



Title: Performance of coatings on acetylated Scots pine sapwood in outdoor exposure

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Appendices: 1

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Entries: Acetylation, Scots pine, outdoor exposure, white opaque alkyd, white opaque acrylic, black opaque alkyd, black opaque acrylic, teak coloured transparent alkyd, teak coloured transparent acrylic

Abstract

The condition of coatings - white, black opaque and teak coloured transparent alkyd and acrylics - on acetylated and untreated Scots pine sapwood panels, has been evaluated after nearly 10 years of outdoor exposure.

It is known that acetylation of wood enhances the durability and dimensional stability of the wood. A reduction of 70-80% of swelling / shrinkage can be obtained. Dimensionally stable wood is beneficial to the durability of wood coatings. In the end, this results in a decreased maintenance frequency.

The results of the research described in this report, lead to the following conclusions.

Acetylated wood has a significant better result with respect to long term coating performance compared to untreated wood. After 9½ years outdoor exposure, untreated samples had substantially cracked and flaked coating systems and in some cases the coating was even completely eroded. The tested acetylated samples were only envelope treated and to an acetyl content of less than 20%. It is expected that full acetylation up to 20% acetyl or higher, gives an even more significant improvement of the coating performance.

The adhesion of the coating after 9½ years outdoor exposure is still good. This is valid under both dry and wet conditions. Water uptake does not influence the adhesion of the coating. Since acetylated wood is also very durable, this leads to the conclusion that acetylated wood is not negatively affected by water uptake.

The intrinsic quality of the coating itself has become the main factor affecting the durability of coatings on acetylated wood. With an acrylic opaque white coating the condition of the coating after 9½ years without any maintenance was still good.

The only point of concern with acetylated wood is its vulnerability to blue stain fungi. These fungi give the wood a grey to black appearance but do not influence the integrity. An intact, undamaged coating layer is enough to offer protection against blue stain fungi. Again the quality of the coating itself is the key-factor. In practice it is difficult to realise a completely closed undamaged coating. Therefore additional protective measures against blue stain are strongly recommended.

If a coating system is adapted to be used on acetylated wood and the application is done in the appropriate way it is expected that the maintenance frequency can be as low as once every ten years.

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1 Background

Apart from the obvious positive effect on durability, chemical (and thermal) modification of wood results in a reduction of swelling (Rowell 1983, Kumar 1984). Dimensional changes can be reduced by up to 80% by acetylation compared to untreated wood (Beckers and Militz 1994, Goldstein *et al* 1961, Rowell and Plackett 1988). Less swelling and shrinkage of wood results in less stress on a coating, which enhances durability of the coating system on exterior used wood (De Meijer, 2002). Water borne acrylics are, depending on their formulation, in the end, more elastic than solvent borne alkyds. Solvent borne alkyds are more commonly used for exterior topcoats because of their gloss, aesthetics and ease of application. However, due to ongoing oxidative drying, they show increased cross-linking, resulting in a brittle coating. On a permanently shrinking and swelling substrate, this leads to cracks, flaking of the paint and in the end to an unprotected substrate. Therefore, a more dimensionally stable substrate, as obtained by modification, will result into better outdoor durability of applied coatings.

Titan Wood commissioned SHR to evaluate finished acetylated panels after 9½ year of outdoors exposition. Results after 5½ years of outdoor exposure have already been published during the First European Conference on Wood Modification (Nienhuis *et al.* 2003). In this report both the results after 5½ and 9½ years are reported.

2 Material and method

Panels (10 x 80 x 300 mm) of envelope acetylated Scots pine sapwood, were exposed since September 1995 at the exposition site of SHR Timber Research, Wageningen, the Netherlands. Panels were placed on a rack facing south in an angle of 45°. Part of the acetylated samples contains 3 to 4% residual acetic acid, while the other acetylated samples are totally free of residual acetic acid. The panels were coated with commercial waterborne and solvent borne coatings, both opaque and transparent ones applied in a layer thickness of 80 – 100 µm in two layers. As a reference, untreated Scots pine sapwood panels were coated and exposed. Before exposition, some panels were damaged by artificially applied hail.

In 1995 1-meter long boards have been acetylated in a small-scale pilot plant. The treatment was merely an envelope treatment. After removing the residual acetic acid (where applicable) the boards have been cross cut to 300 mm length, and finished with the following coatings:

- 1 Transparent teak coloured alkyd (*solvent based*)
- 2 Transparent teak coloured acrylic (*water based*)
- 4 Opaque white acrylic (*water based*)
- 5 Opaque black acrylic (*water based*)
- 6 Opaque white alkyd (*solvent based*)
- 7 Opaque black alkyd (*solvent based*)

The coating systems have been evaluated after 5½ and 9½ years of outdoor exposure with regard to the visual aspects. In this period there has been no maintenance whatsoever of the coating system. After 9½ years, also the adhesion (according to ISO 2409) of two samples per coating system and wood treatment has been determined under wet and dry conditions. After visual inspection of the coating layer, a 2-cm strip has been sawn from the lower part of one sample per coating system and per wood treatment. The 2-cm strip has been used for the determination of the coating layer thickness (by microscopy). The moisture content of the sample was measured by weighing and drying during 48 hours at 103 °C. Finally the 2-cm strip has been used to determine the acetyl content (see paragraph “degree of acetylation”). The remaining boards (with removed 2-cm strip) have been used to determine the water uptake (through the cross cut side). In figure 1 a schematic overview of the research set-up is given.

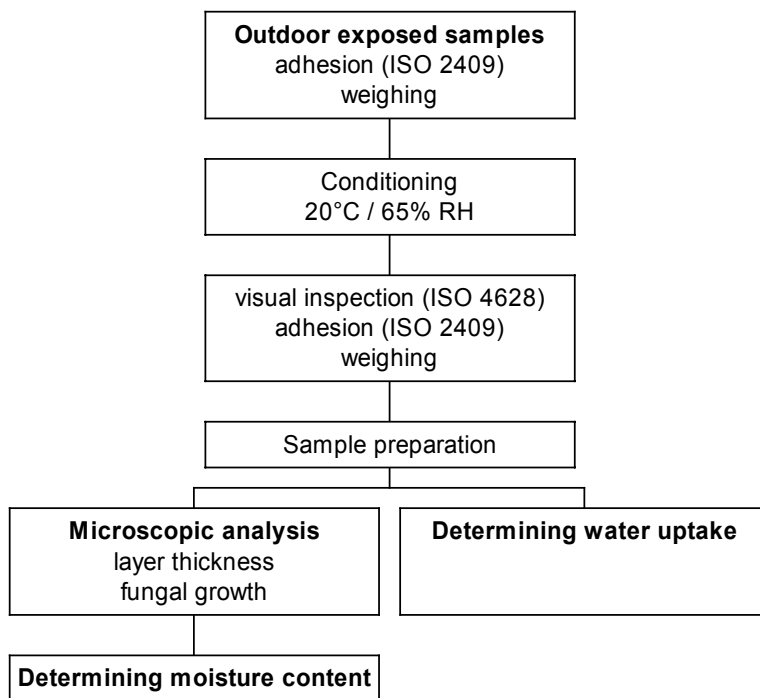


Figure 1. Overview test schedule.

2.1 Visual assessment

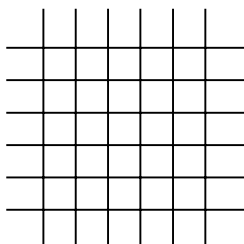
All coating systems have been visually assessed after conditioning upon the following aspects:

- Degree of blistering (ISO 4628/2). The evaluation is based on pictorial references for a numerical classification of the degree of blistering. Blistering is described by a number for the **density** (0 = no blisters, 5 = high density of blisters) and a number for the **size** ranging from 1 to 5 (5 = largest size of blisters).
- Degree of cracking (ISO 4628/4). The evaluation is based on pictorial references for a numerical classification of the degree of cracking. Cracking is described by a number for the **quantity** (0 = no cracks, 5 = high density of cracks) and a number for the **size** (0 = not visible, 5 = larger than 1 mm wide). 2S3 indicates: quantity = 2 and size = 3.

-
- Degree of flaking (ISO 4628/5). The evaluation is based on pictorial references for a numerical classification of the degree of flaking. Flaking is described by a number for the **quantity** (flaked area %: 0 = 0%, 5 = 15% flaking) and a number for the **size** (0 = not visible, 5 = larger as 30 mm). 2S3 indicates: quantity = 2 and size = 3
 - Degree of chalking (ISO 4628/6). The evaluation is based on pictorial references for a numerical classification of the degree of chalking ranging from 0 to 5 (5 = high degree of chalking).
 - Mould growth (EN 927-3). The evaluation is based on pictorial references for a numerical classification of the degree of mould growth ranging from 0 to 5 (5 = highest degree of mould growth).
 - Rate of decay (EN 330). The evaluation is based on a description of the degree of wood decay (0 = sound, 4 = very severe and extensive rot).

2.2 Adhesion tests

The adhesion of the coating was determined on the “wet” outdoor exposed panels and after conditioning (dry conditions) according to ISO 2409. Twelve cuts were made in the paint systems with the following pattern:



The distance between the cuts was 3 mm. A tape was placed over the cuts and pulled off after two minutes in an angle of around 60° in 1 second. The amount of removed paint due to the tape was evaluated and based on pictorial references a numerical classification was made of the degree of adhesion (scale 0 to 5; 0 = no failure of the adhesion of the coating, 5 = complete failure of the adhesion of the coating).

