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THE USE OF GLUTEN ADHESIVE AND REMOVABLE SURFACE FINISHES IN RECYCLABLE FURNITURE PANELS

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Abstract

A general problem in the recycling of furniture is that different materials and components are included within a single piece of furniture. Not only is the furniture built of components such as wood, leather, textiles, foams, steel and others but the wood component is also very often a composite made of wood, adhesives and functional additives such as water repellents or chemical substances as surface treatments. Sometimes these additives make cost-effective recycling of the composite wood difficult because of problems related to the separation of the components. The purpose of this study was to present an alternative product design for wood-based panels i.e. particleboards, which reduces or avoids many of the problems in the recycling of wood-based panels used in furniture. The results show that it is possible to produce wood-based panels in a way that facilitates the recycling of these panels although there are still some challenges which have to be dealt with. The concept as such seems to be promising.

Key words: *particleboard; bio-based adhesive; surface coating; waste separation.*

INTRODUCTION

In the literature, various ways of recycling different products and components are presented for wood and wood-based products, where wood and wood-based products are often considered separately from demolition (Höglmeier et al. 2013) and from furniture, (Handfield et al. 1997) because their recycling requires different strategies. The recycling of furniture can be considered either from a logistics-oriented approach such as product-service systems (Besch 2005) or from a more technically oriented approach such as particleboards made of recycled waste wood (Lykidis and Grigoriou 2008). The problem in the recycling of furniture having wood-based components is that they use a mixture of different materials (Besch 2005). A single wooden component such as a particleboard, for example, is often composed of different materials (Falk 1997; Lykidis and Grigoriou 2008). Recovered wood waste is therefore often used for thermal energy recovery if it is not contaminated with hazardous substances (Krook et al. 2008), but there are often restrictions for the use of the ash from such a combustion.

For wood-based components in furniture the challenges and problems relating to recycling strategies are similar to those which have been well analysed and researched for plastics. For example, plastics used in the automotive industry are combined with other components such as steel, textiles, and other plastics. A single plastic component is often heterogeneous, being mixed with other plastics or additives which make recycling difficult or even impossible (Miller et al. 2014). Parallels can be drawn between the recycling concepts and systems for thermosetting plastics (Al-Salem et al. 2009; Hopewell et al. 2009) and those for wood-based panels. The challenges in wood recycling are therefore related to the following factors:

- The mixture of diverse materials makes sorting necessary;
- The processing leads to different sizes and shapes;
- The material is contaminated with materials or substances such as fasteners, dirt, finishes and adhesives;
- Mechanical stress in use or in demolition leads to poorer raw material properties than the virgin raw material;

- Recycling of composites is difficult when the materials cannot be separated from hazardous components (cleaning after size reduction and further separation);
- Compared to the value of the raw material the logistics and technology are relatively cost-intensive.

Besides landfill with or without incineration, breakdown, and simple re-use, there are four categories for plastics recycling viz.: (a) mechanical reprocessing to a product with equivalent properties (closed-loop recycling), (b) mechanical reprocessing into products requiring lower properties (downgrading), (c) recovery of chemical constituents (de-polymerisation), and (d) recovery of energy (valorisation) (Hopewell et al. 2009). For plastics, the recovery of chemical constituents can also be referred to upcycling, i.e. a conversion into higher value product(s). One example is the conversion of PET (polyethylene terephthalate) into the biodegradable PHA (polyhydroxyalkanoate) (Kenny et al. 2008). For wood waste, the recovery of secondary fibres for papermaking purposes can be interpreted as upcycling (Monte et al. 2009). Logistical costs, a lack of infrastructure which enables a continuous supply of clean recycled wood and a lack of definitions and material standards are reasons why wood waste is mainly recycled in urban areas, where both a high volume of wood waste and high volume users such as solid-fuel boiler operators are nearby (Falk 1997).

The production of particleboards, where particles are glued together with (melamine-) urea-formaldehyde adhesive, under the action of other additives, pressure and temperature, goes back to the year 1941, and is nowadays a well-established process (Klauditz 1966; Saravia-Cortez et al. 2013). The synthetic adhesives in combination with other additives lead however to a contamination of the wood-based panels which can make recycling a problem. Even when the wood-based composite is produced solely from biodegradable components, for commercial use in furniture a surface treatment or coating is generally applied (Netravali and Chabba 2003; Bovea and Vidal 2004; Nemli and Çolakoğlu 2005). Nowadays, surface lamination is in general done using a high-pressure laminate (HPL) which is available in many different printed designs and with different types of surface texture (Busch 2010). Surface treatment, coating or lamination, also causes problems in recycling. In summary, there are three main issues to face in the recycling of wood-based panels:

- Adhesives and additives which are added during the production process are difficult to separate at the end of the product lifetime;
- Surface treatment or a coating applied as a finish is difficult to separate from the panel at the end of the product lifetime;
- Thermo-mechanical treatment of the wood during the production process leads to poorer mechanical properties of the wood as raw material when such panels are recycled.

