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# Bonding behaviour of chemically modified wood particles for board production

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**Abstract** The objective of this paper was to evaluate the bonding behaviour of chemically modified wood particles towards an isocyanate resin system, as determined from internal bond strength of the board, and to determine which resin system, isocyanate or formaldehyde is suitable for use in boards made from modified raw material. It was found that chemical modification of wood chips and strands did not significantly affect the bonding efficiency of isocyanate resin, but the bonding efficiency of formaldehyde resins was strongly influenced. This behaviour can be a consequence of the usage of a less pH dependent resin that is fully cured during hot pressing in combination with the high mobility of the resin which causes penetration to considerable depth into compressed particles repairing weak zones, which are created during the modification process as chips are exposed to elevated temperatures, by sticking them together. It is suggested therefore, that the isocyanate resin system is more suitable for use in boards made from modified raw material than the formaldehyde resin system.

### Klebeverhalten chemisch modifizierter Holzspäne für die Herstellung plattenförmiger Holzwerkstoffe

**Zusammenfassung** Das Klebeverhalten chemisch modifizierter Späne wurde durch Prüfung der Querzugfestigkeit daraus hergestellter Platten untersucht, um zu bestimmen, welches Klebstoffsystem, Isocyanat- oder Formaldehyd-Harz, sich für die Plattenherstellung aus modifiziertem Rohmaterial eignet. Es zeigte sich, dass die chemische Modifizierung von Holzspänen die Klebewirkung von Isocyanat-Harz nicht signifikant beeinflusst, wogegen die Klebewirkung von Formaldehyd-Harzen stark beeinträchtigt wird. Dieses Verhalten kann zurückzuführen sein auf die Verwendung eines weniger pH-abhängigen Harzes, welches bei der Heißpressung voll aushärtet, in Verbindung mit der hohen Mobilität des Harzes, durch die es in beträchtliche Tiefe in gepresste Späne eindringt. Dadurch werden Schwachstellen, die während des Modifizierungsvorganges entstehen, bei dem Späne erhöhten Temperaturen ausgesetzt sind, repariert, indem sie die Teile miteinander verbinden. Dies deutet darauf hin, dass Isocyanat-Harz zur Herstellung von Platten aus modifiziertem Rohmaterial besser geeignet ist als Formaldehyd-Harz.

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## 1 Introduction

Bonding of timber and wood has a history of several thousand years and has overcome the limitations given by size and shape of the naturally grown trees. So called solid wood as boards, planks, edgings and laths, square timber or other products is restricted to the size of the primary log originating from the tree felled. Various methods for recombining solid wood and smaller parts of the wood substance, e.g. veneers, chips, particles and even fibres have opened new possibilities to overcome these restrictions in size and also limitations due to the factors influencing the strength, elasticity (stiffness) and toughness of wood like knots and other anatomical features. Especially the use of various adhesives as auxiliary means for re-jointing has enabled a huge diversity of applications, which climaxed in 150 billion $m^3$ of annual global production of wood panel products. Bonding of timber shows a high degree of flexibility in process and in preserving the naturally wooden appearance. Besides this, some limitations in technology still exist, which might hinder an extensive use of bonding practises in various applications, since the basic properties of wood as the by far dominating raw material of all types of wood panel products and of so called engineered structural timber still remain decisive for the behaviour of the final product.

One such limitation is the poor bonding of chemically modified wood particles that have been used for board production. Chemical modification is a complementary technique that can be applied to improve dimensional stability of wood based panels.

