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Section 4 **Processes and properties**

The resistance of Accoya® and Tricoya® to attack by wood-destroying fungi and termites

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The resistance of Accoya® and Tricoya® to attack by wood-destroying fungi and termites

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ABSTRACT

The resistance of high acetyl WPG solid timber (Accoya®) and medium density fibreboard (Tricoya®) to attack by wood-destroying fungi and termites was investigated under both laboratory and field conditions. Laboratory decay studies were conducted in Australia and New Zealand. Field studies were conducted in Australia, Japan, New Zealand, Thailand and USA. The results of the laboratory and field studies against decay fungi support previously published work showing that high acetyl WPG timber materials are highly resistant to attack by wood destroying fungi. The field studies against termites have further enhanced knowledge of the resistance of acetylated timber materials to attack by termites; it has been demonstrated that Accoya® and Tricoya® are resistant to attack by the highly destructive Australian subterranean termite species *Mastotermes darwiniensis*. It would be expected that Accoya® and Tricoya® would exhibit excellent long-term performance against wood destroying fungi and termites in most regions in the world.

Keywords: acetylation, Accoya®, Tricoya®, MDF, fungi, termites

1. INTRODUCTION

The acetylation of wood to improve its dimensional stability and durability has been studied for over 60 years (Tarkow *et al* 1946, Goldstein *et al* 1961, Peterson and Thomas 1978, Militz 1991, Bongers and Beckers 2003, Papadopoulos 2010). Considerable research has been conducted to determine the effect of acetylation on the resistance of modified wood to fungal degradation (Peterson and Thomas 1978, Nilsson *et al* 1988, Rowell *et al* 1989, Takahashi *et al* 1989, Beckers *et al* 1994, Rowell *et al* 1997, Ohkoshi *et al* 1999, Suttie *et al* 1999, Birkinshaw and Hale 2002, Papadopoulos and Hill 2002, Hill *et al* 2006), and there is generally good agreement amongst researchers that, at least above acetyl weight percent gains (WPG) of 15-20%, acetylated wood shows marked resistance to attack by most wood destroying fungi. Data from long running in-ground stake studies (18 years) have confirmed that long term durability against fungal decay is only likely to be achieved at acetyl WPG of 22% or above (Larsson-Brelid and Westin 2010).

The results of studies conducted by previous workers on the resistance of high acetyl WPG timber materials against decay fungi have been supported by recently published data (Alexander *et al* 2013). This work, and that of Hague *et al* (2014), has also significantly improved knowledge on the resistance of high acetyl WPG timber materials against attack by subterranean wood-destroying termites. It has been demonstrated that both Accoya® and Tricoya® are highly resistant to attack by at least two of the more economically important species of the *Coptotermes*

genus, namely *Coptotermes formosanus* Shiraki in both Japan and the USA, and *Coptotermes acinaciformis* (Froggatt) in Australia, as well as the highly destructive Australian termite species *Mastotermes darwiniensis* Froggatt.

Accsys Technologies has developed a commercial scale production process for the manufacture of high acetyl WPG solid timber (Accoya® wood) and has adapted its proprietary acetylation technology to enable the production of high acetyl wood elements (Tricoya® wood elements) for use within panel products such as MDF. The exploitation of Tricoya® is now carried out by Tricoya Technologies Limited, a joint venture between Accsys and INEOS Industries Holdings Limited. As part of its due diligence, the company has commissioned a number of laboratory and field studies around the world to assess the termite resistance of its products. The latest results from these studies are reported here.

2. MATERIALS AND METHODS

2.1 Laboratory Testing

2.1.1 Fungal bioassay

Australian test

The test methodology used was in accordance with that specified in the AWPC Protocols for Assessment of Wood Preservatives (2007). Prior to exposure in the field test specimens were first leached in water for seven days, and then artificially weathered in vacuum ovens for five days at 40°C and 0.05 mBar to remove any residual volatiles. The decay resistance of Accoya® Radiata and Tricoya® was investigated in the test, and the performance of these materials was compared with that of untreated radiata pine (*Pinus radiata* D. Don) sapwood, untreated exterior grade MDF and the heartwood of spotted gum (*Corymbia maculata* (Hook.) K.D. Hill & L.A.S. Johnson) and western red cedar (*Thuja plicata* Donn ex D.Don). Test specimens were exposed to four species of brown-rotting decay fungi (*Coniophora olivacea*, *Fomitopsis lilacino-gilva*, *Gloeophyllum abietinum* and *Antrodia xantha*) and the white-rotting decay fungus *Perenniporia tephropora*. The duration of the test was 12 weeks. Performance of the test materials was determined by measured mass loss.