2.3 Water uptake

The acetylated samples (outdoor exposed during 9½ years), where the 2-cm strip was removed for other analysis, were used to determine the water uptake. Also 5 unexposed Scots pine sapwood panels were used in the test as references. The samples have been put into water with the cross cut downwards. The water uptake has been recorded by measuring the weight at various intervals during 5 days.

2.4 Acetyl content

The degree of acetylation can be directly determined by measuring the amount of acetyl content in the wood. Untreated wood has a small acetyl content and by acetylation the amount of these hydrophobic groups increases.

The acetyl content has been determined by means of FTIR-ATR Spectroscopy (Fourier Transform Infra Red – Attenuated Total internal Reflection geometry) according to SHR's Standard Operation Procedure WVS_SHR_061-EN. With FTIR-spectroscopy carbonyl and sugar groups of wood can be identified. By comparing measurement results of the carbonyl-peak (around 1740 cm^{-1}) and the sugar-peaks (around 1010 cm^{-1}), the acetyl content is quantified. The relation between this ratio and the acetyl content has been established earlier by comparing FTIR-values (carbonyl-peak / sugar-peak) with HPLC analysis results (SHR Standard Operation Procedure WVS_SHR_056-EN).

Titan Wood has determined the acetyl content of the (finished) acetylated samples, using a Bomem MB 100 spectrometer and Specac Golden Gate Mk II ATR-package. The acetyl content has been determined 2 mm under the wood's surface and in the core of the sample by using equation 1.

$$\textit{Acetyl content} = 42.663 \times \textit{FTIRvalue} - 2,3074 \quad [\%] \quad (1)$$

3 Results & discussion

3.1 Visual assessment

In the tables 1 and 2 the visual assessment of all panels after 5½ and 9½ years outdoor exposure is summarised per coating system and wood treatment. None of the coatings showed any signs of blistering. In Appendix 1 all individual assessments are given per coating type, as well as a photographic overview of the state of the coating systems on untreated, acetylated and acetylated with residual acetic acid samples.

Table 1. Summary of the visual assessments after 5½ years of outdoor exposure.

1 Transparent teak coloured alkyd

The coating of the untreated samples has a severe degree of flaking (5S3 to 5S5) and cracking (2S3 to 3S3). All untreated samples have deep wood cracks, and one board is severely decayed by fungi.

There was not much difference between acetylated, acetylated with residual acetic acid and hailed or not hailed samples. The coating of the acetylated samples does not show any flaking, and only a low degree of cracking (on sides and due to hail damage). The acetylated samples with residual acetic acid have a few large wood cracks. All acetylated samples have a black surface mould on the coating.

2 Transparent teak coloured acrylic

The coating of one of the untreated samples has a severe degree of flaking. The coating of the other untreated samples does not show any flaking. The degree of cracking of the coating is limited for all samples, but most severe on the untreated samples (1S3 to 2S4) due to wood cracks (acetylated samples 1S3). Damaging of the coating by hailing did not lead to any cracking of the coating. One acetylated and one acetylated with residual acetic acid sample contained wood cracks. All acetylated samples have a black surface mould on the coating, although the degree is more severe for the acetylated samples with residual acetic acid.

4 Opaque white acrylic

The coating of 2 untreated samples and 1 acetylated with residual acetic acid sample shows a small degree of flaking. The coating of the untreated samples is relatively more cracked (1S3 to 3S3) compared to the acetylated samples (1S3, or none). A few untreated samples show blistering of the coating and 1 untreated sample is decayed. The coating of the acetylated samples with residual acetic acid is covered with a dark greenish surface mould. Hailing of the samples led to severe damage (cracking: 1S3 to 3S3) on especially the acetylated samples with residual acetic acid.

5 Opaque black acrylic

The coating of the untreated samples had many cracks (1S3 to 4S3) and flaking (2S3 to 3S3). Four untreated samples show wood cracks, and one sample is decayed.

The coating of 1 acetylated and 2 acetylated samples with residual acetic acid had a mild degree of flaking. The coating showed cracks to a slight extent for the acetylated (1S2 to 3S3) and acetylated with residual acetic acid samples (1S2 to 1S3). A few acetylated samples have some superficial wood cracks. Hailing of the samples did not lead to any cracking of the coating. The coating of especially the acetylated samples with

residual acetic acid is covered with a dark surface mould.

6 Opaque white alkyd

The coating of the untreated samples had many cracks (2S3 to 3S3) and flaking (3S3 to 5S4). Three untreated samples show deep wood cracks. The coating is covered with a greenish surface mould.

The coatings of the acetylated samples showed almost no flaking and only a minor degree of cracking. Superficial wood cracks are found in 3 of the acetylated samples. The coating of especially the acetylated samples with residual acetic acid is covered with a dark greenish surface mould. Hailing of the samples did not lead to any cracking of the coating.

7 Opaque black alkyd

The coating of the untreated samples had many cracks (2S3 to 3S3) and flaking (3S3 to 5S4). One of the untreated samples is almost completely decayed. Under the coating layer probably blue stain has grown resulting in small dips in the coating.

The coating of the acetylated samples does not show any degree of flaking, but is slightly cracked. Four acetylated samples have wood cracks. The coating of the hailed samples is in the same condition as the not-hailed samples. However, due to hailing, some degree of cracking and adhesion problems (intercoat adhesion) is visible on the acetylated samples.

Table 2. Summary of the visual assessments after 9½ years of outdoor exposure.

1 Transparent teak coloured alkyd

The coating of the untreated samples was almost completely disappeared. All untreated samples had moderate to severe wood decay.

There was not much difference between acetylated, acetylated with residual acetic acid and hailed or not hailed samples. All acetylated samples had (many) cracks in the coating. As a result of degradation of the coating itself, there were also many superficial cracks in the coating. There was severe mould growth on the coating. One of the acetylated samples had some wood decay.

2 Transparent teak coloured acrylic

The coating of the untreated samples had many cracks and some flaking. All untreated samples had moderate to severe wood decay.

There was not much difference between acetylated, acetylated with residual acetic acid and hailed or not hailed samples. All acetylated samples had some cracks in the coating. As a result of degradation of the coating there were also many superficial cracks in the coating. There was no mould growth on the coating's surface. One of the acetylated samples had some wood decay in the centre of the board.

4 Opaque white acrylic

All samples had some mould growth. Chalking was evaluated in class 2.

The coating of the untreated samples had many cracks and some flaking. All untreated samples had moderate to severe wood decay.

There was not much difference between acetylated, acetylated with residual acetic acid and hailed or not hailed samples. The coating on the acetylated samples had a few cracks and showed no signs of flaking.

Wood decay was found in 2 out of 13 acetylated samples.

5 Opaque black acrylic

The coating of the untreated samples had many cracks and flaking. All untreated samples had moderate to severe decay.

There was not much difference between acetylated, acetylated with residual acetic acid and hailed or not hailed samples. The coating on the acetylated samples had many small cracks due to coating degradation and little amount of flaking. Moderate to severe wood decay was found in 6 out of 13 acetylated samples.

6 Opaque white alkyd

At the surface of the untreated samples hardly any coating was left. All untreated samples had severe wood decay.

There was not much difference between acetylated, acetylated with residual acetic acid and hailed or not hailed samples. The coating of all acetylated samples had many cracks and some degree of flaking. All acetylated samples were sound (no wood decay). Blue stain was penetrating through the coating at all samples.

7 Opaque black alkyd

There was hardly any coating left at the surface of the untreated samples. All untreated samples had moderate to severe decay.

There was not much difference between acetylated, acetylated with residual acetic acid and hailed or not hailed samples. The coating of the acetylated samples had many cracks and some degree of flaking. Out of 14 acetylated samples 7 had moderate to severe wood decay.

Summarising, the results after 5½ years of outdoor exposure show that:

- The untreated uncoated samples are severely (and deeply) cracked over the whole length of the panel. The acetylated samples (with and without residual acetic acid) have a remarkably smoother surface and have less and less deep wood cracks. Blue stain is found on all samples.
- The transparent teak coloured acrylic and opaque white acrylic coatings give the best results for untreated wood. Cracking of the coatings is found, but in other coating systems most of the coating is already flaking.
- For every coating system, acetylation improves the resistance against weathering. Only the transparent alkyd teak coloured coating shows some cracking of the coating system. Flaking is not found for any coating system on acetylated wood.
- The hailed samples perform identical to the not-hailed samples.
- The acetylated samples, and especially the samples with residual acetic acid, have a black appearance.

After 9½ years of outdoor exposure most untreated samples have hardly any coating left, or a severe damage of the coating (cracking / flaking). The condition of the coatings on acetylated wood was remarkably better when compared to the coatings of the untreated samples. The transparent coatings (alkyd / acrylic) showed a degradation of the coating itself. On the acetylated samples the acrylic opaque coatings, and especially the white coloured coating, showed the best results after the outdoor exposure.

Blue stain

In outdoor exposure, blue stain attacked finished acetylated wood after a few months. Although the wood moisture content of acetylated wood is lower, blue stain appeared locally on some surfaces, and is causing degradation of the coating at sound spots (cracking). The amount of acetic acid does seem to influence the development of blue stain fungi, however, the exact nature of how blue stains develop in acetylated wood is not known.

3.2 Adhesion tests

In table 3 the results of the adhesion under dry and wet conditions are shown. The thickness of the coating layer (based on 1 sample per coating system and wood treatment) and the wood's moisture content during the "adhesion under wet condition"-test are given too. In figure 2 a photographic overview is given of adhesion tests of untreated and acetylated (with and without residual acetic acid) finished with an opaque white acrylic coating. For most untreated wood samples the adhesion could not be determined because almost no coating was left on the surface. A remarkable better adhesion was found for the acetylated samples compared to the untreated samples finished with an opaque white acrylic coating (system 4). The bad adhesion for the acetylated samples finished with opaque alkyd coatings is caused by the loss of intercoat adhesion. In general the acrylic coatings on acetylated wood showed the best adhesion.

