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REED CANARY GRASS AS LIGHT-WEIGHT CORE IN PARTICLEBOARDS

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Abstract:

Particleboards are an important material for furniture production. In this sector, two tasks have had priority during recent years: to reduce the weight of the panels and to reduce the formaldehyde emission. As the production methods have been more or less the same for decades, these tasks have to be tackled by reducing or replacing the raw material in the board production.

In this study, the possibility of replacing wood with reed canary grass (Phalaris arundinacea L.*) to obtain a light-weight particleboard has been studied. The boards studied were three-layered with a core of wood/reed canary grass particles and a surface of 100% wood particles. A protein-based adhesive was tested as an alternative to a UMF adhesive to reduce the formaldehyde emission. Different combinations of densities between 250 and 450kg/m^3 were included in the study and no additional treatments were made to the raw materials.*

The results showed poor mechanical and swelling properties of all the tested boards regardless of the design. The main explanation of the poor properties is the poor wetting of the reed canary grass surface by the adhesives. A pre-treatment of the reed canary grass particles with steam, lipase enzyme or alkali is suggested to increase the wettability.

Key words: *light-weight panel; non-lignified plants; protein adhesive; three-layer chipboard; urea formaldehyde.*

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INTRODUCTION

Particleboards are an important material in furniture production. Most of the over 10 million m^3 of particleboards produced in Germany in 2008 (a quarter of the EU27 production) was used by the furniture industry (Anon 2012). Recent approaches to reduce the weight of particleboards take advantage of a decrease in the core density by using less wood or by introducing polymer - or starch - based granules to replace some of the wooden particles in the core (Kharazipour *et al*. 2011). In recent years, the panel-producing industry has presented some innovative particleboards to reduce costs, partly as participants in the Development of Innovative Particleboard Panels project (DIPP 2012). These alternatives include, for example, the "Balanced Board" (Pfleiderer 2013), "Kaurit Light" (BASF 2013) and "Recoflex" (BSW 2013). These products have less weight and some filling material to save wood while having properties the same as or even in addition to these of conventional particleboards. This is an indication of an on-going specialization of wood-based panels for certain applications and towards multi-component and multi-layered materials (Shalbafan *et al*. 2013).

The main driving force for this development is the increasingly tightening competition for wood between the board industry and the energy-conversion industry. There are forecasts showing that, already in 2020, the European consumption of wood and wood fibre raw material can be as large as Europe's combined forest growth increment (Jonsson *et al*. 2011). An increasing proportion of the forest raw material is expected to be used as fuel for heating, as propellant fuel or to generate electricity. To this scenario is added the mobile outdoor life and not least the preservation of biological diversity, which will require the additional allocation of forest land, and thus reduce the availability of land which can be used for timber production. The future will be characterized by increasing energy prices, which means that the energy sector will be able to pay more for wood raw material. The first material which will be exposed to competition is the raw material for panels.

A trade-off between costs and properties

A lower weight of particleboards can result in a decrease in material usage and lower energy consumption, which would lead to lower costs, but less weight is often realized by substituting one raw material for another, and this may lead to benefits not in material costs but in handling and transport costs, for example. In Balanced Board, the low weight is reached with granules of wheat and corn (Kharazipour *et al*. 2011) and in Kaurit Light with polymers (BASF 2013). The Fraunhofer Institute has concentrated on producing particleboards from agricultural plants and residues with densities in the range of 200-550kg/m^3. Panels produced from hemp, sunflowers and maize stalks with a minimum density of 400kg/m^3 passed the requirements for internal bonding strength according to EN312/P2 (WKI 2013). Even if they do not yet reach the norms, these examples show that agricultural residues might make it possible to produce light-weight particleboards (Boquillon *et al*. 2004). In most cases when annual plants are used in particleboard production, a combination of plant raw material and wood is used. An example on the market is the "Spanplatte leicht" with a density of 400 kg/m^3 which is based on a combination of hemp and wood (Elka 2013).