2.1.2 Fungal cellar

New Zealand test

The performance of Accoya® Radiata against attack by wood-destroying fungi was evaluated in comparison with that of untreated radiata pine and kwila (merbau) (*Instia bijuga* (Colebr.) Kuntze). Test specimen size was 10 x 5 x 160 mm. 10 replicates of each material were installed in soil beds in the fungus cellar facility at Scion, Rotorua in March 2005. The chambers in this facility are maintained at 27℃, 85% RH. The condition of stakes in the test have been assessed regularly since they were installed, using a decay assessment scale similar to that described in ASTM D1758. The most recent inspection occurred after nine years' exposure.

2.2 Field Testing

2.2.1 Above-ground

Australian test

The performance of Accoya® Radiata pine, Accoya® Beech, and Tricoya® medium density fibreboard (MDF) (manufactured from both radiata pine and spruce (*Picea* spp.) fibre) against attack by *M. darwiniensis* was evaluated in a Hazard Class H3 field trial. The performance of the acetylated materials was compared with that of the sapwood of untreated radiata pine and European beech (*Fagus sylvatica* L.), untreated exterior grade MDF, and the naturally durable heartwood of kwila (merbau), spotted gum, western red cedar, American white oak (*Quercus*

alba L.) and PNG Rosewood (*Pterocarpus indicus* Willd.). Solid timber test specimens had volumes of approximately 125 cm^3, whilst MDF test specimens measured 105 x 100 x 12 mm.

The test methodology used was in accordance with that specified in the AWPC Protocols for Assessment of Wood Preservatives (2007). Prior to exposure in the field test specimens were first leached in water for seven days, and then artificially weathered in vacuum ovens for five days at 40°C and 0.05 mBar to remove any residual volatiles. Test specimens were contained within stainless steel exposure chambers with equal volumes of susceptible bait-wood, the latter present in order to attract and maintain the presence of the target termite species. Exposure chambers were connected to active galleries of *M. darwiniensis*, and removed from the field once all susceptible material had been consumed and termites had vacated the chambers; the exposure period was five months. Seven replicate test specimens of each sample were exposed in the field trials against seven different colonies of each termite species. The test site was located at Humpty Doo, Northern Territory, Australia.

2.2.2 In-ground

Japanese test

The performance of Accoya® Radiata against attack by *C. formosanus* was evaluated in accordance with JIS K 1571: 2004 in an in-ground vertical stake field trial at a site located in the Kyushu region, Japan (it should be noted that the termite species *R. speratus* is also present at this location). The performance of the Accoya® was compared with that of untreated radiata pine. Untreated Japanese red pine (*Pinus densiflora* Siebold & Zucc.) sapwood stakes were included in the trial as susceptible bait-wood to attract termites into the test site. The test stakes measured 30 x 30 x 350 mm, and their condition was evaluated after one, two and four years' in-ground exposure using a visual rating system. Five replicate test specimens of each sample were exposed in the field trial.

The performance of Accoya® Radiata against attack by wood-destroying fungi was also evaluated in accordance with JIS K 1571 in a similar in-ground vertical stake field trial at the same site located in the Kyushu region of Japan. The test site is located on a slope subject to moisture laden winds coming off the nearby ocean. The warm temperatures and high annual rainfall in excess of 2.3 metres create an environment where severe decay conditions are prevalent for much of the year. The performance of the Accoya® was compared with that of untreated radiata pine. The test stakes measured 30 x 30 x 600 mm. The latest inspection of the condition of the test specimens occurred after three years' in-ground exposure using a visual rating system. Twenty-five replicate test specimens of each sample were exposed in the field trial.

New Zealand test

The performance of Accoya® Radiata against attack by wood-destroying fungi was evaluated in an in-ground graveyard test at the Whakarewarewa outdoor test area at Scion. For comparison stakes made from untreated radiata pine and the heartwood of teak (*Tectona grandis* L.f.), Western red cedar and macrocarpa (*Cupressus macrocarpa* Hartw.) were included in the trial. Test specimen size was 20 x 18 x 500 mm. 10 replicates of each material were installed in the trial in 2005. The condition of stakes in the test have been assessed regularly since they were installed, using a decay assessment scale similar to that described in ASTM D1758. The most recent inspection occurred after nine years' exposure.