Table 3. Adhesion of the coating systems under wet and dry conditions after 9½ years of outdoor exposure determined according to ISO 2409 (scale 0 to 5; 0 = no failure of the adhesion of the coating, 5 = complete failure of the adhesion of the coating).

Treatment	Coating	Layer thickness (µm)	Moisture content (%)	Adhesion wet condition		Adhesion dry condition	
				After brushing	With tape	After brushing	With tape
1	1	-	143	-	-	-	-
2	1	156	33	1 / 0	1 / 0	2 / 1	2 / 1
3	1	180	24 / 67 ⁺	0 / 3	1 / 3	1 / 2	1 / 2
1	2	250	110	0 / 0	0 / 0*	0 / 0	0 / 2
2	2	180	14 / 105 ⁺	0 / 0	0 / 0*	0 / 0	0 / 0
3	2	300	19	0 / 0	0 / 0	-	-
1	4	180	317	4 / 4	4 / 4	5 / 3	5 / 4
2	4	144	21	0 / 0	0 / 0	1 / 0	1 / 0
3	4	120	22	0 / 0	0 / 0	0 / 0	0 / 0
1	5	-	253	-	-	-	-
2	5	120	54 / 137 ⁺	0 / 0*	0 / 0*	0 / 1	0 / 1
3	5	108	121 / 179 ⁺	0 / 0	0 / 0	0 / 0	0 / 1
1	6	-	166	-	-	-	-
2	6	156	16	2 / 1	2 / 4**	2 / 1	3 / 1**
3	6	120	25	1 / 1	5 / 2**	2 / 1	2 / 2**
1	7	-	158	-	-	-	-
2	7	108	120 ⁺ / 35	0 / 0	2 / 0*	4 / 1	5 / 1
3	7	108	111 ⁺ / 114	0 / 0	0 / 0	2 / 2	2 / 2

⁺ part of the (acetylated) sample is decayed

* failure of adhesion of tape

** failure of intercoat adhesion

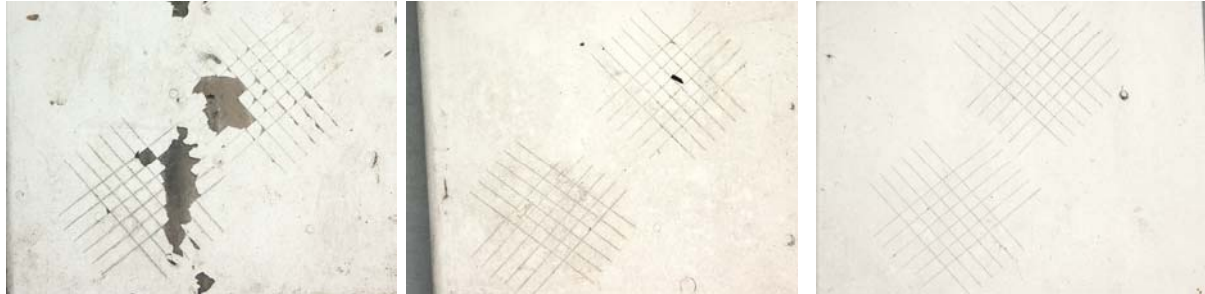


Figure 2. Adhesion test (ISO 2409) under wet conditions of untreated (left), acetylated and acetylated with residual acetic acid finished with an opaque white acrylic coating after 9½ years of outdoor exposure.

3.3 Water uptake

In figure 3 the amount of water uptake of the acetylated samples compared to unexposed Scots pine sapwood is shown. The water uptake of the acetylated exposed Scots pine samples was in most cases higher than the water uptake of unexposed Scots pine sapwood. This confirms the conclusion that part of the acetylated wood was decayed (due to too low acetyl content, see paragraph 3.4) and/or colonised by blue stain fungi. However, the surface of the acetylated wood samples was sufficiently acetylated to prevent wood decay.

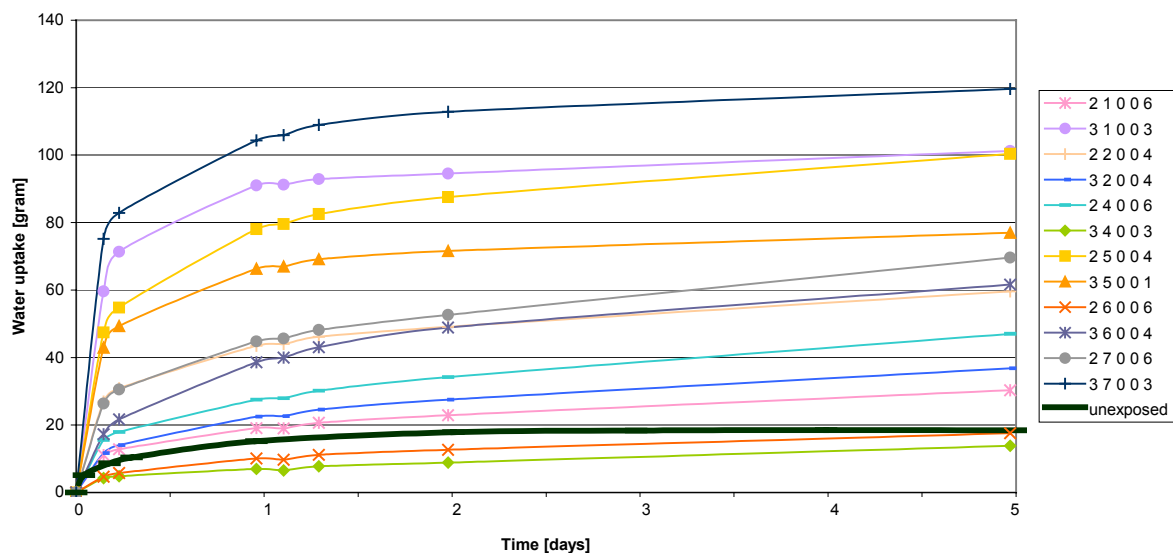


Figure 3. Water uptake of the acetylated samples compared to “fresh” Scots pine sapwood.

3.4 Acetyl content

In table 4 the acetyl content in the core of the sample and 2 mm under the surface is summarised. The degree of acetylation is relatively low considering the required acetyl content of approximately 20% for a durability class 1 (according to EN 350-1). Most acetylated samples are superficially treated and no obviously acceptable degree of protection against wood decay was achieved in the centre of the panels. Therefore the acetylated samples are to be considered as envelope treated only. The observed cupping and warping of the exposed samples would have been much less if the treatment had been throughout the whole sample. For this reason, fully acetylated samples are expected to score even better on coating performance.

Table 4. The acetyl content of acetylated samples 2 mm under the surface and in the core of the sample.

Sample no.	Acetyl content (%)	
	2 mm under surface	Core
21006	11.3 (1.6)	5.1 (1.0)
22004	17.9 (0.8)	7.4 (1.0)
22006	12.9 (1.3)	4.3 (0.3)
24006	16.3 (1.4)	4.9 (0.4)
25004	16.8 (1.2)	6.1 (1.4)
25006	3.7 (0.6)	n.a.
26006	16.9 (0.8)	2.3 (0.6)
27004	14.9 (0.6)	2.5 (0.8)
27006	11.8 (2.0)	4.5 (0.9)
31003	15.5 (0.8)	10.9 (1.8)
31004	9.7 (0.8)	n.a.
32004	14.5 (0.9)	3.8 (0.5)
34003	13.7 (2.5)	5.2 (0.7)
35001	17.9 (1.0)	-
35003	12.7 (1.6)*	n.a.
36004	13.9 (1.4)	4.5 (0.9)
37001	14.2 (0.8)	n.a.
37004	3.9 (0.8)	2.7 (0.5)

* the acetyl content of sample 35003 is determined 1 mm under the surface

4 Conclusion

The results of the research described in this report, lead to the following conclusions.

Acetylated wood has a significant better result with respect to long term coating performance compared to untreated wood. After 9½ years outdoor exposure, untreated samples had substantially cracked and flaked coating systems and in some cases the coating was even completely eroded. The tested acetylated samples were only envelope treated and to an acetyl content of less than 20%. It is expected that full acetylation, up to 20% acetyl or higher, gives an even more significant improvement of the coating performance.

The adhesion of the coating after 9½ years outdoor exposure is still good. This is valid under both dry and wet conditions. Water uptake does not influence the adhesion of the coating. Since acetylated wood is also very durable, this leads to the conclusion that acetylated wood is not negatively affected by water uptake.

The intrinsic quality of the coating itself has become the main factor affecting the durability of coatings on acetylated wood. With an acrylic opaque white coating the condition of the coating after 9½ years without any maintenance was still good.

The only point of concern with acetylated wood is its vulnerability to blue stain fungi. These fungi give the wood a grey to black appearance but do not influence the integrity. An intact, undamaged coating layer is enough to offer protection against blue stain fungi. Again the quality of the coating itself is the key-factor. In practice it is difficult to realise a completely closed undamaged coating. Therefore additional protective measures against blue stain are strongly recommended.

If a coating system is adapted to be used on acetylated wood and the application is done in the appropriate way it is expected that the maintenance frequency can be as low as once every ten years.

5 Recommendations

The results show that acetylation significantly improves the performance of coatings on wood. However, the outdoor exposure test has been performed with coatings systems that were commercially available 10 years ago, and with an acetylation process that was not yet optimised. Since then, both the acetylation process and the coating systems have improved considerably. When degradation of coatings by blue stain is prevented, the maintenance frequency is expected to decrease significantly by using acetylated wood.

