Titan Wood LIMITED

Research Overview

Version 1
30 May 2007

Executive Summary

Accoya™	The technology behind Accoya™ wood is based on acetylation of Radiata Pine (*Pinus radiata* D. Don). Acetylation of wood is a chemical modification process that is known to significantly improve the dimensional stability, UV-stability and durability (resistance against brown-, white- and soft rot fungi).
Durability class (EN 350-1)	1
To be applied in use classes (EN 335-1)	1, 2, 3 and 4
Density and spreading (at 65% RH, 20 °C)[1]	(438) - 510 - (599) kg/m^3
Equilibrium moisture content at 65% RH and 20 °C in adsorption[1]	(3.0) - 3.3 – (3.8) %
Shrinkage wet – 65% RH, 20 °C[1] - radial - tangential	 (0.2) - 0.4 – (0.6) % (0.4) - 0.8 - (1.4) %
Shrinkage wet – ovendry[1] - radial - tangential	 (0.5) - 0.7 - (1.2) % (0.9) - 1.5 - (2.7) %
Bending strength and stiffness	The average bending stiffness and –strength slightly (2%) increase due to the acetylation process.
Janka hardness[1] - radial - tangential - end grain	 (2860) - 4050 - (5420) N (3150) - 4190 - (5620) N (5350) - 6600 - (8030) N
Impact bending strength[1]	(25) - 50 – (100) kJ/m^2
Processing	Excellent
Glueing (non-load bearing applications) - lamination - finger jointing	Tested and approved Dynea Prefere 6151 / 6651 (EPI) Dynea Prefere 6151 / 6651 (EPI)
Finishing[2]	Tested and approved Hybrid coating systems may need special attention for sufficient adhesion

[1] the results are expressed as (minimum value) - average value – (maximum value) and are based on the tested samples.

[2] *Finishing of Accoya™ has been tested with a few "model" coatings. These tests show good coating performances. However, since coating performance depends on the substrate, coating as well as on the coating application, it is recommended to test together with the coating supplier the coating performance after application.*

Contents

1. Background

Titan Wood B.V. will start production of Accoya™ in Arnhem, the Netherlands. The technology behind Accoya™ (www.accoya.info) is based on wood acetylation. Acetylation of wood is a chemical modification process that is known to significantly improve the dimensional stability, UV-stability and durability (resistance against brown-, white- and soft rot fungi).

Accoya™ wood has been extensively tested by independent research organisations, suppliers of raw materials to the wood working industry (with among coating and glue manufacturers) and own research efforts, both at laboratory level and in the field. This document gives primarily an overview of all official test results of independent research organisations.

2. Durability

The durability of acetylated wood in respect to resistance against fungal decay strongly depends on the degree of acetylation. In this respect the durability of Radiata Pine, which has been acetylated to various degrees, has been investigated by SHR Rimber Research (Wageningen, the Netherlands) and reported in SHR report 6.244-3[1]. The durability has been investigated according to EN 113[2] and ENV 807[3] in which the resistance against fungal decay by brown-, white-, and soft rot fungi is studied. Prior to the testing the samples have been leached according to EN 84. The results of the durability tests have been used determine the durability class according to EN 350-1[4]. The results of the study show that the minimum degree of acetylation (acetyl content) to classify acetylated Radiata Pine as durability class 1, which is the specification of Accoya™, can be determined. At this degree of acetylation the variation in fungal decay within the samples is decreased, resulting in a better reliability of Accoya™ in respect to durability compared to that of untreated Radiata Pine.

2.1 Sample preparation

Radiata Pine (*Pinus radiata*) boards were acetylated to various degrees within different batches. After acetylation the boards were conditioned at 65 % RH and 20 °C, and finally cut to samples EN 113 test and ENV 807 test. The acetyl content of one EN 113 sample of each board was determined according to the standard HPLC-method of Titan Wood. The rest of the samples were leached according the EN 84 leaching test. The samples were impregnated with distilled water, and subsequently refreshed nine times over a period of 14 days. Finally the samples were dried and conditioned at 20 °C, 65% RH to equilibrium moisture content.

