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CHALLENGES USING ANNUAL PLANTS AS SUBSTITUTES FOR WOOD IN PARTICLEBOARD PRODUCTION – MODIFICATION OF REED CANARY GRASS

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ABSTRACT

Forecasts show 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. An increasing proportion of the forest raw material is expected to be used as fuel for heating, as propellant fuel or to generate electricity. This means an increasingly tight competition for wood between the board industry and the energy-conversion industry and a need for the board industry to find new raw material sources.

High productivity in the boreal regions makes reed canary grass interesting as a raw material for several applications where wood is today the main raw material. One possible application is in board manufacture, e.g. as a substitute for wood in the core of multi-layer particleboards. The properties of reed canary grass must, however be modified to meet the industrial standards for particleboard production and for the mechanical properties of the boards. Alternatively, different adhesives can be chosen.
The purpose of this paper is to present some pre-treatments and adhesives suitable for use when reed canary grass is used as core material in industrial particleboard production. An overview of different methods for pre-treatment and optional adhesives that can be used to increase the bonding properties of annual plants in the context of particleboard production is also presented.

The bonding properties have been studied through mechanical tests and through light microscopy studies. Untreated and NaOH-pre-treated reed canary grass in combination with MUF, PVAc, Lignin, and PUR adhesives have been used in the tests.
The results show that an adhesion suitable for particleboard production can be achieved with a NaOH-pre-treatment of the grass together with melamine urea formaldehyde (MUF), and especially PVAc and PUR adhesive. The adhesive system must, however, be optimized for industrial conditions.

Key words: Lignocellulose plants, surface modification, adhesive, light-weight panel

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INTRODUCTION

The particleboard industry is seeking cheap substitutes for wood in their production. The main reason is the increasing competition from the energy-conversion industry. One way of reducing the wood content of particleboards is to use non-wooden plants as raw material (Boquillon et al. 2004). *Phalaris arundinacea* L. (reed canary grass, RCG) which can be grown in the northern part of Europe with a good yield (Pahkala et al. 2008, Xiong et al. 2008, Kukk et al. 2011) and which can be used as a raw material for paper production or for energy conversion (Pahkala and Pihala 2000, Finell 2003) might be an option as a substitute for wood in particleboards. The surface properties of RCG, however, make it necessary to modify the surface or to use alternative adhesives in board production, the reason being that the external layers consist of cuticules and epicuticular waxes. The wax layer itself can be divided into a thin film, in general only a few nanometres thick, as a final layer of the cuticle and superimposed wax (Barthlott and Neinhuis 1997, Wiśniewska et al. 2003).

Studies on barley straw showed a high chemical and morphological heterogeneity as well as a roughness on the surface of various parts of the straw which affect the water contact angle. A contact angle of 36 to 129 degrees had been measured, the main chemical components of the wax layer being β-diketones, alkanes and esters (Wiśniewska et al. 2003). No such investigations have been reported for RCG but the properties of RCG are probably similar to those of barley straw. De-waxing can be achieved by modification with hexane (C_6H_{14}), carbon tetrachloride (CCl_4), alkali (NaOH, $NaNH_2$, CaH_2, KOH, H_2O_2) or enzymes such as lipases (*Candida cylindracea*) (Jiang et al. 2009, Liu et al. 2011, Fernandes et al. 2011, Shen et al. 2011, Zhu et al. 2012).

Besides surface modification, the use of surfactants might result in better wettability and penetration of adhesives. Surfactants generally can be divided into spray modifiers which change the characteristics of the water-based solution and sorption activators which influence the rate of absorption by the plant (Hess and Foy 2000). Examples of surfactants on monocotyledons are non-ionic surfactants like alkyl pentosides (biomass-derived) which are used in cosmetics, detergents, cold emulsification processes, solvents, and agricultural formulations (Papadopoulou et al. 2011), surfactants in herbicide solutions like the non-ionic polyoxyethylene sorbitan monolaurate, polyoxyethylene sorbitan monooleate, alkylaryl polyoxyethylene glycols, free fatty acids and isopropanol, polyoxyethylene polyproxylene polyols and the anionic sodium dioctylsulfosuccinate, sodium lauryl sulfate and others (Foy and Smith 1965, Dayan et al. 1996).