It is advised to start a new outdoor exposition test for modern coating systems and with wood treated in an up to date acetylation process (possibly in combinations with anti-blue-stain treatment). Besides testing of coating performance on panels (according to EN 927-3), an evaluation of coating performance on joinery in practice is recommended.

Literature

Beckers, E.P.J., Stevens, M., De Meijer, M. and Militz, H. (1998) Performance of finishes on wood which is chemically modified by acetylation, *Journal of Coatings Technology*, **70** (878), 59- 67

Beckers, E.P.J., Militz, H. (1994) Acetylation of solid wood - Initial trials on lab and semi industrial scale. Second Pacific Rim Bio-Based Composites Symposium, Vancouver, Canada

De Meijer, M, (2002) Mechanisms of Failure in Exterior Wood Coatings. In: Congress Papers of the Third International Wood Coatings Congress, The Hague, the Netherlands

EN 330 (1994). Wood preservatives. Field test for determining the relative protective effectiveness of a wood preservative for use under a coating and exposed out of ground contact: L-joint method.

EN 350-1 (1994). Durability of wood and wood-based products. Natural durability of solid wood. Part 1: Guide to the principles of testing and classification of the natural durability of wood.

EN 927-3 (2000). Paints and varnishes. Coating materials and coating systems for exterior wood. Part 3: Natural weathering test.

Goldstein, I.S., Jeroski, E.B., Lund, A.E., Nielson, J.F., Weaver, J.W. (1961) Acetylation of wood in lumber thickness. *Forest Products Journal* **11** (8), 363-370

ISO 2409 (1994). Paints and varnishes. Cross-cut test.

ISO 2808 (1999). Paints and varnishes. Determination of film thickness.

ISO 4628/2 (1982). Paints and varnishes. Evaluation of degradation of paint coatings. Designation of intensity, quantity and size of common defect. Part 2: Designation of degree of blistering.

ISO 4628/4 (1982). Paints and varnishes. Evaluation of degradation of paint coatings. Designation of intensity, quantity and size of common defect. Part 4: Designation of degree of cracking.

ISO 4628/5 (1982). Paints and varnishes. Evaluation of degradation of paint coatings. Designation of intensity, quantity and size of common defect. Part 5: Designation of degree of flaking.

ISO 4628/6 (1982). Paints and varnishes. Evaluation of degradation of paint coatings. Designation of intensity, quantity and size of common defect. Part 6: Rating of degree of chalking by tape method.

Kumar, S. (1994) Chemical modification of wood. *Wood and Fiber Science*, **26** (2), 270-280

Nienhuis, J.G., Velde, B. van de, Cobben, W.N.H. and Beckers, E.P.J. (2003). Exterior durability of coatings on modified wood. In: Van Acker, J. and Hill, C. (eds.). Proceedings of the First European Conference on Wood Modification, 3-4 April 2003, Ghent, Belgium, p. 203-206.

Rowell, R.M., Plackett, D.V., (1988) Dimensional stability of flakeboards made from acetylated *Pinus radiata* heartwood or sapwood flakes. *New Zealand Journal of Forestry Science* **18** (1), 124-131

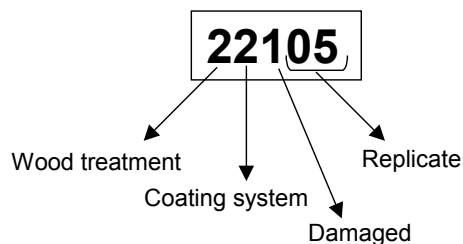
Rowell, R.M. (1983) Chemical modification of wood. *Forest Products Abstracts* **6** (12), 363-382

WVS_SHR_056-EN (2002). Determination of the acetyl content of wood by means of HPLC. Version 1, d.d. 05-08-2002. Standard Operation Procedure SHR Timber Research, Wageningen.

WVS_SHR_061-EN (2002). Determination of the acetyl content of wood with ATR-FTIR. Version 1, d.d. 22-07-2002. Standard Operation Procedure SHR Timber Research, Wageningen.

Appendix 1. Evaluation of coated panels after 5½ and 9½ outdoor exposure

All samples are numbered according the following system:



Wood treatment

- 1 Untreated
- 2 Acetylated
- 3 Acetylated with residual acetic acid

Coating system

- 1 Transparent teak coloured alkyd
- 2 Transparent teak coloured acrylic
- 4 Opaque white acrylic
- 5 Opaque black acrylic
- 6 Opaque white alkyd
- 7 Opaque black alkyd

Damaged before outdoor exposure

- 1 Not damaged
- 2 Hailed

On the following pages the results of the evaluation of all panels after 5½ and 9½ years of outdoor exposure is given per coating system. The panels are evaluated on the following aspects:

- Degree of blistering (ISO 4628/2)
- Degree of cracking (ISO 4628/4)
- Degree of flaking (ISO 4628/5)
- Degree of chalking (ISO 4628/6)
- Adhesion (ISO 2409)
- Mould growth (EN 927-3)
- Rate of decay (EN 330)

Coating system 1 – Transparent teak coloured alkyd



Untreated (left), acetylated and acetylated with residual acetic acid panels finished with a transparent teak coloured alkyd coating after 9½ years of outdoor exposure.



Cracking of coating surface (sample 21004) as result of coating degradation after 9½ years of outdoor exposure.

cracking ISO 4628/4													
sample code		after 5 ½ years			after 9 ½ years								
treatment	coating	1 damaged	replicate	density	size	depth	direction	remarks	density	size	depth	direction	remarks
not treated													
1	1	0	0	1	1	3			n.a.				almost no coating left
1	1	0	0	2	1	3		many small cracks (5S2) at 1/3 of the surface	n.a.				almost no coating left
1	1	0	0	3	2	3			n.a.				almost no coating left
1	1	0	0	4	3	3			n.a.				almost no coating left
1	1	0	0	6	1	3							
acetylated													
2	1	0	0	1	1	3		5S1c at small part of the surface	4	3	c	y	also many superficial cracks because of coating degradation
2	1	0	0	2	1	3		5S1c at small part of the surface					
2	1	0	0	3	1	3		5S1c at small part of the surface	2	3	c	y	also many superficial cracks because of coating degradation
2	1	0	0	4	1	3		5S1c at small part of the surface	3	3	c	y	also many superficial cracks because of coating degradation
2	1	0	0	6					2	3	c	y	also many superficial cracks because of coating degradation
acetylated with acid													
3	1	0	0	1	1	3			2	3	c	y	also many superficial cracks because of coating degradation
3	1	0	0	2	1	3		2 superficial wood cracks 4.5cm.					
3	1	0	0	3	1	3		1 superficial wood crack 1.5cm.	2	3	c	y	also many superficial cracks because of coating degradation
3	1	0	0	4	1	3		1 superficial wood crack 12.5cm.	4	3	c	y	also many superficial cracks because of coating degradation

flaking ISO 4628/5						
sample code		after 5 ½ years			after 9 ½ years	
treatment coating I damaged replicate	density size depth direction	remarks			density size depth direction	remarks
not treated						
1	1 0 0 1	5	4		n.a.	almost no coating left
1	1 0 0 2	5	4		n.a.	almost no coating left
1	1 0 0 3	4	4		n.a.	almost no coating left
1	1 0 0 4	5	3		n.a.	almost no coating left
1	1 0 0 6	5	5	large part of the sample decayed		
acetylated						
2	1 0 0 1	0			0	
2	1 0 0 2	0			0	
2	1 0 0 3	0			0	
2	1 0 0 4	0			0	
2	1 0 0 6	0			0	
acetylated with acid						
3	1 0 0 1	0			0	
3	1 0 0 2	0			0	
3	1 0 0 3	0			0	
3	1 0 0 4	1	2		3	5 b y

After 9½ years										
sample code		adhesion, wet condition EN ISO 2409		adhesion, dry conditions EN ISO 2409		EN 927-3	EN330	ISO 4628/6	general remarks	
treatment coating I damaged replicate	after brushing with tape	remarks	after brushing with tape	remarks	mould growth	decay	chalking			
not treated										
1	1 0 0 1	n.a.	n.a.	n.a.	n.a.	n.a.	3	n.a.	almost no coating left	
1	1 0 0 2								sample not present	
1	1 0 0 3	n.a.	n.a.	n.a.	n.a.	n.a.	2	n.a.		
1	1 0 0 4	n.a.	n.a.	n.a.	n.a.	n.a.	3	n.a.		
1	1 0 0 6								sample not present	
acetylated										
2	1 0 0 1	n.a.	n.a.	n.a.	n.a.	4	0	2	sample not present	
2	1 0 0 2									
2	1 0 0 3	n.a.	n.a.	n.a.	n.a.	5	0	2		
2	1 0 0 4	1	1	bad adhesion of tape due to moisture	2	2	5	0		2
2	1 0 0 6	0	0		1	1	3	0		2
acetylated with acid										
3	1 0 0 1	n.a.	n.a.	n.a.	n.a.	3	0	2	sample not present	
3	1 0 0 2									
3	1 0 0 3	0	1		1	1	2	0		2
3	1 0 0 4	3	3		2	2	2	0		2