2.2 Resistance against basidiomycetes

The prepared acetylated samples were tested according to EN 113 for the following wood destroying basidiomycetes:

- *Coniophora puteana* (cellar fungus, wet rot fungus, cellar rot fungus)
- *Coriolus versicolor* (Turkey tail fungus, shelf fungus)
- *Gloeophyllum trabeum* (conifer mazegill)
- *Poria placenta* (pore fungus)
- *Serpula lacrimans* (true dry rot fungus)

The samples were placed in culture vessels, which contained sterilised culture medium (agar) which was inoculated with one of the wood destroying fungi. In each culture vessel two acetylated samples and one reference sample (Scots Pine sapwood) were placed. These culture vessels were placed in a culture chamber (22 °C, 70% RH) for a period of 16 weeks. After the exposure period, the mass loss as result of fungal decay of the samples was determined (see Figure 1).

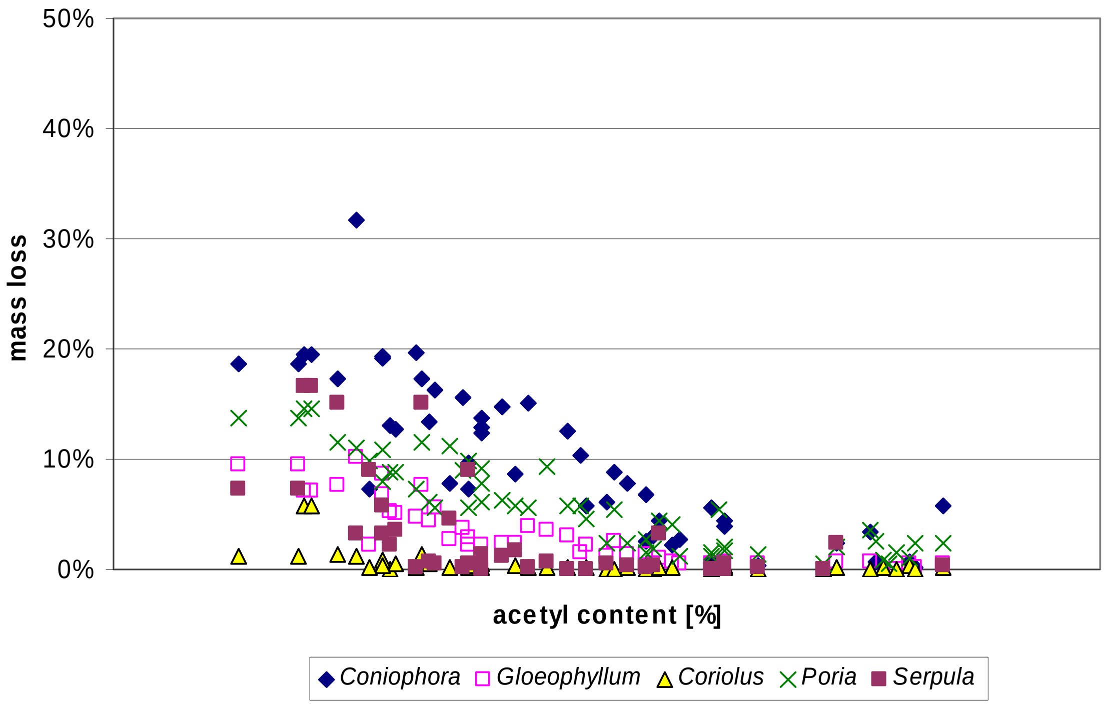

Figure 1. *Mass loss of acetylated Radiata Pine caused by basidiomycetes (EN 113 test) in relation to the acetyl content.*

2.3 Resistance against soft rot fungi

The ENV 807 method II test was performed with acetylated samples of the same boards that were selected for the EN 113 test. Scots Pine sapwood (*Pinus sylvestris*) was used as reference. The samples were placed in containers with specially prepared soil of known moisture content and water holding capacity. These containers were placed in a (dark) culture chamber (27 °C, 95% RH). After an exposure period of 12 weeks additional Scots Pine sapwood samples (virulence control samples) indicated a more than sufficient mass loss to validate the test. The mass loss, as result of fungal decay, was determined for all samples (see Figure 2).

