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Dimensional stabilisation and strength of particleboard by chemical modification with propionic anhydride

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Chemical modification of wood chips using propionic anhydride resulted in improved dimensional stability of particle boards manufactured with these chips. The TS values of the UF bonded boards were about 104% lower than controls and were in accordance with the stringent requirements of the ANSI standard. The internal bond strength, however, decreased significantly, but was still substantially higher than the requirements of the EN 312 and ANSI standards for P4 load-bearing boards or M3 boards. As in the case of acetylated chips, the majority of failure was due to the resin and not to wood.

Dimensionsstabilität und Festigkeit von Spanplatten nach Modifikation der Chips mit Propionanhydrid

Die chemische Modifikation des Holzes mit Propionanhydrid führte zu verbesserter Dimensionsstabilität. Die Dickenquellung der mit UF-Harz verklebten Platten war um 104% geringer als die der Kontrollproben. Sie erfüllten jedoch die strengen Anforderungen des ANSI-Standards. Die Querzugfestigkeit verringerte sich deutlich, lag aber immer noch über den Anforderungen der EN 312 oder des ANSI-Standards für belastete P4-Platten oder M3-Platten. Wie bei acetylierten Proben lagen die Schwachstellen im Bruchfall im Bereich der Verleimung, nicht im Holz.

1 Introduction

Many researchers have tried to improve the dimensional stability (thickness swell and water absorption) of particleboards by studying various processing variables, the most important of them being density, particle configuration, press cycle and degree of bonding. Chemical modification is a complementary technique that can be applied to the same purpose. The presence and availability of the hydroxyl group gives lignocellulosic material their strength and versatility, but it is also the reason for the problems that arise with lignocellulosics. The hydroxyl groups are in such large numbers that hydrogen bonding within and between the polymeric species occurs throughout the material. It is hydrogen bonding that allows hydrophilic substances like water to enter the structure and interact with the polymers and alter their properties.

The natural reactivity of lignocellulosics can be utilized to enhance their properties with the resulting material being superior in terms of performance and versatility. The basic types of chemical modification use simple monofunctional modifying agents while others use difunctional, or even polyfunctional modifying agents. One of the most practical of these is the reaction of a hydroxyl group with acetic anhydride, known as acetylation (Rowell 1975). Recently, acetylation has been successfully employed to improve the dimensional stability of oriented strand board (Papadopoulos and Traboulay 2002). Although, there have been few papers published concerning modification of solid wood with other linear chain anhydrides (i.e. propionic, butyric, valeric, hexanoic) (Stamm and Tarkow 1947; Hill and Papadopoulos 2002; Papadopoulos 2002), there has been no study dealing with the application of chemical modification with the above anhydrides in particleboard manufacture.

Consequently, the objective of this study was to examine the performance of one layer experimental particleboards made from wood chips modified with propionic anhydride. The generalized chemical reaction is shown in Fig. 1. The propionic anhydride replaces the hydroxyl groups in the wood with propionyl groups (by way of covalent bonds), and leaves the wood in swollen condition, because of the bulking action of the propionyl groups within the cell walls.

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2 Experimental

2.1 Wood chips

Industrially produced wood chip furnish, comprising predominantly mixed softwoods was the raw material used in this study. The chips were dried in an oven at 105°C to approximately 2.5–3% moisture content (MC). Control boards were made from chips dried to this MC. Chips, which were to be propionylated, were subjected to an additional 12 h drying; to achieve a bone dried condition.

2.2 Propionylation of chips

The oven-dried chips were propionylated by impregnation with propionic anhydride (98% anhydride, 2% propionic

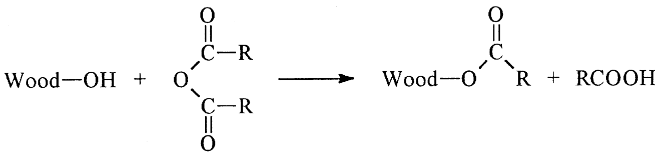

Fig. 1. Reaction of wood with propionic anhydride (R=C_2H_5 propionic anhydride)
Bild 1. Reaktion des Holzes mit Propionanhydrid R=C_2H_5

acid) purchased from Aldrich. The chips were reacted at 120°C for 60 minutes in a reaction vessel. At the end of the reaction, the excess chemical was decanted from the vessel. The chips were removed and dried overnight at 105°C, prior to board manufacture. A weight percent gain (WPG) of 12.2% was obtained after 60 minutes reaction, based on the oven dry weight of chips.