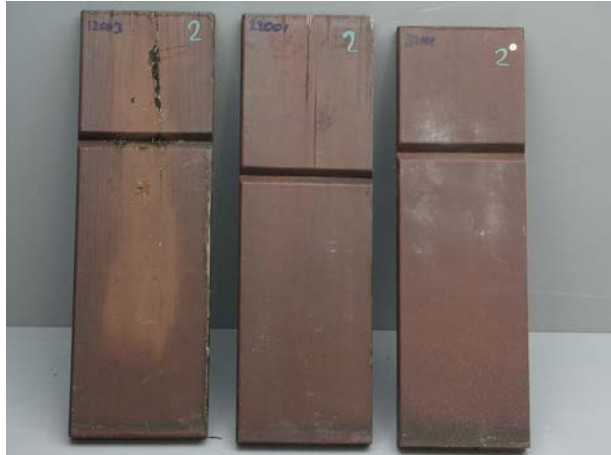
Hailed samples

cracking ISO 4628/4							
sample code		after 5 ½ years			after 9 ½ years		
treatment coating I damaged replicate	density size depth direction	remarks		density size depth direction	remarks		
not treated							
1 1 1 0 1	2 3						
1 1 1 0 2	2 3						
1 1 1 0 3	2 3						
acetylated							
2 1 1 0 1	5 1 a/ b	cracks only at lower part of the sample		1 3 c n	also many superficial cracks because of coating degradation		
2 1 1 0 2	4 2	local blue stain growing through coating		2 3 c n	also many superficial cracks because of coating degradation		
2 1 1 0 3	5 1	local blue stain growing through coating		4 3 c y	also many superficial cracks because of coating degradation		
acetylated with acid							
3 1 1 0 1	5 1			3 3 c y	also many superficial cracks because of coating degradation		
3 1 1 0 2	1 3	local 5S1		1 3 c n	also many superficial cracks because of coating degradation		
3 1 1 0 3	1 3	local 5S1		3 3 c y	also many superficial cracks because of coating degradation		

flaking ISO 4628/5							
sample code		after 5 ½ years			after 9 ½ years		
treatment coating I damaged replicate	density size depth direction	remarks		density size depth direction	remarks		
not treated							
1 1 1 0 1	5 4	decay					
1 1 1 0 2	4 4						
1 1 1 0 3	5 4						
acetylated							
2 1 1 0 1	0			0			
2 1 1 0 2	0			0			
2 1 1 0 3	0			3 5 b y			
acetylated with acid							
3 1 1 0 1	0			1 4 b y			
3 1 1 0 2	0			0			
3 1 1 0 3	0			1 4 b y			

After 9½ years									
sample code		adhesion, wet condition EN ISO 2409		adhesion, dry conditions EN ISO 2409		EN 927-3	EN330	ISO 4628/6 chalking	general remarks
treatment coating I damaged replicate	after brushing with tape	remarks		after brushing with tape	remarks		mould growth	decay	
not treated									
1 1 1 0 1									sample not present
1 1 1 0 2									sample not present
1 1 1 0 3									sample not present
acetylated									
2 1 1 0 1	n.a.	n.a.		n.a.	n.a.		5	0	n.a.
2 1 1 0 2	n.a.	n.a.		n.a.	n.a.		5	0	n.a.
2 1 1 0 3	n.a.	n.a.		n.a.	n.a.		4	0	n.a.
acetylated with acid									
3 1 1 0 1	n.a.	n.a.		n.a.	n.a.		4	0	n.a.
3 1 1 0 2	n.a.	n.a.		n.a.	n.a.		5	0	n.a.
3 1 1 0 3	n.a.	n.a.		n.a.	n.a.		5	0	n.a.

Coating system 2 – Transparent teak coloured acrylic



Untreated (left), acetylated and acetylated with residual acetic acid panels finished with a transparent teak coloured acrylic coating after 9½ years of outdoor exposure.



Cracking of coating surface (sample 12003) as result of coating degradation after 9½ years of outdoor exposure.

cracking ISO 4628/4													
sample code		after 5 ½ years			after 9 ½ years								
treatment	coating	l damaged	replicate	density	size	depth	direction	remarks	density	size	depth	direction	remarks
not treated													
1	2	0	0	1	2	4		1 wood crack	4	3	c	n	also many superficial cracks because of coating degradation
1	2	0	0	2	2	4		1 wood crack, without cracking coating					
1	2	0	0	3	1	3		1 wood crack, without cracking coating	3	3	c	n	also many superficial cracks because of coating degradation
1	2	0	0	4	1	4		1 wood crack	3	3	c	n	also many superficial cracks because of coating degradation
1	2	0	0	6	1	3		only cracks at the edge	4	3	c	n	also many superficial cracks because of coating degradation
acetylated													
2	2	0	0	1	1	3		1 long crack from the end	1	3	c	n	also many superficial cracks because of coating degradation
2	2	0	0	2	1	3							
2	2	0	0	3	1	3			1	3	c	n	also many superficial cracks because of coating degradation
2	2	0	0	4	1	4			1	3	c	n	also many superficial cracks because of coating degradation
2	2	0	0	6	1	3		cracks at the edge	2	3	c	n	also many superficial cracks because of coating degradation
acetylated with acid													
3	2	0	0	1	1	3			1	3	c	n	also many superficial cracks because of coating degradation
3	2	0	0	2	1	3							
3	2	0	0	3	1	3		1 wood crack	3	3	c	n	also many superficial cracks because of coating degradation
3	2	0	0	4	1	3			1	3	c	n	also many superficial cracks because of coating degradation

flaking ISO 4628/5						
sample code		after 5 ½ years			after 9 ½ years	
treatment coating I damaged	replicate	density size depth direction	remarks		density size depth direction	remarks
			not treated			
1 2 0 0 1	1	3	flaking at the ends		1 5 b y	
1 2 0 0 2	0					
1 2 0 0 3	0				1 5 b y	
1 2 0 0 4	0				1 5 b y	
1 2 0 0 6	1	3	1 small blister		1 5 b y	
acetylated						
2 2 0 0 1	0				0	
2 2 0 0 2	0					
2 2 0 0 3	0				1 3 b y	1 spot
2 2 0 0 4	0				1 3 b y	1 spot
2 2 0 0 6	0					
acetylated with acid						
3 2 0 0 1	0				0	
3 2 0 0 2	0					
3 2 0 0 3	0				0	
3 2 0 0 4	0				0	

After 9½ years									
sample code		adhesion, wet condition EN ISO 2409		adhesion, dry conditions EN ISO 2409		EN 927-3	EN330	ISO 4628/6 chalking	general remarks
treatment coating I damaged	replicate	after brushing with tape	remarks	after brushing with tape	remarks	mould growth	decay		
									not treated
1 2 0 0 1	n.a.	n.a.		n.a.	n.a.	0	4	1	sample not present
1 2 0 0 2									
1 2 0 0 3	n.a.	n.a.		n.a.	n.a.	0	3	1	
1 2 0 0 4	0	0		0	0	0	4	1	
1 2 0 0 6	0	0	bad adhesion of tape due to moisture	0	2	0	2	1	
acetylated									
2 2 0 0 1	n.a.	n.a.		n.a.	n.a.	0	0	1	sample not present
2 2 0 0 2									
2 2 0 0 3	n.a.	n.a.		n.a.	n.a.	0	0	1	
2 2 0 0 4	0	0		0	0	0	0	1	
2 2 0 0 6	0	0	bad adhesion of tape due to moisture	0	0	0	2	1	
acetylated with acid									
3 2 0 0 1	n.a.	n.a.		n.a.	n.a.	0	0	1	sample not present
3 2 0 0 2									
3 2 0 0 3	0	0				0	0	1	
3 2 0 0 4	0	0				0	0	1	

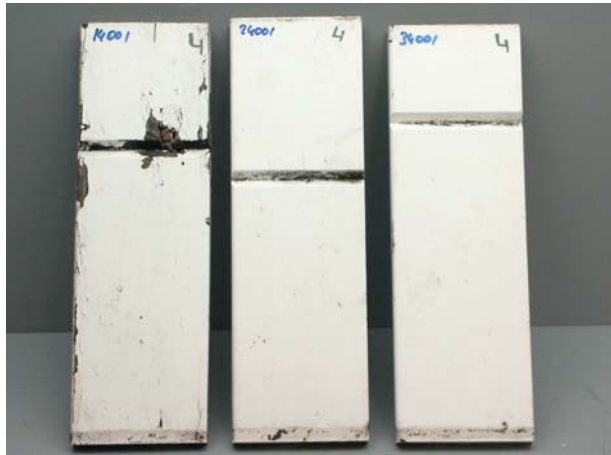
Hailed samples

cracking ISO 4628/4											
sample code		after 5 ½ years				after 9 ½ years					
treatment coating I damaged	replicate	density	size	depth	direction	remarks	density	size	depth	direction	remarks
not treated											
1	2	1	0	1	2	3					some large wood cracks
1	2	1	0	2	1	3					also many superficial cracks because of coating degradation
1	2	1	0	3	2	3					some large wood cracks
							4	3	c	y	also many superficial cracks because of coating degradation
acetylated											
2	2	1	0	1	1	3					also many superficial cracks because of coating degradation
2	2	1	0	2	1	3					also many superficial cracks because of coating degradation
2	2	1	0	3	1	3					also many superficial cracks because of coating degradation
acetylated with acid											
3	2	1	0	1	1	3					also many superficial cracks because of coating degradation
3	2	1	0	2	1	3					also many superficial cracks because of coating degradation
3	2	1	0	3	1	3					also many superficial cracks because of coating degradation