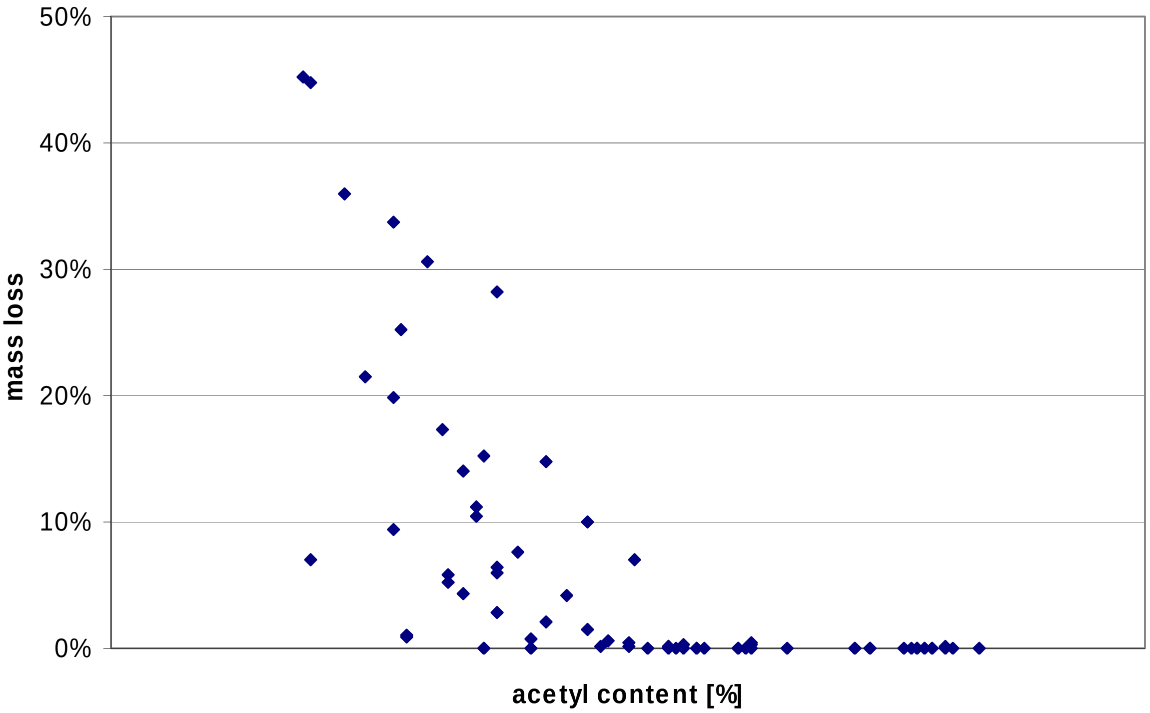

Figure 2. *Mass loss of acetylated Radiata Pine caused by soft rot decay (ENV 807 test) after 12 weeks soil exposure in relation to the acetyl content.*

2.4 Durability classification

Based on the results of the EN 113 and ENV 807 test, the durability of acetylated wood can be classified according to EN 350-1. The classification is based on comparing the mass loss of the test specimens (acetylated wood) with the mass loss of the reference wood species Scots Pine sapwood (see Equation 1). On the basis of the x-value the durability classification is made according to

Table 1.

Equation 1

$$x - value = \frac{average\ corrected\ mass\ loss\ of\ test\ specimens}{average\ mass\ loss\ of\ reference\ specimens}$$

Table 1. *Durability classification according to EN 350-1 for laboratory tests.*

Durability class	Description	x-value
1	Very durable	x ≤ 0.15
2	Durable	0.15 < x ≤ 0.30
3	Moderately durable	0.30 < x ≤ 0.30
4	Slightly durable	0.60 < x ≤ 0.90
5	Not durable	0.90 < x

The test results show that the most aggressive fungus for acetylated wood is the brown rot fungus *Poria placenta*. Based on regression the miminum degree of acetylation (acetyl content) to classify acetylated Radiata Pine as durability class 1, which is the specification of Accoya™, could determined (see Figure 3). At this degree of acetylation the variation in fungal decay within the samples is decreased, resulting in a better reliability of Accoya™ in respect to durability compared to that of untreated Radiata Pine.

