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# Modified Wood-Protein Adhesive Bondline Strength Development during Curing

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## ABSTRACT

New adhesives from renewable sources are of interest for wood composites for both ecological and economic reasons. Both formaldehyde emission and the availability of petrol are driving forces behind the research to find alternatives for synthetic resins. However, the bonding strength and water tolerance of natural adhesives are often insufficient. Increasing the compatibility of wood towards the hydrogen bonding common in natural adhesives can produce composites with stronger cross-linking and thus better mechanical and water-tolerance properties. The compatibility of a wood surface towards natural adhesives can be improved by chemical and mechanical means. The effect of chemical activation, such as acetylation, on the adhesive bond strength was evaluated on beech (*Fagus silvatica* L.) veneers using an automatic bond evaluation system (ABES).

## INTRODUCTION

The use of soy protein as an adhesive dates back to ancient times, but its commercial use as an adhesive for plywood began in the 1930s. As a wood adhesive, soy protein is inexpensive, easy to handle, has low press temperatures and is able to bind wood with relatively high moisture content. However, soy protein adhesives have high viscosities and short pot lives, and the wood composites bound with them have relatively low strength, low water tolerance, and are sensitive to biological degradation (Li *et al.* 2004).

The performance of wood is mainly a result of the chemistry of its cell-wall components; cellulose, hemicellulose, lignin, and extractives. Changing the chemistry of these components allows us to change and improve the properties of wood. In chemical modification simple chemicals are attached to the reactive sites of wood by covalent bonds. In the literature, wood has been modified, with various different chemicals, e.g. aldehydes, anhydrides, acid chlorides, isocyanates, and epoxides.

Acetylation is the most extensively studied method for chemical wood modification. The acetylation of wood was first performed in Germany in 1928 by Fuchs, with acetic anhydride, and sulphuric acid as catalyst. Acetic acid anhydride esterifies the hydroxyl groups of the cell wall releasing acetic acid as a by-product. Acetylation has been reported to reduce water sorption and swelling and to increase the bioresistance of wood cell-wall material (Rowell 2006).

Dry wood swells under high moisture conditions, while most wood adhesives do not show great dimensional changes. Under moist conditions, this leads to a high stress concentration in the bondline and reduces the strength of the final material. Acetylation can reduce the swelling of the wood and lessen this interfacial stress. However, acetylation is likely to reduce the number of hydrogen bonds formed between wood and adhesive and this affects adhesion process. The rate of strength development of PF-resins-wood bonds has been shown to be reduced by acetylation (Chowdhury and Humphrey 1997). When thermosetting adhesives are used in particleboard production, the bond strength is developed during the curing process. The automatic bond evaluation system (ABES), developed by P.E. Humphrey from Oregon State University, is a practical way of examining the mechanical properties of the adhesive during curing. ABES provides information on the shear strength development as a function of pressing parameters (e.g. time and temperature).

## EXPERIMENTAL

Conditioned (20ºC and 65% RH) beech veneers with a thickness of 0.6 mm were cut into 20x117 mm strips. Some of the veneers were acetylated with a solution of acetic anhydride for 1 hour at room temperature and then washed with distilled water. The veneers were then dried in an oven at 103ºC for 24h. A total amount of 0.012 g of commercial soy-protein-based adhesive was brushed onto each veneer strip over an area of 20x3 $mm^2$ (200 $g/m^3$). Pairs of strips were lapped together with an overlay of 3 mm and placed between the hotplates in the ABES. The press time and temperature were varied. A bonding pressure of 1.4 MPa was used for all the tests. The samples were tested at 110ºC, 120ºC, 130ºC, and 150ºC with press times from 20 to 50 s. At 110ºC, the samples were also tested at a press time of 80 s. The samples were cooled with an airflow for 15s after pressing and before pulling. The results are summarized in Table 1. For each temperature/press time combination, three specimens were tested.

***Table 1. Shear strengths at different temperatures and pressing times. Shear strength is expressed as force (N) / area of adhesion (60 $mm^2$)***

| *Temperature* | *Press time [s]* | *Unmodified [$N/mm^2$]* | *Acetylated [$N/mm^2$]* |
|---|---|---|---|
| 110ºC | 40 | 0.57 | 0.17 |
| | 50 | 1.01 | 2.86 |
| | 80 | 5.12 | 5.27 |
| 120ºC | 30 | 3.14 | 2.83 |
| | 40 | 4.70 | 4.80 |
| | 50 | 5.70 | 6.08 |
| 130ºC | 20 | 3.42 | 1.96 |
| | 30 | 5.92 | 6.05 |
| | 40 | 6.76 | 6.24 |
| | 50 | 7.70 | 7.68 |
| 150ºC | 10 | 1.70 | - |
| | 20 | 6.39 | 7.31 |
| | 30 | 7.62 | 8.03 |
| | 40 | 8.03 | 6.82 |
| | 50 | 8.13 | 8.32 |

The shear strength development curves shows of three stages: initiation, growth, and termination. Initiation starts at different press times at different temperatures as seen in Figure 1. At 110ºC, a press time longer than 40 s was needed to start the shear strength development of the bond. At higher temperatures, the shear strength development was naturally significantly faster.