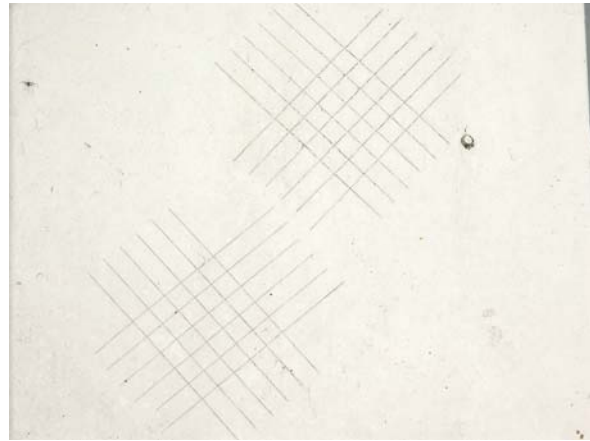
flaking ISO 4628/5											
sample code		after 5 ½ years				after 9 ½ years					
treatment coating I damaged	replicate	density	size	depth	direction	remarks	density	size	depth	direction	remarks
not treated											
1	2	1	0	1	1	2					
1	2	1	0	2	1	1					flaking from cracks
1	2	1	0	3	1	1					flaking from cracks
							2	5	b	y	
							0				
							1	5	b	y	
acetylated											
2	2	1	0	1	0						0
2	2	1	0	2	0						0
2	2	1	0	3	0						0
acetylated with acid											
3	2	1	0	1	0						0
3	2	1	0	2	0						0
3	2	1	0	3	0						0

After 9 ½ years									
sample code		adhesion, wet condition EN ISO 2409		adhesion, dry conditions EN ISO 2409		EN 927-3	EN330	ISO 4628/6	general remarks
treatment coating I damaged	replicate	after brushing with tape	remarks	after brushing with tape	remarks	mould growth	decay	chalking	
not treated									
1	2	1	0	1	n.a.	n.a.	n.a.	n.a.	
1	2	1	0	2	n.a.	n.a.	n.a.	n.a.	
1	2	1	0	3	n.a.	n.a.	n.a.	n.a.	
						0	1	n.a.	
						0	4	n.a.	
						0	4	n.a.	
acetylated									
2	2	1	0	1	n.a.	n.a.	n.a.	n.a.	
2	2	1	0	2	n.a.	n.a.	n.a.	n.a.	
2	2	1	0	3	n.a.	n.a.	n.a.	n.a.	
						0	0	n.a.	
						0	0	n.a.	
						0	0	n.a.	
acetylated with acid									
3	2	1	0	1	n.a.	n.a.	n.a.	n.a.	
3	2	1	0	2	n.a.	n.a.	n.a.	n.a.	
3	2	1	0	3	n.a.	n.a.	n.a.	n.a.	
						0	0	n.a.	
						0	0	n.a.	
						0	0	n.a.	

Coating system 4 – Opaque white acrylic



Untreated (left), acetylated and acetylated with residual acetic acid panels finished with an opaque white acrylic coating after 9½ years of outdoor exposure.



Adhesion test (ISO 2409) under wet (top) and dry conditions of acetylated (with residual acetic acid) Scots pine finished with an opaque white acrylic coating after 9½ years outdoor exposure (sample 34004)

cracking ISO 4628/4													
sample code		after 5 ½ years			after 9 ½ years								
treatment	coating	1 damaged	replicate	density	size	depth	direction	remarks	density	size	depth	direction	remarks
not treated													
1	4	0	0	1	2	3			3	3	c	n	
1	4	0	0	2	2	3							
1	4	0	0	3	3	3		2 long cracks	4	3	c	y	
1	4	0	0	4	2	3			4	3	c	n	
1	4	0	0	6	1	3		1 crack from the end	2	3	c	n	
acetylated													
2	4	0	0	1	1	3			2	2	c	n	
2	4	0	0	2	1	3							
2	4	0	0	3	1	3			1	2	c	n	
2	4	0	0	4	1	3			1	2	c	n	
2	4	0	0	6					2	2	c	n	
acetylated with acid													
3	4	0	0	1	1	3		hail damage and cracks at the edge cracks at the edge	1	2	c	n	
3	4	0	0	2	1	3							
3	4	0	0	3	0				1	2	c	n	
3	4	0	0	4	0				1	2	c	n	

flaking ISO 4628/5						
sample code		after 5 ½ years			after 9 ½ years	
treatment coating I damaged replicate	density size depth direction	remarks			density size depth direction	remarks
not treated						
1 4 0 0 1	2 3	flaking around groove, decay			1 4 b y	
1 4 0 0 2	0					
1 4 0 0 3	1 3				2 4 b y	
1 4 0 0 4	1 3	flaking at the edges and backside			2 5 b y	
1 4 0 0 6	0				1 4 b y	
acetylated						
2 4 0 0 1	0				0	
2 4 0 0 2	0					
2 4 0 0 3	0				0	
2 4 0 0 4	0				0	
2 4 0 0 6	0				0	
acetylated with acid						
3 4 0 0 1	0				0	
3 4 0 0 2	0					
3 4 0 0 3	0				0	
3 4 0 0 4	1 3	flaking around groove			0	

After 9½ years									
sample code		adhesion, wet condition EN ISO 2409		adhesion, dry conditions EN ISO 2409		EN 927-3	EN330	ISO 4628/6	general remarks
treatment coating I damaged replicate	after brushing with tape	remarks	after brushing with tape	remarks	mould growth	decay	chalking		
not treated									
1 4 0 0 1	n.a.	n.a.	n.a.	n.a.	2	3	3	sample not present	
1 4 0 0 2									
1 4 0 0 3	n.a.	n.a.	n.a.	n.a.	2	2	3		
1 4 0 0 4	4	4	5	5	2	5	3		
1 4 0 0 6	4	4	3	4	2	2	3		
acetylated									
2 4 0 0 1	n.a.	n.a.	n.a.	n.a.	2	0	3	sample not present	
2 4 0 0 2									
2 4 0 0 3	n.a.	n.a.	n.a.	n.a.	2	0	3		
2 4 0 0 4	0	0	1	1	2	0	3		
2 4 0 0 6	0	0	0	0	3	0	3		
acetylated with acid									
3 4 0 0 1	n.a.	n.a.	n.a.	n.a.	2	0	3	sample not present	
3 4 0 0 2									
3 4 0 0 3	0	0	0	0	2	0	3		
3 4 0 0 4	0	0	0	0	2	0	3		

Hailed samples

cracking ISO 4628/4												
sample code		after 5 ½ years				after 9 ½ years						
treatment coating I damaged	replicate	density	size	depth	direction	remarks	density	size	depth	direction	remarks	
not treated												
1	4	1	0	1	1	3		4	3	c	y	
1	4	1	0	2	1	3	hail damage	5	3	c	y	
1	4	1	0	3	1	3		4	3	c	n	
acetylated												
2	4	1	0	1	1	3		1	3	c	y	
2	4	1	0	2	1	3		3	3	c	y	
2	4	1	0	3	0			1	2	c	y	
acetylated with acid												
3	4	1	0	1	1	3		1	2	c	n	
3	4	1	0	2	2	3	blue stain growing through coating	1	2	c	n	
3	4	1	0	3	3	3	1 long wood crack	3	3	c	y	some wood cracks

flaking ISO 4628/5												
sample code		after 5 ½ years				after 9 ½ years						
treatment coating I damaged	replicate	density	size	depth	direction	remarks	density	size	depth	direction	remarks	
not treated												
1	4	1	0	1	0		2	5	b	y		
1	4	1	0	2	0		2	4	b	y		
1	4	1	0	3	1	3		3	5	b	y	
acetylated												
2	4	1	0	1	0		0					
2	4	1	0	2	0		0					
2	4	1	0	3	0		0					
acetylated with acid												
3	4	1	0	1	0		0					
3	4	1	0	2	0		0					
3	4	1	0	3	0		0					

After 9½ years									
sample code		adhesion, wet condition EN ISO 2409		adhesion, dry conditions EN ISO 2409		EN 927-3	EN330	ISO 4628/6	general remarks
treatment coating I damaged	replicate	after brushing with tape	remarks	after brushing with tape	remarks	mould growth	decay	chalking	
not treated									
1	4	1	0	1	n.a.	n.a.	n.a.	n.a.	
1	4	1	0	2	n.a.	n.a.	n.a.	n.a.	
1	4	1	0	3	n.a.	n.a.	n.a.	n.a.	
acetylated									
2	4	1	0	1	n.a.	n.a.	n.a.	n.a.	
2	4	1	0	2	n.a.	n.a.	n.a.	n.a.	
2	4	1	0	3	n.a.	n.a.	n.a.	n.a.	bleu stain under paint
acetylated with acid									
3	4	1	0	1	n.a.	n.a.	n.a.	n.a.	bleu stain under paint
3	4	1	0	2	n.a.	n.a.	n.a.	n.a.	
3	4	1	0	3	n.a.	n.a.	n.a.	n.a.	

Coating system 5 – Opaque black acrylic



Untreated (left), acetylated and acetylated with residual acetic acid panels finished with an opaque black acrylic coating after 9½ years of outdoor exposure.