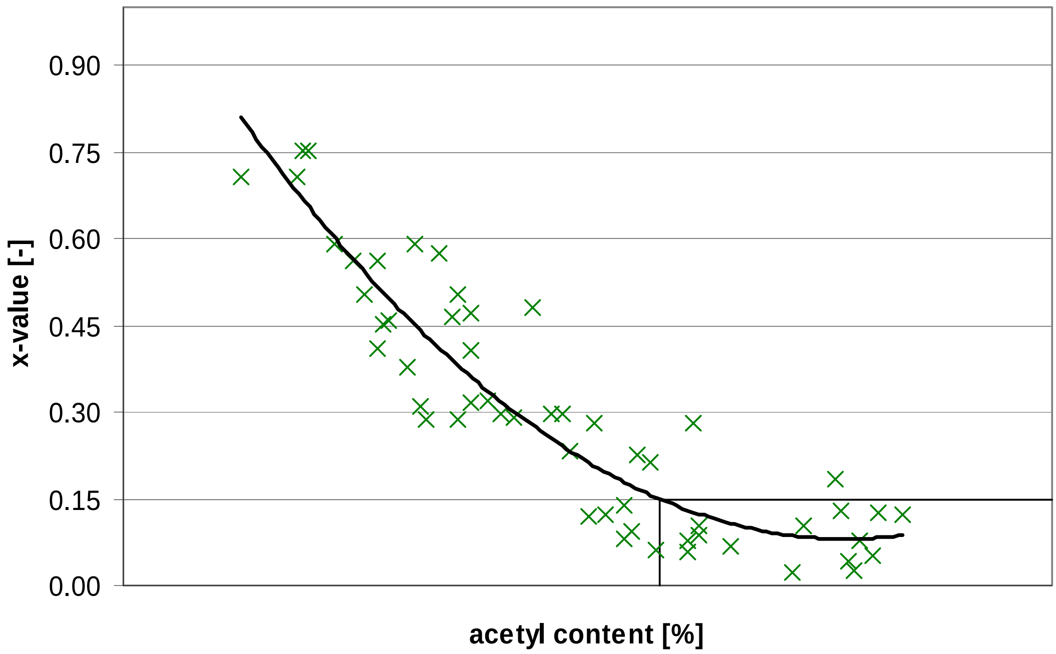

Figure 3. X-values of acetylated Radiata Pine in relation to the acetyl content, based on the EN 113 test with *Poria placenta*.

3. Dimensional stability

The dimensional stability of Accoya™ wood was extensively investigated by SHR Timber Research (Wageningen, the Netherlands) and reported in SHR report 6.322[5].

Samples were conditioned at the following climates: oven dry, 25, 35, 50, 65, 80, 95% relative humidity and water saturated (all at a temperature of 20 °C). In this order (adsorption sequence), as well as in the reverse order (desorption sequence). The weight and dimensions (radial and tangential) of the samples were determined for each of the conditions. Based on the weight measurements, the relation between the relative humidity (of the air) and the corresponding Equilibrium Moisture Content (EMC) of the wood was determined for both the adsorption and desorption sequence. The corresponding shrinking and swelling was measured in the radial and tangential orientations of the wood structure.

