverwertung von Platten aus Sägemehl (Eiche) und Polypropylen-Pulver

wood thermoplastic composites present a higher global water absorption but a lower thickness swelling than commercial particleboard. A complementary explanation for this behaviour could be that the inert thermoplastic resin makes such a strong network to oppose the wood particles swelling, hence the global thickness swelling of the composite.

3.3 Recyclability test

As they are made from wood and thermoplastics, the boards made are, at least inpart, recyclable. To evaluate their recycling potential, the evolution of MOR for runs of successive recycling of composite boards (oak polypropylene) was followed. Figure 5 shows the results obtained with composites of oak sawdust-polypropylene. Boards G1 to G4 have followed the same cycle of pressure (30 bars, 200 °C) described previously ; board G2 is obtained by re-chipping and hot pressing of G1, board G3 is obtained the same way from G2, and board G4 comes from the chipping of G3. These tests show the possibility of direct re-using, after chipping, of the residues and waste of the initial products without any additional supply ; this is a possibility that the presently commercial boards don't have.

4 Conclusions

This study shows the possibility to make composites coming from 100 % of recycled products. The boards made haven't only ecological interest : their mechanical properties and their dimensional stability allow for a wider spectrum of applications : decoration, furniture, packing, profiled sections... Though the mechanical characteristics of the products obtained are moderately good, the dimensional stability of the composites and their potential recyclability offer new perspectives in the field of wooden boards.

The composite wood-thermoplastic boards are also easy to cut and machine and have closed and homogeneous edges, able to be post-formed. Their composition also shows the possibility of shaping them by extrusion or by post-forming.

There is still the problem of the cost of manufacturing such products : it seems difficult to compete against the low price of particleboards (due to their massive production). However, legislation and taxation supposed to help recycling could, sooner or later, make these composites economically interesting.

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