A light-weight panel with a low-density core has the disadvantage of lower mechanical properties (Kutnar *et al*. 2008). Compared to conventional particleboards, agro-residuals are less qualified than wood as raw material for particleboards. Even if some properties such as the withdrawal capacity of fasteners may be reached by a frame-construction system, for example, the property requirements specified in EN312/P2 for panels for the furniture industry still have to be met. These properties are internal bonding strength, bending strength, modulus of elasticity, surface soundness as well as formaldehyde emission and thickness swelling (Kües 2007). The production process has to be adapted to the properties of the agro-residuals. For example, the heat transfer to the core of the board during pressing is considerably lower for agro-residuals than for wood, and the temperature must then be increased during the particleboard production to maintain the productivity (Azizi *et al*. 2011). When particleboards are produced from kenaf stalks, for example, both the temperature and the pressing time have a significant influence on the mechanical properties of the boards (Kalaycıoglu and Nemli 2005). An increase in the amount of straw increases both the water absorption and on the thickness swelling (Azizi *et al*. 2011).

The economic pressure on the particleboard industry is forcing the industry to search for alternative raw material sources. One option might be to use agro-residues from annual and perennial plants. A technical reason why these plants or parts of them are of interest is the opportunity to produce panels of lower weight than panels of wood alone. Nevertheless, there seems to be a loss of physical properties with an increasing amount of monocotyledons in the board, and this has to be handled.

Monocotyledons as raw material for particleboards

Monocotyledons, in particular non-wood plants or plant parts, are different from wood in e.g. the size and chemical composition of the cells. Further the raw material affects the wettability, depending on whether the internal or external surface is considered (Wiśniewska *et al*. 2003). The reason is that plants have

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special external layers consisting of cuticules and epicuticular waxes (Barthlott and Neinhuis 1997). The structure of the external layer includes the layer of epidermal cells followed by a layer of pectin on which there is a thick cutinised layer with embedded waxes and finally as a barrier to the environment on epicuticular wax layer (Wiśniewska *et al*. 2003). This gives the external surface an extremely hydrophobic character, and also prevents the specially designed roughness of the wax layer water from forming large contact areas (Taiz and Ziegler 2010). When the straw is chipped into particles, this leads to quite a heterogeneous material with respect not only to size but also to the chemical properties of the surfaces, and this leads to problems for the industry which seeks to use non-lignified plants in, for example particleboards glued with common aqueous adhesives.

In addition, the amount of biomass available is important. The amount of agricultural residues can be estimated based on the data for harvested corn using a suitable corn-to-straw ratio (Kaltschmitt *et al*. 2009). Not only agro-residues but also fast-growing species with a high annual productivity such as giant reed (*Arundo donax* L.), giant cane (*Arundinaria gigantean* (Walter) Muhl.), and reed canary grass (*Phalaris arundinacea* L.), can be interesting raw materials in particleboard production. Further research in the area of bioenergy can also suggest possible raw materials. Frączek *et al*. (2011) and Šiaudinis et al. (2012) have suggested the use of the cup plant (*Silphium perfoliatum* L.) for energy conversion, but this plant may also be an option for panel production.

Based on a chemical classification of the inorganic matter in high-temperature biomass ashes, herbaceous and agricultural biomass, including grass, straw and residues all belong to the same class (Vassilev *et al*. 2010). Comparing four optional non-wood sources for particleboards according to their amounts of cellulose, lignin and hemicelluloses it is obvious that they differ only slightly from each other and this might facilitate substitution, Table 1. The difference in their stem structure make it difficult, however, to use annual plants in the same way as wood, but if a way can be found to use this material, substitution and variation of the raw material appear to be possible and this should prevent supply bottlenecks.