In

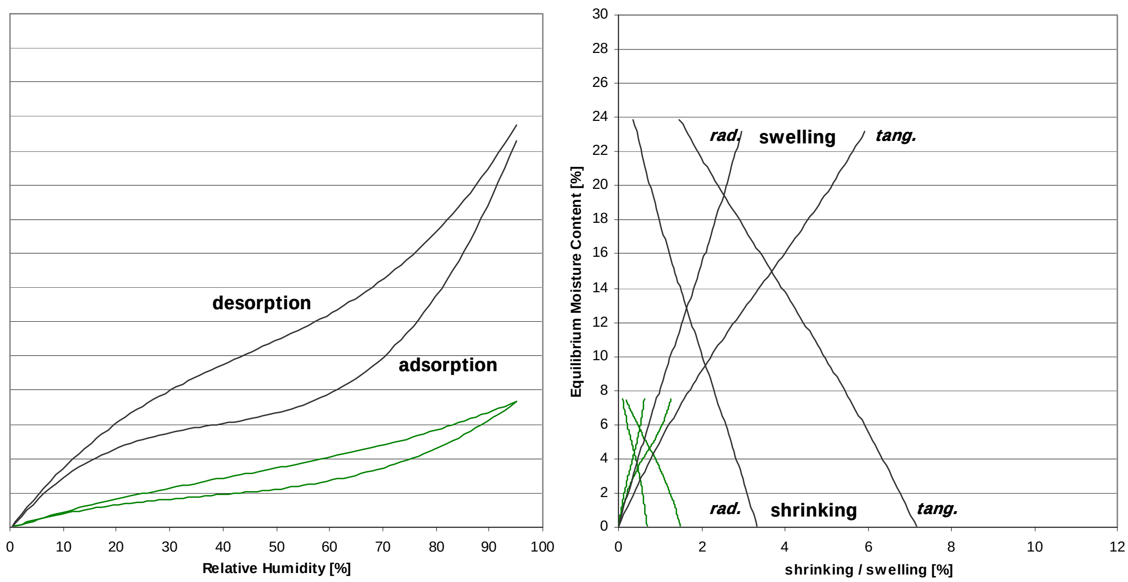

Figure 4 the hygroscopic behaviour (water vapour desorption and adsorption) of Accoya™ wood and untreated Radiata Pine is shown in changing relative humidities (of the surrounding air). The corresponding (percentage of) swelling or shrinking due to moisture uptake or loss is shown in the right part of the graphic. For example a change in relative humidity from 0% to 90% will result in a water adsorption of 6% and corresponding circa 1.2% swelling in tangential direction.

The dimensional stability of Accoya™ wood in relating to common joinery wood species is shown in Figures 5 and 6 respectively for Meranti (*Shorea spp.*) and Merbau (*Intsia bijuga*).

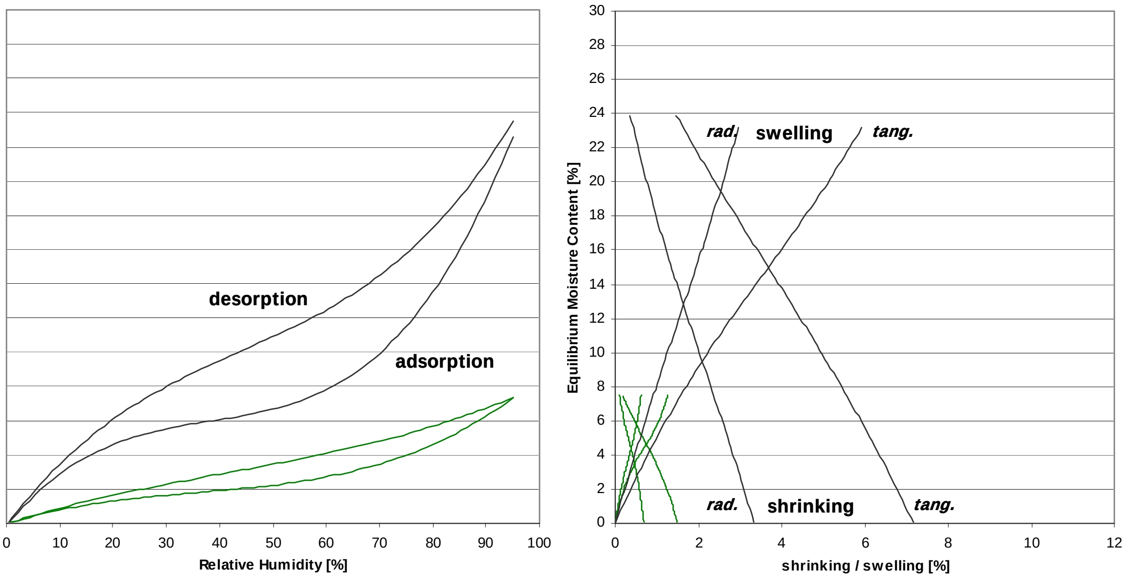

Figure 4. Hygroscopic behaviour (left) of Accoya™ wood (green line) and (untreated) Radiata Pine (black line) under different moisture conditions and the corresponding swelling and shrinking behaviour (Source: SHR report 6.322).