Thailand test

The test was established in accordance with the AWPA E7-09 standard method of evaluating wood preservatives by field tests with stakes. The performance of Accoya® Radiata against

attack by wood-destroying fungi and termites was evaluated in in-ground graveyard tests located at five different sites in Thailand against a variety of termite species, including *Coptotermes gestroi* Wasmann. Teak and makha (*Afzelia xylocarpa* (Kurz) Craib.) were included as naturally durable reference timbers. Test specimen size was 90 x 22 x 470 mm. 20 replicates of each material were installed at each trial site in 2010. The condition of stakes in the test have been assessed regularly since they were installed, using an assessment scale similar to that described in ASTM D1758. The most recent inspection occurred after three years' exposure.

USA test

The test was established in accordance with the AWPA E7-09 standard method of evaluating wood preservatives by field tests with stakes. The performance of Accoya® Radiata (from both NZ and Chile) and Accoya® SYP against attack by wood-destroying termites and fungi was evaluated in in-ground graveyard tests located at two different sites, one in Gainesville, Florida (against the termite species *R. flavipes*) and the other in San Luis, Costa Rica. Untreated stakes of each timber type were included in the test. The condition of the stakes was assessed after one and two years' exposure.

3. RESULTS AND DISCUSSION

3.1 Laboratory Testing

3.1.1 Fungal bioassay

Australian test

A summary of the mean mass losses of test specimens after exposure to five decay fungi in the laboratory for 12 weeks is given in Table 1.

Table 1: Percent mean mass loss of test specimens after exposure to five decay fungi for 12 weeks.

Material Type	**Mean[a] Mass Loss (%)**				
	C. olivacea **BR[b]**	***F. lilacino-gilva*** **BR[b]**	***G. abietinum*** **BR[b]**	***A. xantha*** **BR[b]**	***P. tephropora*** **WR[c]**
Radiata pine	63.3	68.3	56.5	58.8	46.8
Spotted gum	3.5	4.2	1.6	0.5	7.5
Western red cedar	0.5	26.7	8.8	3.5	16.1
Exterior grade MDF	58.1	60.2	37.4	42.3	30.2
Accoya® Radiata	0.3	1.5	0.5	0.2	0.0
Tricoya®	0.6	2.1	0.7	0.1	0.0

[a]Mean of six replicates. [b]Brown rot. [c]White rot.

Accoya® Radiata and Tricoya® showed a very high level of resistance to decay against all five fungi. Against four of the fungi mean mass losses were less than 1%. The highest mean mass losses were incurred against the brown rotting fungus *F. lilacino-gilva*. Accoya® Radiata and Tricoya® showed higher resistance to decay compared with the heartwood of spotted gum, and markedly higher resistance to decay compared with the heartwood of western red cedar. Spotted gum heartwood is rated in AS 5604 as durability class 1 (life expectancy greater than 40 years) for outside, above-ground applications, whilst the heartwood of western red cedar is rated as durability class 2 (life expectancy of between 15 and 40 years).

3.1.2 Fungal cellar

New Zealand test

A summary of the mean decay ratings for test specimens after exposure in the fungal cellar test for two, four, eight and nine years is given in Table 2. The untreated radiata stakes had failed to decay after 18 months' exposure. In contrast, only one of the 10 Accoya® Radiata stakes is exhibiting evidence of decay after nine years' exposure. The durable reference timber, kwila, has decayed steadily over the course of the test, with most stakes now having failed or exhibiting severe levels of decay.

Table 2: Mean decay ratings for test specimens after exposure in the Scion fungal cellar test for nine years.

Material Type	Decay Rating[a]			
	2 years	4 years	8 years	9 years
Accoya® Radiata	10.0	10.0	9.9	9.8
Untreated Radiata	0.0	0.0	0.0	0.0
Kwila	7.1	4.8	3.4	3.2

[a] *10 = Sound, 0 = Complete failure*

3.2 Field Testing

3.2.1 Above-ground

Australian test

A summary of the mean mass loss data for test materials exposed for five months in the Hazard Class H3 field trial is given in Table 3. At the conclusion of the field trial, all test specimens within the seven exposure containers had evidence of contact by *M. darwiniensis.* All untreated bait-wood had been destroyed. The majority of the susceptible sapwood and exterior grade MDF test specimens were destroyed or severely attacked by *M. darwiniensis*. The mean mass losses for each material type ranged from 95% to 100%. These mass losses, together with the destruction of the susceptible bait-wood, demonstrated that test specimens were subjected to a high level of termite pressure during the field trial.