Table 1

Chemical properties (% of dry weight) of reed canary grass compared to three other species of non-lignified plants and wood

Species	Cellulose	Lignin	Hemicelluloses	Ash	References
Wheat straw (*Triticum aestivum* L.)	41	8	31	6.3	Bridgeman et al. (2008)
Miscanthus (*Miscanthus x giganteus*)	49	11	30	2.6	Hodgson et al. (2011)
Reed canary grass (*Phalaris arundinacea* L.)	30–43	8–11	25–30	1.3–6	Dien et al. (2006), Bridgeman et al. (2008), Jansone et al. (2012)
Cup plant (*Silphium perfoliatum* L.)	36	12	18	9	Wulfes (2012)
Softwoods	40–45	25–35	25–30	0.2–0.4	Fengel and Grosser (1975), Pettersson (1984)
Hardwoods	40–50	20–25	25–35	0.2–0.8	

Reed canary grass

Reed canary grass is a perennial grass reaching a height of up to 2 metres and yielding a maximal dry mass production of 4–10 tonnes per hectare depending on whether it is a summer harvest (8–10 tonnes per hectare) or a delayed harvest (6–8 tonnes per hectare) (Finell 2003). This rhizome-building perennial C_3-grass is well adapted to wet soils with a low pH-value (Hall 2008) and can be found in the whole of northern Europe such as Sweden (Xiong *et al*. 2008, Anderberg 2009), as well as Finland (Pahkala *et al*. 2008) and the Baltic countries (Kukk *et al*. 2011). A great advantage of this species is the high production of biomass even in boreal zones, which makes it an interesting species for energy conversion (Xiong *et al*. 2008) and also for pulp and paper production (Thykesson *et al*. 1998, Finell 2003). To consider it as a raw material for particleboards has not yet been presented in the literature, but the idea of producing a high-density fibre board of reed canary grass was introduced by Olsson *et al*. (2005).

The area devoted to reed canary grass production in Finland increased from 500 hectares to 17.000 hectares between 2001 and 2006 (Casler *et al*. 2009). A general feature of delayed-harvest reed canary grass is that the crop has then withdrawn nutrients and minerals to the underground rhizome system, leading to a lower content of inorganic substances in the straw. The chemical composition of the reed canary grass differs depending on the harvesting time, and differences in chemical composition between spring and autumn harvest are shown in Table 2 (Pahkala and Pihala 2000).

Table 2

Chemical composition (g/kg or mg/kg dry matter) of reed canary grass at different harvesting times (spring/autumn harvesting)

Plant component	Ash (g/kg)	SiO_2 (g/kg)	K (g/kg)	Cu (mg/kg)	Fe (mg/kg)	Mn (mg/kg)
Stem (internode)	50 / 47	40 / 17	3 / 15	6 / 6	61 / 19	48 / 20
Leaf sheath (node)	90 / 84	74 / 43	4 / 20	7 / 4	267 / 67	140 / 53
Leaf blade	130 / 115	107 / 57	4 / 21	8 / 6	491 / 110	213 / 80

OBJECTIVE

The aim of this study has been to evaluate reed canary grass as a light-weight component in particleboard production and to identify the main drawbacks from a technical point of view.

MATERIALS AND METHOD

Eleven different samples of three-layered particleboard with dimensions of 500x500mm and thicknesses between 12 and 30mm have been produced and tested. The design of the individual boards is presented in Table 3. The target density in all cases was between 250 and 450kg/m^3 and the substitution of wood by reed canary grass was 33-75% of the dry weight of the board. The amount of adhesive was 10% of the weight of the board.

Delayed-harvest reed canary grass from northern Sweden was used in the study. It was chipped to a length of 1 to 50mm and stored in the dry form at a moisture content (MC) of 7.4%. Wood particles mainly of spruce (*Picea abies* Karst.) were used in the tests. The wood particles were graded into two groups according to size: SP with a length up to about 5mm (MC 5.3%) and LP with a length between 5 and 25mm (MC 6.2%). Wood and reed canary grass particles were used without any additional mechanical or chemical treatment.