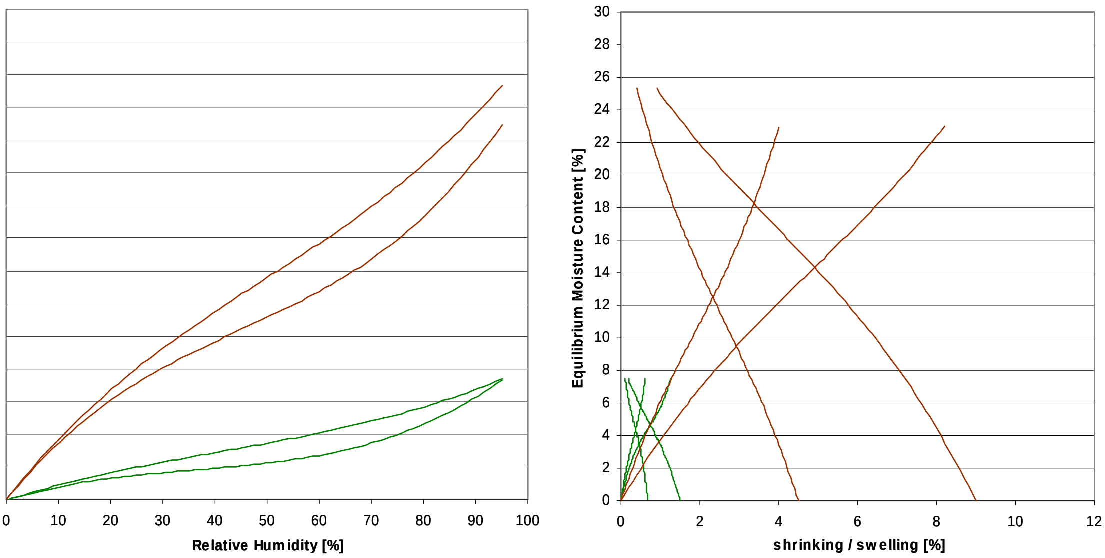

Figure 5. Hygroscopic behaviour (left) of Accoya™ wood (green line) and Meranti (red line) under different moisture conditions and the corresponding swelling and shrinking behaviour (Source: SHR report 6.322 / Rijsdijk & Laming, 1994[6]).

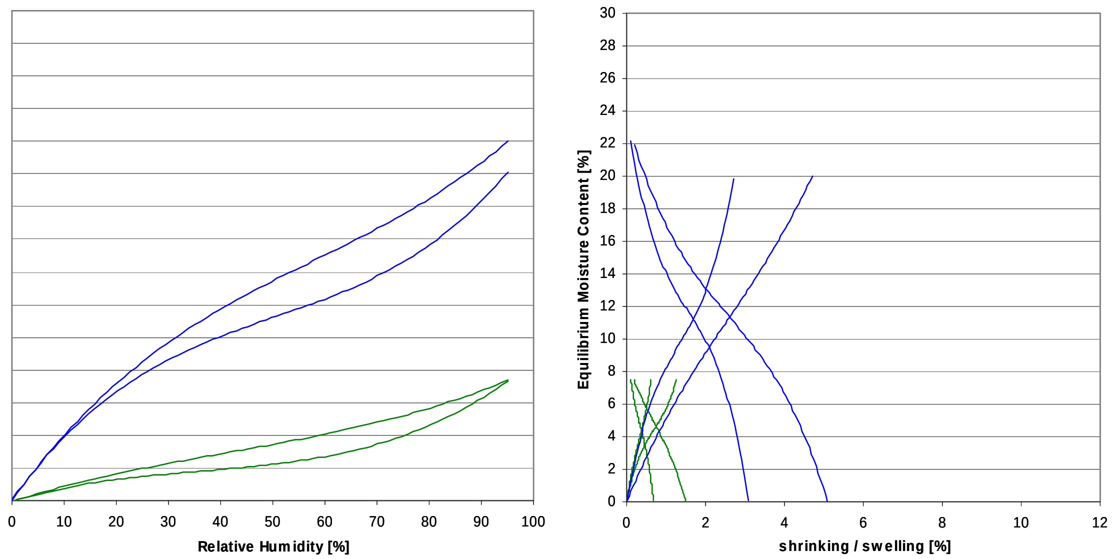

Figure 6. Hygroscopic behaviour (left) of Accoya™ wood (green line) and Merbau (blue line) under different moisture conditions and the corresponding swelling and shrinking behaviour (Source: SHR report 6.322 / Rijsdijk & Laming, 1994).

4. Processing

In co-operation with 2 joinery producers, Titan Wood has investigated the processing (machine ability) of Accoya™. This has been reported in Titan Wood Research Report 200601[7].