Further, some adhesives result in better wettability and tacking onto surfaces of annual plants. Examples are isocyanate-based adhesives such as MDI (diphenylmethane diisocyanate), polymeric MDI (pMDI), and polyurethane (PUR) due to their non-specific adhesion properties (Frazier 2003, Boquillon et al. 2004, Torkaman 2010). The synthetic polymers PVA (polyvinyl alcohol) and PVAc (polyvinyl acetate) may also be suitable, as these adhesives allow a large variety of modifications (Qiao et al. 2002). Other opportunities might be matrix building adhesives for WPCs and lignin.

OBJECTIVES

The purpose of this paper is to present some pre-treatments, modifications, and adhesives for use with reed canary grass (RCG) as core material in particleboards. Pre-treatment of the RCG and four different adhesives with and without a surfactant have been tested.

MATERIAL AND METHODS

In this study, delayed harvest reed canary grass from northern Sweden was used. It was chipped to a length of 1 to 50 mm and stored in a dry form at a moisture content (MC) of 7.4 %. For the tests, the single straw was unrolled and glued with the inner face on a wooden cube with a contact area of $1x1cm^2$ (Fig. 1). As adhesive between A and B in Fig. 1, a PVAc-adhesive was chosen. In a second step, four different adhesives were tested by gluing a second wooden cube with a contact area of $1x1cm^2$ on the outer face covered by the cuticule or wax layer. This external layer of RCG was either left in its natural state or treated with NaOH. As adhesives, MUF, PVAc, PUR and lignin were used both with and without an additional surfactant DSS (dioctyl sodium sulfosuccinate). Thermosetting adhesives were cured in an oven after application. After a curing time of 24 hours, samples were tested with regard to tensile strength. The highest value for the internal bond strength of particleboards of 0.5 N/mm^2 (EN 312) was chosen as reference. Areas of fracture were evaluated by light microscopy.

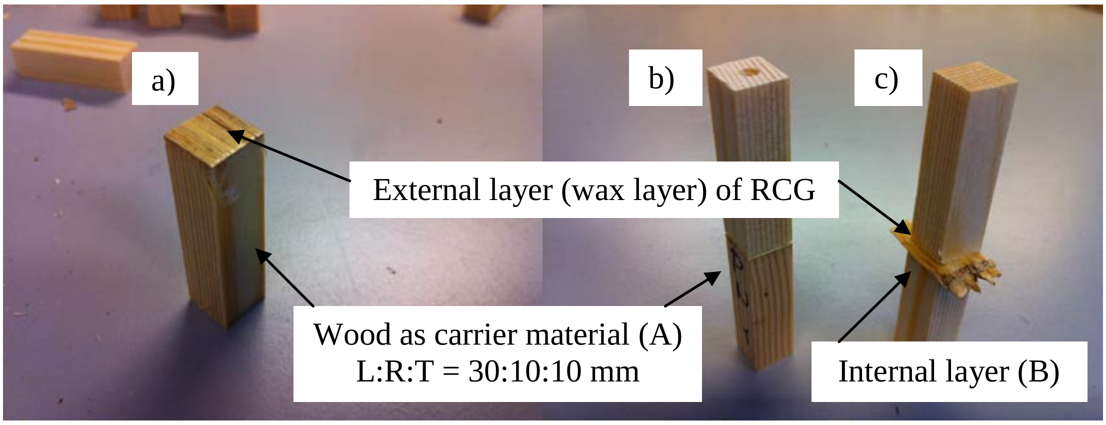

Fig. 1 Design of the samples. a) Reed canary grass (RCG) glued onto wood with PVAc as its internal layer, and b) and c) in a second step by another adhesive to the test bonding between the adhesive and external layer

RESULTS AND DISCUSSION

Table 1 show the results of the tensile test and microscopy studies. PUR fulfilled the requirement regarding internal bond strength for particleboards of 0.5 N/mm^2 (EN 312) in all combinations. For PVAc, a pre-treatment of the RCG was necessary to achieve acceptable strength values. MUF and lignin failed in all combinations, but the highest values obtained show that MUF in combination with a pre-treatment and lignin in combination with surfactant also have the potential to fulfil the requirements. The low values for MUF can also be affected by the test design as this adhesive had a very low viscosity and was oozing out of the glue line. The low values for lignin may be due to the adhesive formulation.

Table 1. Strength of the joint between wood and untreated and pre-treated reed canary grass glued with four different adhesives with and without an additional surfactant.