**Table 1** Bonding behaviour of boards, as determined by internal bond strength (IBS), made from chemically modified wood raw material and bonded with formaldehyde resin systems
**Tabelle 1** Querzugfestigkeit (IBS) von Holzwerkstoffplatten aus chemisch modifiziertem und mit Formaldehyd-Harz Verbindungen verklebtem Rohmaterial

| Board type | Resin system | IBS Reduction (%) | WPG (%) | Source |
|---|---|---|---|---|
| OSB | PF 5% | 17.5 | 11.2 | a |
| Particleboard | UF 12% | 48 | 12.2 | b |
| Flakeboard | PF 7% | 25 | 17.8 | c |
| Flakeboard | PF 6% | 35 | 20 | d |
| Hardboard | PF 7% | 41 | 23 | e |

a: Papadopoulos and Gkaraveli 2003
b: Papadopoulos and Traboulay 2002
c: Fuwape and Oyagade 2000
d: Youngquist et al. 1986
e: Chow et al. 1996

Papadopoulos and Traboulay (2002) reported that the dimensional stability of OSB was greatly improved by acetylating fir strands with acetic anhydride and the boards met the more stringent EN300 criteria for OSB/4 (heavy duty load-bearing boards for use in humid conditions). Similar results were also obtained in boards made with chips modified with propionic anhydride (Papadopoulos and Gkaraveli 2003).

Thickness swelling values for propionylated boards were about 104% lower than controls and conformed to the more stringent requirements of the ANSI standard (8%). However, a big limitation of the technique, is the poor bonding of chemically modified wood particles that have been used for board production. For example, Papadopoulos and Traboulay (2002) have reported that acetylation of strands to about 11.2 and 20.4% WPG resulted in 17.5% and 30% decrease in IB respectively. Similar reduction in IB values were reported for acetylated flakeboards (36%) and particleboards (25%) (Youngquist et al. 1986, Fuwape and Oyagade 2000) and for propionylated particleboards (48%) (Papadopoulos and Gkaraveli 2003).

In all cases appeared in the literature (Table 1), only formaldehyde based resins have been used to manufacture boards from chemically modified wood particles, presumably in order to offset the cost of modification. Consequently, the purpose of this paper was two-fold:

1. to evaluate the bonding behaviour of chemically modified wood particles towards an isocyanate resin system, determined from the internal bond strength of the board
2. to compare this with the performance of formaldehyde based resins and to determine which resin system is suitable for use in boards made from modified raw material.

## 2 Experimental

### 2.1 Raw material

Industrially produced wood chip furnish, comprising predominantly mixed softwoods and fir ring-cut strands (*Picea abies*) with average strand size of 75 mm × 20 mm × 0.75 mm (length × width × thickness), were the raw material used in this study. The raw material was dried in an oven at 105 °C to approximately 2.5%–3% moisture content (MC). Control boards were made from chips or strands dried to this MC. Chips or strands which were to be chemically modified, were subjected to additional 12 hr of drying; to achieve a bone dried condition.

### 2.2 Chemical modification of raw material

The oven-dried strands and chips were chemically modified by impregnation with acetic anhydride (98% anhydride, 2% acetic acid) and propionic anhydride (98% anhydride, 2% propionic acid) respectively, both purchased from Aldrich. The strands were acetylated at 120 °C for 30 minutes and the chips were propionylated for 60 minutes in a reaction vessel. The vessel held approximately 700 gr. of dry raw material, enough to produce one board. At the end of the reaction, the excess chemical was decanted from the vessel. The raw material was removed and dried overnight at 105 °C, prior to board manufacture. Weight percent gain (WPG) of 11.2% and 12.2% was obtained based on the oven dry weight of strands and chips respectively.

### 2.3 Board manufacture and testing

Control and chemically modified raw material was resinated with a pneumatic atomising nozzle in a rotary drum blender with the suitable resin. 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 manufacture of particleboard, at a rate of 12%. A resol liquid phenol formaldehyde resin (53% solids content) was used for the manufacture of OSB at a rate of 4%. An isocyanate EMDI resin (3%), 100% solid, was used for the manufacture of both particleboard and OSB. Mattresses were hand-formed and hot pressed at 200 °C for 5 minutes using a maximum pressure of 3.4 MPa. Target particleboard density was 0.75 $g/cm^3$ and target particleboard thickness 17.5 mm, whereas target OSB density was 0.65 $g/cm^3$ and target particleboard thickness 12.5 mm. After manufacture the boards were conditioned at 20 °C and 60% relative humidity. Three replications of each board were made, giving a total of 12 boards. Each board was cut into twelve specimens each measuring 50 × 50 mm.