In total four windows frames of 100 x 40 cm outside dimension (inward open sash) have been produced. Two window frames were constructed with a dowel type connection and two window frames with a post & I-beam connection. During the production various processing aspects have been studied, which among cross cutting, planing, ripping, profiling, drilling of holes. Further the joinery producers were asked for a general impression of the machine ability of Accoya™ compared to other (traditional) wood species.

It was concluded that Accoya™ is easy to process and results in a very smooth surface compared to other commonly used wood species in the joinery industry. Further the processing of Accoya™ is comparable to that of Meranti (*Shorea spp.*) and Larch (*Larix spp.*), and many times better than Robinia (*Robinia pseudoacacia*) or Merbau (*Intsia bijuga).* Due to the relative light weight Accoya™ is easier to handle. Overall the feeling of the wood during processing gave a positive impression.

5. Mechanical properties

5.1 Bending stiffness and -strength

The effect of acetylation upon the bending stiffness and –strength has been determined in respect to load bearing constructions (see paragraph 5.4). The strength properties of selected boards Radiata Pine (*Pinus radiata*) were determined before and after the acetylation process. It was concluded that the average bending stiffness and –strength were slightly (2%) increased after the acetylation compared with (untreated) Radiata Pine.

5.2 Janka hardness

The Janka hardness of (untreated) Radiata Pine (*Pinus radiata*) and Accoya™ has been determined according to ASTM D143[8]. In this test a steel ball (diameter 11.3 mm) is inserted into the wood on the radial, tangential and cross cut surface. The pressure (load) that is needed to insert the steel ball half into the wood is recorded. The results are reported in SHR report 6.352[9]. In Table 2 the averaged results are shown.

Table 2. Average Janka hardness, density and moisture content of Accoya™ and (untreated) Radiata Pine.

	Janka hardness			Density*	Moisture content*
	Radial [N]	Tangential [N]	Cross cut [N]	[kg/m³]	[%]
Accoya™	4050	4190	6600	520	4.2
Radiata Pine	2750	2750	3640	480	12.1

**conditioned at 65% RH and 20°C.*

Based on the test results, it can be concluded that the acetylation process significantly increases the Janka hardness of Radiata Pine. The average Janka hardness of Accoya™ in radial, tangential and end grain orientation was 44%, 53% and 80% higher respectively, compared to untreated Radiata Pine. These higher values of hardness can be partially explained by the slightly higher density (8%) and substantial lower moisture content of Accoya™ under the same climatic conditions (65% RH and 20 °C).

5.3 Impact bending strength

The impact bending strength of (untreated) Radiata Pine (*Pinus radiata*) and Accoya™ has been determined according to DIN 52189[10]. The test is based on determination of the amount of energy (kJ) that is needed to break a (defect free) sample with an impulse load. The results are reported in SHR report 6.353[11]. In Table 3 the averaged results are shown.

Table 3. Average impact bending strength, density and moisture content of Accoya™ and (untreated) Radiata Pine.

	Impact bending strength [kJ/m^2]	Density* [kg/m^3]	Moisture content* [%]
Accoya™	50	530	4.1
Radiata Pine	50	520	12.1

**conditioned at 65% RH and 20°C.*

Based on the test results, it can be concluded that the impact bending strength of Accoya™ is not significantly different from that of (untreated) Radiata Pine.

5.4 Load bearing constructions

The bending stiffness and –strength of selected Radiata Pine (*Pinus radiata*) has been determined according to EN 408[12] (4-point loading test) prior to and after acetylation. The results were used to determine the characteristic strength properties (conform EN 384[13]) to be able to determine the strength class as defined in EN 338[14]. The results are reported in SHR rapport 6.104[15].

The characteristic values for the bending stiffness and –strength were respectively 10963 N/mm^2 and 40.3 N/mm^2. This corresponds with a strength class of C22. In Europe for the application of Accoya™ in load bearing constructions, it is important that all boards have either been visual (strength) graded or machine graded, and been marked with CE as been stated in EN 14081-1[16].