Wood cracks in acetylated Scots pine finished with an opaque black acrylic coating after 9½ years outdoor exposure (sample 25001).

cracking ISO 4628/4													
sample code		after 5 ½ years				after 9 ½ years							
treatment	coating	1 damaged	replicate	density	size	depth	direction	remarks	density	size	depth	direction	remarks
not treated													
1	5	0	0	1	4	3		some wood cracks through sample	5	3	c	y	
1	5	0	0	2	1	3		1 small wood crack	5	2	c	y	
1	5	0	0	3	4	3		some wood cracks from the groove	5	3	c	y	
1	5	0	0	4	3	3		some wood cracks, decay					
1	5	0	0	6	4	3		sample almost completely decayed					
acetylated													
2	5	0	0	1	3	3		some small wood cracks	5	3	c	y	many small cracks due to coating degradation
2	5	0	0	2	2	2		small superficial wood cracks					
2	5	0	0	3	1	2			5	2	c	y	many small cracks due to coating degradation
2	5	0	0	4	1	2			5	2	c	y	many small cracks due to coating degradation
2	5	0	0	6	1	3		small wood crack	5	3	c	y	many small cracks due to coating degradation
acetylated with acid													
3	5	0	0	1	1	3		1 small wood crack	4	2	c	y	many small cracks due to coating degradation
3	5	0	0	2	1	3		1 small wood crack					
3	5	0	0	3	0				5	3	c	y	many small cracks due to coating degradation
3	5	0	0	4	1	2		small cracks at the end	5	3	c	y	many small cracks due to coating degradation

flaking ISO 4628/5						
sample code		after 5 ½ years			after 9 ½ years	
treatment coating I damaged replicate	density size depth direction	remarks			density size depth direction	remarks
not treated						
1 5 0 0 1	3 3				5 5 b y	almost no coating left
1 5 0 0 2	0				0	no flaking
1 5 0 0 3	3 2				5 5 b y	almost no coating left
1 5 0 0 4	2 3					
1 5 0 0 6	2 2	large part of the sample decayed				
acetylated						
2 5 0 0 1	0				1 2 b y	
2 5 0 0 2	1 2	flaking at the edge				
2 5 0 0 3	0				0	
2 5 0 0 4	0				1 2 b y	
2 5 0 0 6	0				0	
acetylated with acid						
3 5 0 0 1	0				0	
3 5 0 0 2	0					
3 5 0 0 3	1 2	flaking around the groove			0	
3 5 0 0 4	1 2	flaking at the edge			0	

After 9½ years									
sample code		adhesion, wet condition EN ISO 2409		adhesion, dry conditions EN ISO 2409		EN 927-3	EN330	ISO 4628/6	general remarks
treatment coating I damaged replicate	after brushing with tape	remarks	after brushing with tape	remarks	mould growth	decay	chalking		
not treated									
1 5 0 0 1	n.a.	n.a.	n.a.	n.a.	n.a.	4	n.a.		only part of the panel was present sample not present sample not present
1 5 0 0 2	n.a.	n.a.	n.a.	n.a.	n.a.	4	n.a.		
1 5 0 0 3	n.a.	n.a.	n.a.	n.a.	n.a.	4	n.a.		
1 5 0 0 4									
1 5 0 0 6									
acetylated									
2 5 0 0 1	n.a.	n.a.	n.a.	n.a.	n.a.	3	n.a.		sample not present
2 5 0 0 2						0	n.a.		
2 5 0 0 3	n.a.	n.a.	n.a.	n.a.	n.a.	0	n.a.		
2 5 0 0 4	0	0	0	0	0	0	n.a.		
2 5 0 0 6	0	0	1	1	n.a.	3	n.a.		
acetylated with acid									
3 5 0 0 1	n.a.	n.a.	n.a.	n.a.	n.a.	2	n.a.		sample not present
3 5 0 0 2									
3 5 0 0 3	0	0	0	0	n.a.	4	n.a.		
3 5 0 0 4	0	0	0	1	n.a.	4	n.a.		

Hailed samples

cracking ISO 4628/4												
sample code		after 5 ½ years				after 9 ½ years						
treatment coating I damaged	replicate	density	size	depth	direction	remarks	density	size	depth	direction	remarks	
not treated												
1	5	1	0	1	3	3	many wood cracks					
acetylated												
2	5	1	0	1	3	3	1 wood crack	5	3	c	y	many small cracks due to coating degradation
2	5	1	0	2	1	3	1 crack	5	2	c	y	many small cracks due to coating degradation
2	5	1	0	3	2	2		5	2	c	y	many small cracks due to coating degradation
acetylated with acid												
3	5	1	0	1	2	2	small cracks	5	3	c	y	many small cracks due to coating degradation
3	5	1	0	2	4	2		5	3	c	y	many small cracks due to coating degradation
3	5	1	0	3	4	2		5	3	c	y	many small cracks due to coating degradation

flaking ISO 4628/5											
sample code		after 5 ½ years				after 9 ½ years					
treatment coating I damaged	replicate	density	size	depth	direction	remarks	density	size	depth	direction	remarks
not treated											
1	5	1	0	1	5	3	large part of the sample decayed				
acetylated											
2	5	1	0	1	0		0				
2	5	1	0	2	0		0				
2	5	1	0	3	0		0				
acetylated with acid											
3	5	1	0	1	0		1	2	b	y	
3	5	1	0	2	0		3	5	b	y	
3	5	1	0	3	0		2	5	b	y	

After 9½ years									
sample code		adhesion, wet condition EN ISO 2409		adhesion, dry conditions EN ISO 2409		EN 927-3	EN330	ISO 4628/6	general remarks
treatment coating I damaged	replicate	after brushing with tape	remarks	after brushing with tape	remarks	mould growth	decay	chalking	
not treated									
1	5	1	0	1					sample not present
acetylated									
2	5	1	0	1	n.a. n.a.	n.a. n.a.	n.a.	0	n.a.
2	5	1	0	2	n.a. n.a.	n.a. n.a.	n.a.	4	n.a.
2	5	1	0	3	n.a. n.a.	n.a. n.a.	n.a.	0	n.a.
acetylated with acid									
3	5	1	0	1	n.a. n.a.	n.a. n.a.	n.a.	0	n.a.
3	5	1	0	2	n.a. n.a.	n.a. n.a.	n.a.	0	n.a.
3	5	1	0	3	n.a. n.a.	n.a. n.a.	n.a.	0	n.a.

Coating system 6 - Opaque white alkyd



Untreated (left), acetylated and acetylated with residual acetic acid panels finished with an opaque white alkyd coating after 9½ years of outdoor exposure.



Wood cracks, cracks in the coating and degradation of the coating layer by blue stain fungi of acetylated (with residual acetic acid) Scots pine finished with an opaque white alkyd coating after 9½ years outdoor exposure (sample 36102).

cracking ISO 4628/4													
sample code		after 5 ½ years			after 9 ½ years								
treatment	coating	1 damaged	replicate	density	size	depth	direction	remarks	density	size	depth	direction	remarks
not treated													
1	6	0	0	1	3	3		deep wood cracks	5	3	c	y	
1	6	0	0	2	2	3							
1	6	0	0	3	3	3		deep wood cracks	5	3	c	y	
1	6	0	0	4	3	3		deep wood cracks	5	3	c	y	
1	6	0	0	6	3	3			5	3	c	y	
acetylated													
2	6	0	0	1	2	3		superficial wood crack	4	3	c	y	
2	6	0	0	2	1	3							
2	6	0	0	3	1	3			3	3	c	y	
2	6	0	0	4	1	3			4	3	c	y	
2	6	0	0	6	2	3		superficial wood crack	2	3	c	y	
acetylated with acid													
3	6	0	0	1	2	3			4	3	c	y	
3	6	0	0	2	1	3							
3	6	0	0	3	3	3		1 long superficial wood crack	4	3	c	y	
3	6	0	0	4	1	3		1 long superficial wood crack	3	3	c	y	

flaking ISO 4628/5						
sample code		after 5 ½ years			after 9 ½ years	
treatment coating I damaged replicate	density size depth direction	remarks			density size depth direction	remarks
		not treated				
1 6 0 0 1	4 4				5 5 b y	
1 6 0 0 2	4 3					
1 6 0 0 3	5 4				5 5 b y	
1 6 0 0 4	4 4				5 5 b y	
1 6 0 0 6	3 3				5 5 b y	
acetylated						
2 6 0 0 1	0				2 2 a n	topcoat flaked
2 6 0 0 2	0					
2 6 0 0 3	0				2 2 a n	topcoat flaked
2 6 0 0 4	0				2 3 b y	
2 6 0 0 6	0				1 1 a n	topcoat flaked
acetylated with acid						
3 6 0 0 1	1 2				2 4 b y	
3 6 0 0 2	0					
3 6 0 0 3	0				2 3 b y	
3 6 0 0 4	0				1 2 a n	

After 9½ years										
sample code		adhesion, wet condition EN ISO 2409		adhesion, dry conditions EN ISO 2409		EN 927-3	EN330	ISO 4628/6 chalking	general remarks	
treatment coating I damaged replicate	after brushing with tape	remarks		after brushing with tape	remarks		mould growth	decay		
		not treated								
1 6 0 0 1	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	5	n.a.	hardly no paint left sample not present	
1 6 0 0 2										
1 6 0 0 3	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	5	n.a.	hardly no paint left	
1 6 0 0 4	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	5	n.a.	hardly no paint left	
1 6 0 0 6	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	5	n.a.	hardly no paint left	
acetylated										
2 6 0 0 1	n.a.	n.a.	n.a.	n.a.	n.a.	3	0	2	blue stain penetrating through paint sample not present	
2 6 0 0 2										
2 6 0 0 3	n.a.	n.a.	n.a.	n.a.	n.a.	4	0	2	blue stain penetrating through paint	
2 6 0 0 4	2	2		2	3	3	0	2	blue stain penetrating through paint	
2 6 0 0 6	1	4	tape:intercoat between top and primer	1	1	intercoat class 2	3	0	2	blue stain penetrating through paint
acetylated with acid										
3 6 0 0 1	n.a.	n.a.	n.a.	n.a.	n.a.	4	0	2	blue stain penetrating through paint sample not present	
3 6 0 0 2										
3 6 0 0 3	1	5	tape:intercoat between top and primer	2	2	intercoat class 4	3	0	2	blue stain penetrating through paint
3 6 0 0 4	1	2		1	2	intercoat class 2	3	0	2	blue stain penetrating through paint