Internal bond strength (IB) tests were conducted on the specimens (six from each board) to evaluate the bonding behaviour of chemically modified wood particles towards the isocyanate and formaldehyde based resins. The tests were carried out according to EN 319.

## 3 Results and discussion

The bonding behaviour of chemically modified wood particles towards an isocyanate resin system, determined by internal bond strength of boards, is summarised in Table 2. From this it can be seen that the chemical modification of wood chips and strands

**Table 2** Bonding behaviour of boards, as determined by internal bond strength (IBS), made from chemically modified wood raw material and bonded with various resin systems. Footnotes as Table 1 (Standard deviations in parentheses)

**Tabelle 2** Querzugfestigkeit (IBS) von Holzwerkstoffplatten aus chemisch modifiziertem und mit verschiedenen Harzverbindungen verklebtem Rohmaterial. Fußnoten wie in Tabelle 1 (Standardabweichungen in Klammern)

| Board type | Resin system | IBS ($N/mm^2$) | IBS Reduction (%) |
|---|---|---|---|
| Particleboard (normal chips) | UF 12% | 1.08[a] (0.03) | |
| Particleboard (modified chips) | UF 12% | 0.73[a] (0.02) | **48** |
| Particleboard (normal chips) | EMDI 4% | 0.89 (0.01) | |
| Particleboard (modified chips) | EMDI 4% | 0.79 (0.03) | **11.7** |
| OSB (normal strands) | PF 5% | 0.57[b] (0.02) | |
| OSB (modified strands) | PF 5% | 0.49[b] (0.01) | **17.5** |
| OSB (normal strands) | EMDI 4% | 0.52 (0.03) | |
| OSB (modified strands) | EMDI 4% | 0.48 (0.03) | **5** |

did not significantly affect the bonding efficiency of EMDI isocyanate resin. The reduction in IB of boards made with modified chips and strands, compared to control boards, was 11.7% and 5% respectively. At the same time, the reduction in IB of boards made with modified chips and strands and bonded with formaldehyde resin systems, compared to control boards, was 48% and 17.5% respectively (Papadopoulos and Traboulay 2002, Papadopoulos and Gkaraveli 2003). They interpreted this finding to the low wettability of the modified wood chips and strands and, therefore poor penetration of the water soluble formaldehyde resin. It was also suggested that the hydrophobic nature of propionylated wood caused poorer wetting than the acetylated wood.

The results obtained in this study showed that the chemical modification did not affect the bonding efficiency of EMDI isocyanate resin. This behaviour can be a consequence of the usage of a less pH dependent resin, like EMDI, that is fully cured during hot pressing.

Another possible explanation for this behaviour of isocyanate resins is due to their high mobility into the wood surface. One reason for this is their self-activated flow; when isocyanate droplets are placed on the wood surface they spread out spontaneously without the need of any external forces. This high mobility, according to Roll (1997), causes penetration to considerable depth into compressed particles, which can result in their total impregnation. This penetration may repair weak zones, which are created during the modification process as chips are exposed to elevated temperatures by sticking them together. Therefore it is suggested that the isocyanate resin system is more suitable for use in boards made from modified raw material than the formaldehyde resin system.

## 4 Conclusions

The aim of this paper was to examine the bonding behaviour of chemically modified wood particles towards an isocyanate resin system. It was found that chemical modification of wood chips and strands did not significantly affect the bonding efficiency of EMDI isocyanate resin. The reduction in IBS of boards made with modified chips and strands, compared to control boards, was 11.7% and 5% respectively. This behaviour can be a consequence of the usage of a less pH dependent resin that is fully cured during hot pressing in combination with the high mobility of the resin which causes penetration to considerable depth into compressed particles repairing weak zones, which are created during the modification process as chips are exposed to elevated temperatures, by sticking them together.

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