6. Glue ability

6.1 Lamination

The ability of laminating Accoya™ wood with Dynea Prefere 6151 (adhesive) / 6651 (hardener) was investigated according to BRL 2339[17] and reported in SHR report 6.349w[18]. Three Accoya™ lamellas were glued together according to the instructions (product information sheets) provided by the glue manufacturer. After conditioning the samples, test samples were prepared and exposed to one of the following weathering cycle:

1. Weathering of unfinished samples (duration of 3 weeks)
   - 8 hours of IR-radiating with a maximum surface temperature of 70 °C
   - 24 hours sprinkling with water of 15 °C
   - 40 hours freezing at a temperature of -10 °C
   - 8 hours sprinkling with water of 15 °C
   - 16 hours resting (no actions)
   - 8 hours of IR-radiating with a maximum surface temperature of 70 °C
   - 64 hours resting (no actions)
2. Weathering of <u>finished</u> samples (duration of 3 weeks)
   - 8 hours sprinkling with water of 15 ± 2°C
   - 8 hours of IR-radiating with a surface temperature of 75 ± 5 °C
3. Boiling test (of unfinished samples)
   - 4 hours boiling in water
   - 20 hours drying at 65 ± 1 °C
   - 4 hours boiling in water
   - 20 hours drying at 65 ± 1 °C

After weathering the test specimens were visually evaluated and the percentage of open glue joint was measured.

After weathering all samples did not show any open glue connections. Therefore it can be concluded that Accoya™ laminated with Dynea Prefere 6151 / 6651 (glued according to the specifications of the glue manufacturer) more than fulfils the requirements as described in the BRL 2339.

7. Finishing

7.1 Opaque and transparant film forming coatings

The paintability of Accoya™ in respect to opaque and transparent film forming coatings was tested according to SKH Publicatie 97-04[19]. The tests were performed with an opaque hybrid system, an opaque acrylic dispersion and a transparent (in a critical colour) alkyd emulsion coating system. These coating systems have been extensively tested according to SKH Publication 99-02[20] (opaque coating systems) or SKH Publication 00-01[21] (transparent coating systems) and admitted for use in the production of KOMO certified joinery products.

The opaque paint systems were applied in two layers using airless spraying, with a total dry layer thickness of 100 µm. The transparent paint system was applied in three layers using airless spraying, with a total dry layer thickness of 140 µm. All coating systems were applied according to the (Dutch) KOMO regulations. The finished Accoya™ panels were subjected to the following tests:

- Dry and wet adhesion: adhesion of the coating layer to the wood substrate was tested according to SKH Publicatie 05-01[22] after the finished samples were conditioned at 23 °C and 50% RH for one week.
- Discharging of volatile deposits: (finished) samples were irradiated by InfraRed radiation to a surface temperature of 70 °C for 48 hours. After exposure the samples were visually evaluated for bleeding of wood extractives and other volatile extractives and coating defects.
- Blistering test: (finished) samples were placed in a blistering cabinet for ten days. The coated surface was exposed to a climate of 23 °C and 50% RH, whereas the unfinished side was exposed to a water bath of 40 °C. After exposure the samples were visually evaluated on the degree of blistering according to ISO 4628-2[23], as well as other (possible) coating defects.

The results have been reported in detail in SHR report 6.381[24]. Based on the results, it can be concluded that the paintability of Accoya™ wood is good for the tested coating formulations based on alkyd emulsion (transparent) and acrylic dispersion (opaque). For the tested hybrid coating system (opaque) the wet adhesion is considered to be critical. In general Accoya™ wood can be successfully finished with opaque and transparent alkyd emulsion and acrylic dispersion coating systems. For hybrid coating systems, wet adhesion might be critical in some joinery applications.

8. Various

8.1 Reaction with metals

The corrosively of various types of metal bolts and nuts within Accoya™ was tested with an accelerated test (water sprinkling / temperature) and outdoor exposure. The results show that all (iron) metal elements protected with a thin layer of "corrosion resistant" metals (zinc, aluminum, chromium) do not offer fully protection of corrosion over a long period of time. The presence of acetic acid enhances the speed of corrosion. Only stainless steel (A2) seems to be resistant. Another option is applying a protective coating on the metal. In SHR rapport 6.058[25] bolts have been coated with a 2 layer powder coating system. The first layer consisted of a primer based on epoxy resin (with good chemical and water resistant properties). The top layer was a polyester finish with good UV stability. The results show that as long as the coating layer is complete there is a good protection against corrosion.

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