This information has been used to develop an alternative product based on a particleboard concept which promotes the recycling of such wood-based panels. As it is not possible to exclude all these components, alternative components have been used in this study and the surface finish has been designed so that it can easily be separated by the consumer.

OBJECTIVE

The purpose of this study was to present an alternative product design for wood-based panels i.e. a particleboard, which reduces or avoids many of the problems involved in the recycling of the wood-based panels used in interior furniture.

MATERIAL AND METHODS

Particleboards were produced from a mixture of spruce (mainly) and pine particles using a protein adhesive (Anygluten 110). The dimensions of the boards were 500x500x11mm. The densities of the boards were chosen between 400 and 600kg/m^3. The boards were produced from small particles with a length up to about 5 mm at a moisture content (MC) of 5.3% (single-layer boards) or with a core layer of larger particles between 5 and 25 mm in length (MC 6.2%) (three-layer boards).

The amount of adhesive was 10% based on the weight of the wood particles, applied either as gluten in its natural form (solid) or dissolved in water (liquid), Fig.1.

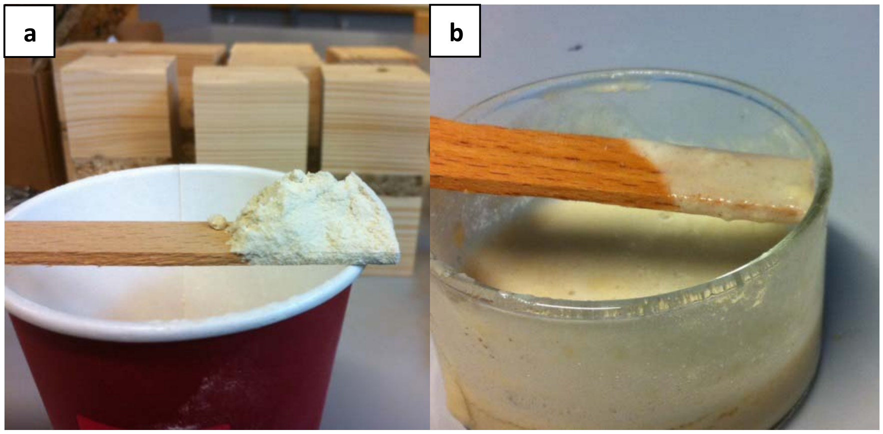

Fig. 1.
Protein (Amygluten) as adhesive (a) in its natural form (vital gluten), and (b) dissolved in water

When the gluten was used in its natural form, steam injection during pressing was simulated by spraying the plates with water (800±60ml/m^2) before pressing. A hydraulic press was used and the temperature at the beginning of the pressing process was 140°C or 200°C. Pressing times were based on the change in temperature during pressing and the related evaporation of water, and was between 8 and 21 seconds per millimetre thickness. The pressure was adjusted according to the pre-calculated desired volume of material. The mechanical properties, i.e. modulus of elasticity (MoE), modulus of rupture in bending (MoR), thickness swelling (TS), and internal bond strength (IB) of each board were determined according to EN 312.

As particleboards in furniture applications are in general surface-treated, a surface lamination was applied. A printable, water-proof, pressure-sensitive lamination of the type generally used for labels was used (Fig. 2). The lamination was tested only regarding removability (peeling-test), and sensitivity to temperature (<90°C), contamination, and cleaning using coffee.

Fig. 2.
Particleboard glued with protein and different surface laminations: (a) silver, (b) white, glossy, (c) transparent, (d) white, opal, and (e) no surface treatment

RESULTS AND DISCUSSION

The mechanical properties of the boards are presented in Table 1. The single-layer boards were made solely of small particles while the three-layer boards had a core layer of larger particles.

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Table 1

Mechanical properties of the particleboards glued with protein: L - No. of layers of the board; D - density (kg/m^3); T - temperature at the beginning of the pressing process (°C); A - type of adhesive; TS - thickness swelling in vol% after 24h; IB - internal bond strength (MPa) at 2mm/min; MoR - modulus of rupture (MPa) at 2mm/min; MoE - modulus of elasticity (MPa) at 2mm/min; Board No. P2 is a reference following criteria in EN 312, class P2 (including TS of class P4).

Board No.	N	D	T	A	TS	IB	MoR	MoE
1	1	480	200	dissolved	21	0.03	3.7	1,962
2	1	540	200	dissolved	21	0.07	5.1	1,740
3	3	490	200	solid	15	0.04	3.8	2,205
4	3	550	200	solid	15	0.10	4.7	2,739
5	3	540	140	dissolved	13	0.38	11.0	3,489
P2	-	680-750	-	-	(16)	0.40	13.0	1,800

Except in thickness swelling (TS) and the modulus of elasticity (MoE), the boards 1 and 2 show similar internal bond strength (IB) and modulus of rupture (MoR) at comparable densities to the boards 3 and 4 (Table 1). The higher MoE values for boards #3 and #4 seem to be due to the core layer of longer particles.

Board 5 performed much better than the others. The IB and MoR values were quite close to the standard criteria (P2), and the board met the standard requirements for TS and MoE even though the was much lower than the standard level.