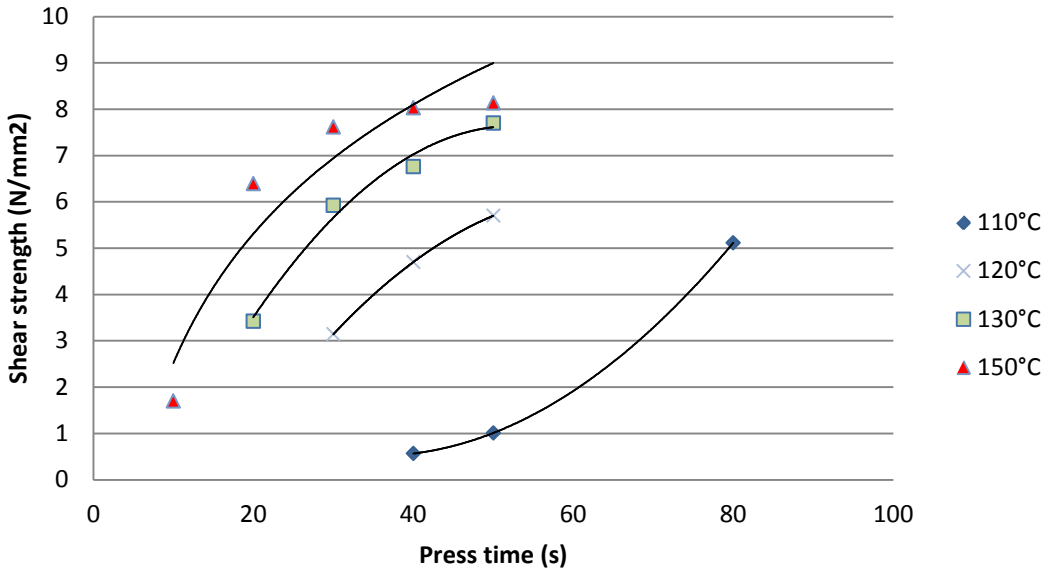


***Figure 1. Shear strength development of soy adhesive on unmodified veneer at different temperatures***

Acetylation lead to only a slight or no increase in the shear strength, Figure 2. However it increased the percentage of wood failure at 130ºC and 150ºC. At the extreme of 150ºC and 50 s press time, the percentage wood failure was 33% for unmodified wood and 100% for acetylated wood. An increase in the percentage wood failure suggests stronger adhesion between glue and wood but it was not expressed as a corresponding greater ~~in~~ shear strength. This is surprising, as the strength of wood seems not to be influenced by acetylation (Rowell 2006).

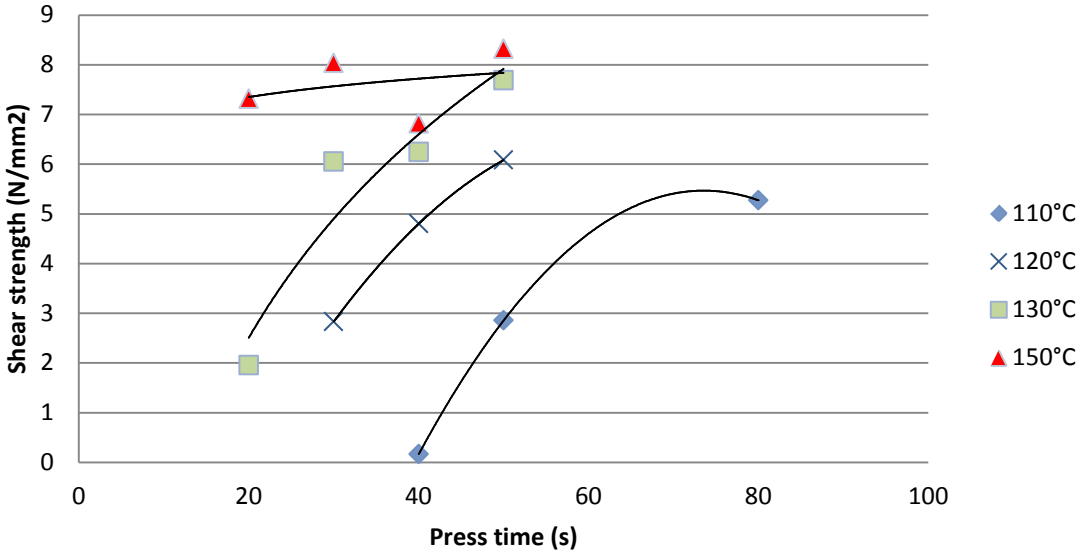


***Figure 2. Shear strength development of soy adhesive on acetylated veneer at different temperatures***

A drop in shear strength was noted at both 150ºC and 130ºC at a press time of 40 seconds on acetylated veneers. The maximum shear strength might have reached at a press time of 30 s. Also at 110ºC, the shear strength development was significantly faster on acetylated veneer than on unmodified, but similar values are reached at a press time of 80 s.

## CONCLUSIONS

Acetylation of the veneer had more effect on the percentage wood failure than on the shear strength development. More measurements with shorter press time intervals would be needed in order to draw reliable conclusions. However, it can be confirmed that acetylation does change the curing behaviour of at least the soy based adhesive tested here.

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