2.3
Particleboard manufacturing and testing

Pre-weighed raw material was placed into a resin blending chamber equipped with a rotary arm agitator. A commercial E1 grade urea formaldehyde (UF) particleboard resin (62.4% solids content), containing 2% (based on resin solids) ammonium chloride as hardener, was used for the manufacturing of boards. 12% resin (solids on oven dry mass of particles) was added in all cases. Additional water was added to bring the furnish to the target moisture content level (10%); this was done after resin application. The total blending and mixing time was 3 minutes. Mattresses were hand-formed and hot pressed at 200°C for 5 minutes using a maximum pressure of 3.4 MPa. Target board density was 0.75 g/cm^3 and target board thickness 17.5 mm. Three replications of each board were made, yielding a total of 6 boards.

After manufacturing, the boards were conditioned at 20°C and 60% relative humidity. Values for internal bond strength (IBS) and thickness swelling (TS) after 24 hours water immersion were then determined according to procedures defined in the American standard for particleboards (ANSI A208.1-1998) as well as the European Union standards EN 310 and EN 319.

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Results and discussion

The thickness swell values of the one layer experimental particleboards made from propionylated wood chips are summarized in Table 1. From this, it can be seen that propionylation resulted in improved dimensional stability. TS values for propionylated boards were about 104% lower than controls and conformed to the more stringent requirements of the ANSI standard (see Table 2). In a previous study, an improvement of approximately 147% in TS value after 24 hours immersion in water was reported for OSB made from strands acetylated to a 11.2% WPG (Papadopoulos and Traboulay 2002).

The internal bond strength (IBS) data are summarised in Table 1. From this, it can be seen that propionylation of chips resulted in significant decrease in IBS. IBS values for the propionylated particleboards were about 48% lower than controls, but still substantially higher than the

Table 1. Mechanical and hygroscopic properties for control and propionylated particleboards. (Standard deviations in parentheses)
Tabelle 1. Mechanische und hygroskopische Eigenschaften der Kontrollproben und propionierten Platten (Standardabweichungen in Klammern)

Board type	TS (%) 24 h	IBS (N/mm^2)
Control	12.6 (1.3)	1.08 (0.03)
Propionylated	5.8 (0.5)	0.73 (0.02)

Table 2. Thickness swell and internal bond values required to meet EN 312 and ANSI A208.1-1998
Tabelle 2. Dickenquellung und Querzugfestigkeit, die von EN 312 und ANSI A208.1-1998 gefordert werden

Class		IBS (N/mm^2)	TS (%)
ANSI A208.1-1998	Commercial use, shelving-M1	0.400	8
ANSI A208.1-1998	Industrial overlaying shelving, countertops-M2	0.450	8
ANSI A208.1-1998	Industrial overlaying shelving, stair treads-M3	0.550	8
EN 312	P2 General Use	0.24	N/A
EN 312	P3 Interior Fitments	0.35	N/A
EN 312	P4 Load Bearing – Dry	0.35	14

0.35 (N/mm^2) and 0.55 (N/mm^2) required by the EN 312 and the ANSI standard for P4 load-bearing boards and M3 boards, respectively (see Table 2).

The 48% reduction in IBS due to propionylation appears to be higher that the corresponding reduction due to acetylation. For example, Papadopoulos and Traboulay (2002) have reported that acetylation of strands to about 11.2 and 20.4% WPG resulted in a 17.5% and a 30% decrease in IBS, respectively. Similar reduction in IBS values were reported for acetylated flakeboards (36%) and particleboards (25%) (Youngqist et al. 1986; Fuwape and Oyagade 2000). It was suggested previously that the hydrophobic nature of the acetylated wood caused poor wetting of wood since failure in case of control strand boards occurred in the wood, whereas in the acetylated boards, the majority of failure was due to the resin and not to wood (Papadopoulos and Traboulay 2002). This was also the case in this study. However, the higher reduction in IBS value obtained in this study, suggests that the hydrophobic nature of propionylated wood caused poorer wetting than the acetylated wood. Further studies are required in order to reaffirm this observation. It would be of interest for example, to modify industrial wood chips with longer linear chain anhydrides (e.g. butyric, valeric) to see the effect of chain length on the wetting of wood.

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Conclusions

One layer experimental particleboards were made, for the first time, from wood chips modified with propionic anhydride. The dimensional stability of boards was greatly improved by propionylating chips with propionic anhydride. Significant decrease in IBS was obtained and this was higher that the reported values for acetylated boards. It is suggested that the hydrophobic nature of propionylated wood caused poorer wetting than the acetylated wood. Further work has to be done on the effect of chain length on the wetting of wood, the optimisation of the minimum moisture content of the chips required to obtain the maximum weight gain, the pressing strategies and the optimisation of the minimum resin dosage required to maintain physical and mechanical standards, since any possible savings in drying chips and reducing resin dosage could partially offset the cost of propionylation.

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