The finish of the board, the printable, water-proof, pressure-sensitive lamination could be removed by hand after cutting with a sharp cutting tool (Fig. 3). Using coffee, it was shown that it was not possible to clean the lamination in a proper way, and that there was no warping or bubbling of the lamination at a temperature up to approximately 90°C (Fig. 3).

Fig. 3.

Lamination layer of the boards: (a) Peeling of the surface lamination by hand was still possible two weeks after application and the separation of wooden component and surface lamination was good, (b) test with coffee at a temperature of approximately 90°C, and (c) the result of the "coffee-test" after 5min showed no warping or bubbling of the lamination but also no effective cleaning

The surface lamination would fulfil the criterion of being removed efficiently at the end of lifetime of the board but it would fail especially with regard to the cleaning. Further, even when it is scratch- and tear-resistant, this type of surface lamination is not cut-resistant, which means such a surface lamination cannot be used for table or worktop surfaces. Adhesives used for such laminations are generally acryl-based (Gehman 1990) and show good aging performance at room temperatures and at higher temperatures. The removability of the laminations can be controlled by adjusting parameters such as the amount of multifunctional isocyanate crosslinkers, ethoxylated amines, and polyalkylene oxides, or UV-crosslinking (Czech 2006). In general, the removability of surface laminations of wood composites in furniture applications does not seem to be a relevant topic nowadays, as similar adhesives are used for wood-based panel production and high pressure lamination (HPL). It only becomes interesting when the wood-based panel is made with bio-based adhesives. Therefore, it is difficult to find an appropriate lamination and the commonly available lamination was used in this study.

Besides the challenges of the surface finish, the production of wood-based panels glued with bio-based adhesives causes problems, especially with regard to pressing time and moisture resistance. A comparison between the boards 1 to 4 suggests that the way of application, using gluten in a solid form combined with steam injection and using gluten dissolved in water, does not affect the bending quality. There are three possible reasons why board 5 performs much better: (1) the lower starting temperature of the pressing process, (2) the way of applying the adhesive (3) a combination of both.

Additional tests with gluten only show that this protein denatures at quite low temperatures (<20°C) when in contact with water. Above this temperature (<120°C) there seem to be no great changes in its properties (Trischler and Sandberg 2015). As the pressing process was stopped with increasing temperature when most of the free water had evaporated, when the temperature in the core of the board was approximately 100°C, it can be assumed that the protein was not destroyed during the pressing process by a too high temperature.

Therefore, it was most probably the method of application that had this positive effect on the mechanical properties of board 5. In the production of this board, the wood particles were cooled down to avoid denaturation of the gluten before pressing. The gluten was applied by hand and the process took approximately half an hour. This is sufficient for the temperature to rise above the level were gluten denatures, and this would result in a strong internal protein bond but a weak protein-wood bond (Trischler and Sandberg 2015).

Using gluten as adhesive in the way presented by Trischler and Sandberg (2015) with some technical optimisation, particleboards glued solely with gluten can become realistic. As these boards contain no other additives, they are theoretically totally bio-degradable if they have no surface treatment or surface coating. For this reason, this study has included some kind of surface coating. Nowadays, a large number of water-proof, pressure-sensitive and printable laminates with different textures and structures are available on the market for use as surface coating. This surface coating should be designed so that it can be removed by the consumer at the end of the lifetime of the product, giving a small amount of laminate material which can be recycled by combustion in district heating plants, and the fully biological degradable board which can be recycled in many different ways such as composting, waste-paper, wood recycling, and combustion. In this way, the board-producing company would shift the responsibility and costs relating to recycling and waste separation towards the consumer.

If gluten is used as adhesive, it should be noted that, even when gluten is insoluble in water at higher temperatures, it still absorbs water. The absorption of water leads to an increase in the flexibility of the gluten and a loss of bending strength and vice versa. These properties of gluten may be beneficial in some types of recycling. Further, if gluten is used as adhesive, formaldehyde is necessary and this would lead to boards nearly free of formaldehyde emission. By optimizing the production process of the boards, i.e. the adhesive application and pressing, the production of boards glued with gluten might also be energetically beneficial.

CONCLUSIONS

In this paper, a recycling concept for wood-based panels used for indoor furniture applications is presented. For this purpose, the production of a particleboard using a bio-based adhesive was achieved by applying wheat protein in a specific way. As a finish for the board, a water-proof, pressure-sensitive lamination was used. The results showed that it seems possible to produce particleboards for furniture applications using wheat protein but further research especially relating to the application technique is necessary. Besides the use of wheat protein as bio-based adhesive, the crux of this concept is to find a type of surface lamination which can be removed by the consumer at the end of the product-lifetime and which fulfils all the requirements regarding surface properties. The advantage of this recycling concept would be that, after removal of the surface lamination, a totally biodegradable wood-based panel is open to a wide range of recycling opportunities, while the surface lamination yields only a small amount of film which can be disposed of separately, so that waste separation leads to waste reduction.

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