No. of samples	Pre-treatment or Modification	Adhesive	Strength (N/mm^2) min – mean – max	Area of fracture (fracture)
12	Non	MUF	0.00 – 0.08 – 0.17	Wax-layer (uniform)
12	Non	PVAc	0.16 – 0.45 – 0.91	Wax-layer (uniform)
12	Non	PUR	0.41 – 0.70 – 1.23	Wax-layer (uniform)
6	Non	Lignin	0.14 – 0.27 – 0.40	Wax-layer (uniform)
6	DSS	MUF	0.04 – 0.07 – 0.13	Wax-layer (irregular)
6	DSS	PVAc	0.18 – 0.32 – 0.48	Wax-layer (uniform)
6	DSS	PUR	0.41 – 0.60 – 0.73	Wax-layer (uniform)
6	DSS	Lignin	0.23 – 0.42 – 0.63	Wax-layer (irregular)
12	NaOH	MUF	0.05 – 0.42 – 0.95	Wax-layer (uniform)
12	NaOH	PVAc	0.51 – 1.57 – 2.00	Both layers (uniform)
12	NaOH	PUR	0.70 – 1.48 – 2.00	Both layers (uniform)
6	NaOH	Lignin	0.21 – 0.30 – 0.40	Wax-layer (irregular)

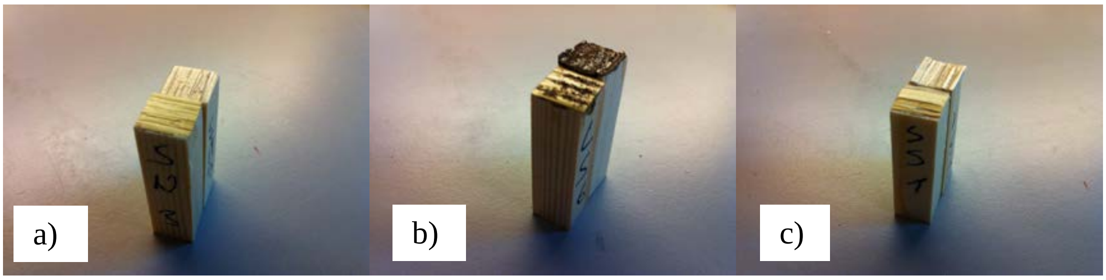

Fig. 2. Examples of fracture surfaces of the test specimens: a) wax-layer (uniform), b) wax-layer (irregular), c) both layers (uniform)

When no pre-treatment of RCG or modification of the adhesive was performed, the interaction between the wax layer of the RCG and the adhesive seems to be only physical, as the area of fracture was uniform between the adhesive and the surface of the RCG (Fig. 2a). The cured adhesive clearly showed the contours of the grass surface. The addition of surfactant resulted in better wettability and interaction in the case of MUF and lignin but the surfactant seemed to degrade all the adhesives except lignin. The better interaction expressed itself by an irregular area of fracture where parts of the adhesive stayed on the wax layer (Fig. 2b). The highest strength values were reached by pre-treatment of the RCG in combination with PVAc and PUR adhesives. The interaction between these two adhesives and the wax layer was slightly stronger than the interaction of the internal layer with PVAc. The areas of fracture were uniform suggesting that there is no penetration of adhesive through the pre-treated layer (Fig. 2c). NaOH treatment also seems to affect the bond between the internal layer and PVAc.

Both modification of adhesives with surfactants for MUF and lignin and pre-treatment for all except lignin show a greater wettability and bonding but there seems to be no real penetration of the adhesive into the RCG through the wax layer, as the fracture areas are quite uniform. It was nevertheless easily possible to fulfil the requirements by using PUR or PVAc in combination with pre-treatment with NaOH. Isocyanate-based adhesives (PUR) seem to give good bonding properties without modification. An alternative might be the use of lignin in combination with a specific surfactant when the formulation is optimized, and this would also give a thermosetting adhesive. MUF, on the other hand, does not seem to be suitable for this purpose.

CONCLUSION

The challenges facing the use of reed canary grass (RCG) as a possible raw material for the core layer in particleboards are a combination of wettability, penetration and choice of adhesive. In general, pre-treatment with NaOH has a positive effect on the adhesion between wood and RCG, and isocyanate-based adhesives also show good results. When PUR was used as adhesive, the requirements regarding the internal bond of particleboards (EN 312) was achieved with all combinations. It was also shown that the use of additional surfactants has an influence on the wettability also affects the adhesive. This means that an optimized formulation of surfactant and adhesive might be better than the time-intensive pre-treatment and expensive isocyanate-based adhesives. Even when wettability and bonding strength are increased there seems to be no real penetration of the adhesive into the wax layer of the RCG.

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