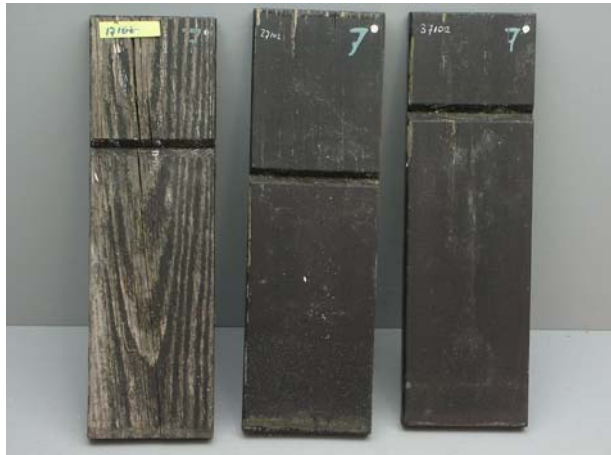
Hailed samples

cracking ISO 4628/4						
sample code		after 5 ½ years			after 9 ½ years	
treatment coating I damaged	replicate	density	size	depth	direction	remarks
not treated						
1 6 1 0 1	3	3				some wood cracks
1 6 1 0 2	4	3				almost no coating left
1 6 1 0 3	3	3				some wood cracks
acetylated						
2 6 1 0 1	2	3				local 5S2
2 6 1 0 2	1	3				
2 6 1 0 3	1	3				
acetylated with acid						
3 6 1 0 1	2	2				local 5S2
3 6 1 0 2	1	3				1 wood crack
3 6 1 0 3	2	3				

flaking ISO 4628/5						
sample code		after 5 ½ years			after 9 ½ years	
treatment coating I damaged	replicate	density	size	depth	direction	remarks
not treated						
1 6 1 0 1	5	4				almost no coating left
1 6 1 0 2	4	4				almost no coating left
1 6 1 0 3	4	5				almost no coating left
acetylated						
2 6 1 0 1	0					
2 6 1 0 2	0					
2 6 1 0 3	0					topcoat flaked
acetylated with acid						
3 6 1 0 1	0					topcoat flaked
3 6 1 0 2	0					
3 6 1 0 3	1	2				topcoat flaked

After 9½ years									
sample code		adhesion, wet condition EN ISO 2409		adhesion, dry conditions EN ISO 2409		EN 927-3	EN330	ISO 4628/6	general remarks
treatment coating I damaged	replicate	after brushing with tape	remarks	after brushing with tape	remarks	mould growth	decay	chalking	
not treated									
1 6 1 0 1	n.a.	n.a.		n.a.	n.a.	n.a.	1	n.a.	no paint left
1 6 1 0 2	n.a.	n.a.		n.a.	n.a.	n.a.	2	n.a.	no paint left
1 6 1 0 3	n.a.	n.a.		n.a.	n.a.	n.a.	1	n.a.	no paint left
acetylated									
2 6 1 0 1	n.a.	n.a.		n.a.	n.a.	3	0	n.a.	blue stain penetrating through paint
2 6 1 0 2	n.a.	n.a.		n.a.	n.a.	3	0	n.a.	blue stain penetrating through paint
2 6 1 0 3	n.a.	n.a.		n.a.	n.a.	3	0	n.a.	blue stain penetrating through paint
acetylated with acid									
3 6 1 0 1	n.a.	n.a.		n.a.	n.a.	3	0	n.a.	blue stain penetrating through paint
3 6 1 0 2	n.a.	n.a.		n.a.	n.a.	3	0	n.a.	blue stain penetrating through paint
3 6 1 0 3	n.a.	n.a.		n.a.	n.a.	4	0	n.a.	blue stain penetrating through paint

Coating system 7 – Opaque black alkyd



Untreated (left), acetylated and acetylated with residual acetic acid panels finished with an opaque black alkyd coating after 9½ years of outdoor exposure.



Adhesion test (ISO 2409) under wet (top) and dry conditions of acetylated (with residual acetic acid) Scots pine finished with an opaque dark alkyd coating after 9½ years outdoor exposure (sample 37003).

sample code		cracking ISO 4628/4			
		after 5 ½ years		after 9 ½ years	
treatment	coating	density	size	depth	direction
I damaged	replicate	remarks	density	size	depth
			direction		direction
not treated					
1	7 0 0 1	2 3	wood cracks	5	3 c y
1	7 0 0 2	3 3	some deep wood cracks		
1	7 0 0 3	3 3		5	3 c y
1	7 0 0 4	2 3		5	3 c y
1	7 0 0 6	3 3	some deep wood cracks	5	3 c y
acetylated					
2	7 0 0 1	0		3	3 c y
2	7 0 0 2	1 3	superficial wood crack		
2	7 0 0 3	2 3	some superficial wood cracks	3	3 c y
2	7 0 0 4	2 3	some deep wood cracks	4	3 c y
2	7 0 0 6			3	3 c y
acetylated with acid					
3	7 0 0 1	1 3	superficial wood cracks	4	3 c y
3	7 0 0 2	1 3			
3	7 0 0 3	2 3		3	3 c y
3	7 0 0 4	1 3	only cracks in upper part	3	3 c y
3	7 0 0 6	2 3	wood crack		

flaking ISO 4628/5													
sample code		after 5 ½ years				after 9 ½ years							
treatment	coating	1 damaged	replicate	density	size	depth	direction	remarks	density	size	depth	direction	remarks
not treated													
1	7	0	0	1	3	3		almost completely decayed	5	5	b	y	almost no coating left
1	7	0	0	2	5	4			5	5	b	y	almost no coating left
1	7	0	0	3	4	4			5	5	b	y	almost no coating left
1	7	0	0	4	4	3			5	5	b	y	almost no coating left
1	7	0	0	6	3	3			5	5	b	y	almost no coating left
acetylated													
2	7	0	0	1	0				1	4	b	y	
2	7	0	0	2	0				1	4	b	y	
2	7	0	0	3	0				5	5	b	y	
2	7	0	0	4	2	2			0				
2	7	0	0	6	0								
acetylated with acid													
3	7	0	0	1	0				2	3	b	y	
3	7	0	0	2	1				2	3	b	y	
3	7	0	0	3	1				2	3	b	y	
3	7	0	0	4	0				2	3	b	y	
3	7	0	0	6	0								

After 9 ½ years											
sample code		adhesion, wet condition EN ISO 2409		adhesion, dry conditions EN ISO 2409		EN 927-3	EN330	ISO 4628/6	general remarks		
treatment	coating	1 damaged	replicate	after brushing with tape	remarks	after brushing with tape	remarks	mould growth	decay	chalking	
not treated											
1	7	0	0	1	n.a. n.a.	n.a. n.a.		n.a.	5	n.a.	sample not present
1	7	0	0	2	n.a. n.a.	n.a. n.a.		n.a.	2	n.a.	
1	7	0	0	3	n.a. n.a.	n.a. n.a.		n.a.	3	n.a.	
1	7	0	0	4	n.a. n.a.	n.a. n.a.		n.a.	3	n.a.	
1	7	0	0	6	n.a. n.a.	n.a. n.a.		n.a.	3	n.a.	
acetylated											
2	7	0	0	1	n.a. n.a.	n.a. n.a.		n.a.	0	n.a.	sample not present
2	7	0	0	2	n.a. n.a.	n.a. n.a.		n.a.	2	n.a.	
2	7	0	0	3	n.a. n.a.	n.a. n.a.		n.a.	2	n.a.	
2	7	0	0	4	0 2 bad adhesion of tape due to moisture	4 5		n.a.	2	n.a.	
2	7	0	0	6	0 0 bad adhesion of tape due to moisture	1 1		n.a.	0	n.a.	
acetylated with acid											
3	7	0	0	1	n.a. n.a.	n.a. n.a.		n.a.	3	n.a.	sample not present
3	7	0	0	2	n.a. n.a.	n.a. n.a.		n.a.	0	n.a.	
3	7	0	0	3	0 0 bad adhesion of tape due to moisture	2 2		n.a.	0	n.a.	
3	7	0	0	4	0 0 bad adhesion of tape due to moisture	2 2		n.a.	0	n.a.	
3	7	0	0	6	n.a. n.a.	n.a. n.a.		n.a.	0	n.a.	

Hailed samples

cracking ISO 4628/4						
sample code		after 5 ½ years			after 9 ½ years	
treatment coating l damaged	replicate	density size depth direction	remarks	density size depth direction	remarks	
not treated						
1 7 1 0 1	2	3	deep wood cracks	5 3 c y		
1 7 1 0 2	2	3	wood cracks	5 3 c y		
acetylated						
2 7 1 0 1	2	3	2 deep wood cracks	3 3 c y		
2 7 1 0 2	2	3	wood cracks	4 3 c y		
2 7 1 0 3	1	3	1 deep wood crack	3 3 c y		
acetylated with acid						
3 7 1 0 1	2	3	1 big wood crack through whole sample	4 3 c y		
3 7 1 0 2	1	3		3 3 c y		

flaking ISO 4628/5						
sample code		after 5 ½ years			after 9 ½ years	
treatment coating l damaged	replicate	density size depth direction	remarks	density size depth direction	remarks	
not treated						
1 7 1 0 1	5	3		5 5 b y		
1 7 1 0 2	5	4		5 5 b y		
acetylated						
2 7 1 0 1	0			2 4 b y		
2 7 1 0 2	0			0		
2 7 1 0 3	0			2 4 b y		
acetylated with acid						
3 7 1 0 1	0			4 5 b y		
3 7 1 0 2	0			1 3 b y		