Two types of adhesive each in an amount of 10% by weight were used in the test: 1) an urea-melamine-formaldehyde (UMF) adhesive (Casco 1125) with urea and ammonium nitrate (NH_4NO_3) as hardener, and 2) a protein (Amygluten 110 from SYRAL Belgium N.V.), which is generally used in the food industry. The protein was delivered as a water-soluble powder.

A hydraulic press was used to manufacture the boards, and the temperature during the pressing of the boards was 200°C. Pressing times were chosen between 8 and 21 seconds per millimetre of thickness. The pressure was adjusted according to the pre-calculated volume of material to reach a board density between 250 and 450kg/m^3.

The mechanical properties, i.e. modulus of elasticity (MoE), bending strength (MoR), thickness swelling (TS), and internal bond strength (IB) of each board according to EN312 were determined.

RESULTS AND DISCUSSION

The main results are:

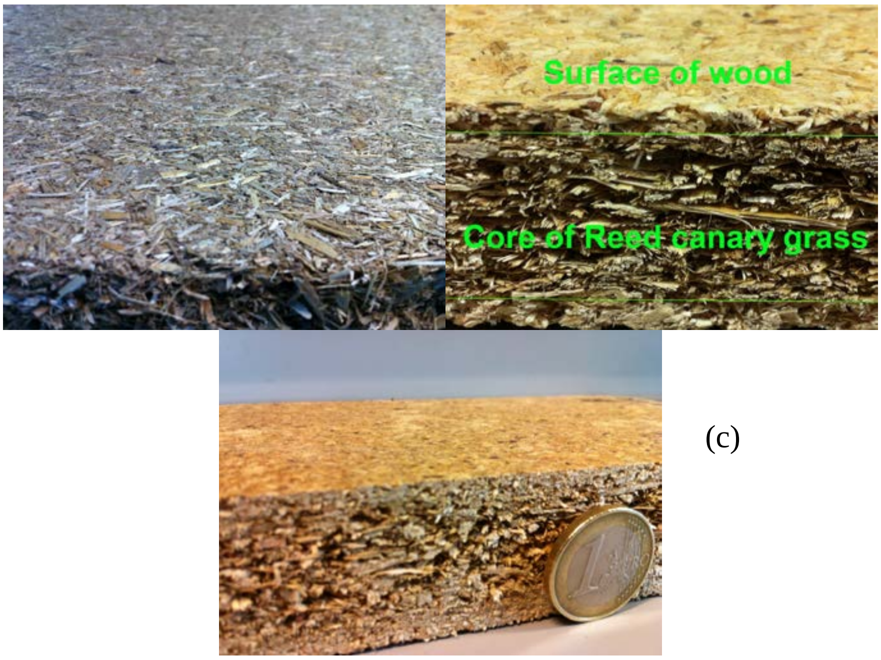
- It was possible to obtain boards of a density from 350 to 450 kg/m^3 with reed canary grass up to 75% of the dry weight of the board and surface layers of acceptable roughness consisting only of wood particles (Table 3 and Fig. 1).
- It was not possible with these boards to reach the mechanical or swelling properties prescribed in the EN312 norm with either MUF or protein as adhesive.
- Values of the properties of the boards were: MoE < 600 MPa; MoR < 2.2 MPa; IB < 0.1 MPa; TS > 20%.
- The weakest link was the poor internal bond strength of the reed canary grass core layer.
- The thickness swelling increased with increasing amount of reed canary grass and the swelling was even greater when the samples were glued with protein.

Table 3

Design of the samples: two sizes of wood particles (SP, LP) and reed canary grass (RCG) 33-75% of the dry weight of the board mixed with 10% urea-melamine-formaldehyde (UMF) or protein adhesive

Sample No.	Board design		RCG % per dry weight	Adhesive	In press	Thickness	Density
	Core	Surface		Type	(sec/mm)	(mm)	(kg/m^3)
1	RCG/LP	SP	33	UMF	9	20	387
2	RCG/LP	SP	33	UMF	10	30	354
3	RCG/LP	SP	50	UMF	10	12	410
4	RCG/LP	SP	50	UMF	18	20	437
5	RCG/LP	SP	50	UMF	9	30	372
6	RCG/LP	SP	50	Protein	10	12	444
7	RCG/LP	SP	50	Protein	21	20	446
8	RCG/LP	SP	50	Protein	18	20	437
9	RCG/LP	SP	50	Protein	9	30	401
10	RCG	SP	66	Protein	8	20	436
11	RCG	SP	75	Protein	8	20	382

(a) (b)



(c)

Fig. 1
Design of the particleboards: a - a surface view of the core layer consisting of pure RCG chips or of RCG in combination with wood particles; b - a cross-section view of a three-layer board; c - surface and dimension of a three-layer board.

These results show that if reed canary grass is to be used in particleboards the same problems regarding gluing arise as for other non-wood plants like straw. The poor adhesion between the surface of the reed canary grass and the adhesive resulted in a low bending strength in all the boards tested. Ways to avoid these problems can be for example:

- Pre-treatment of the grass: De-waxing of different kinds of straw can be achieved with hexane (C6H14), carbon tetrachloride (CCl4), alkali (NaOH, NaNH2, CaH2, KOH, H2O2), enzymes like lipase or steam treatment (Candida cylindracea) (Hua *et al*. 2009, Zhao and Boluk 2010, Bing *et al*. 2011, Shen *et al*. 2011).
- Using additional surfactants or coupling-agents: Surfactants used in herbicide solutions might increase the wettability of the particles. As coupling agent, silane is of great interest. Experiments on reed and wheat straw showed that silane coupling agents like vinyl-, amino-, and epoxide-silane lead to improved properties of particleboards (Han *et al*. 1998). Silane coupling agents have been used in particleboards designed as sound absorption materials consisting of rice straw and wood bonded with UF (Yang *et al*. 2003).
- Using alternatives to MUF adhesive has been shown to result in better wettability and tacking on surfaces of annual plants. Examples are isocyanate-based adhesives such as MDI (diphenylmethane diisocyanate), polymeric MDI (pMDI), and polyurethane (PUR) because of their non-specific adhering properties (Frazier 2003, Boquillon *et al*. 2004, Torkaman 2010). The synthetic polymers PVA (polyvinyl alcohol) and PVAc (polyvinyl acetate) might also be suitable, as these adhesives allow many modifications (Qiao *et al*. 2002).

Another problem, besides the wax layer which gives poor wettability, is that the reed canary grass becomes brittle during heat treatment. Besides modification of the raw material, the production process must be optimized with respect to temperature and time to avoid too severe degradation of the reed canary grass. In this study, two extremes were tried: a very low density and a very high substitution of the wood. At least it was possible to produce boards and, in addition to furniture production, this kind of panel might be interesting for other interior uses such as insulating material. Further tests were carried out using different adhesives with and without pre-treatment of RCG as well as different additives. Results show that it is possible to increase wettability and bonding of adhesives on the external surface of RCG by using a combination of the different options mentioned above.

CONCLUSIONS

This study of particleboards with reed canary grass in the core has shown that it is possible to produce light-weight boards, but that it is not possible to achieve the properties required by the EN 312/P2 norm for particleboards using only UMF or protein adhesives. Literature and further tests showed that either a pre-treatment of the surface of the grass or the use of an additive such as a coupling agent can help to increase the bonding of these adhesives. Alternatively, adhesives with different tacking properties such as isocyanate-based adhesives can be used. The different indicators show that both the production process and the combination and modification of the raw materials have to be optimized to increase the mechanical and reduce the swelling properties. With these methods, it might be possible to achieve the aims of this study to produce light-weight multi-layer particleboards containing an amount of reed canary grass of more than 50%.

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