Table 3: Mean mass loss of test specimens after exposure to *M. darwiniensis* in a Hazard Class H3 field trial.

Material Type	Mean mass loss [g]	Mean mass loss [%]
Accoya® Radiata	6.22	8.5
Accoya® Beech	1.33	1.6
Tricoya® (radiata pine)	2.99	3.5
Tricoya® (spruce)	3.97	3.8
Radiata pine sapwood	57.19	94.9
Beech sapwood	70.77	100.0
Exterior grade MDF	81.81	98.4
American white oak heartwood	108.77	99.8
Kwila heartwood	44.48	47.6
PNG Rosewood heartwood	36.48	48.9
Spotted gum heartwood	104.23	83.8
Western red cedar heartwood	27.40	69.3

All five of the naturally durable reference heartwood timber samples were significantly attacked by *M. darwiniensis*, with mean mass losses ranging from 48% to 100%. The kwila and PNG Rosewood samples were the most resistant to attack, whilst all of the American white oak test specimens were destroyed. The performance of the Accoya® and Tricoya® materials was

markedly superior to that of all the naturally durable reference heartwood timber samples; mean mass losses ranged from 1.6% to 5.1%.

3.2.2 In-ground

Japanese test

A summary of the mean ratings for test materials exposed for four years against *C. formosanus* in the vertical stake field trial is given in Table 4.

Table 4: Mean ratings for stakes after exposure to *C. formosanus* in the field (JIS K 1571) for four years.

Material Type	Rating[a]		
	1 Year	2 Years	4 Years
Accoya® Radiata	0	0	0
Radiata pine	46	76	100
Japanese red pine	Heavy attack	Heavy attack	Destroyed

[a]0=Sound, 10=Shallow damage on surface, 30=Internal damage, 50=Widespread internal damage, 100=Collapse of stake.

After four years' exposure in the field Accoya® stakes were in a sound condition. In contrast, the untreated radiata pine stakes and had been destroyed by *C. formosanus*. The Japanese red pine stakes had also been destroyed by *C. formosanus* after four years' exposure, demonstrating that test specimens were subjected to a high level of termite pressure during the field trial.

A summary of the mean ratings for test materials exposed for three years against wood-destroying fungi in the vertical stake field trial is given in Table 5. After three years' exposure in the field Accoya® stakes were in a sound condition. In contrast, the majority of the untreated radiata pine stakes were either destroyed or severely decayed.

Table 5: Mean ratings for stakes after exposure to wood-destroying fungi in the field for three years.

Material Type	Decay Rating[a]
Accoya® Radiata	0.0
Radiata pine	4.9

[a]0 = Sound, 5 = Complete failure

New Zealand test

A summary of the mean decay ratings for test specimens after exposure in the in-ground graveyard test for two, four, eight and nine years is given in Table 6. The Accoya® stakes are exhibiting evidence of very slight decay after nine years' exposure. In comparison the naturally durable reference timbers are showing much higher levels of decay, with teak having extensive decay and both the western red cedar and macrocarpa now being close to complete failure.

Table 6: Mean decay ratings for test specimens after exposure in the Scion graveyard test for nine years.

Material Type	Decay Rating[a]			
	2 years	4 years	8 years	9 years
Accoya® Radiata	10.0	9.9	9.5	9.2
Teak	8.6	7.6	5.4	5.7
Western red cedar	8.3	6.3	3.0	2.4
Macrocarpa	7.8	3.8	1.5	0.7

[a]10 = Sound, 0 = Complete failure

Thailand test

A summary of the mean decay and termite ratings for test specimens after exposure in the in-ground graveyard tests at five sites for three years is given in Table 7. The Accoya® stakes are exhibiting evidence of very slight decay and slight nibbling by termites after three years' exposure. Teak is performing comparably, whilst makha is performing less well, with many test specimens having been severely degraded by both fungi and termites.

Table 7: Mean decay and termite ratings for test specimens after exposure in the graveyard tests at five sites in Thailand for three years.

Material Type	Decay Rating[a]	Termite Rating[a]
Accoya® Radiata	9.3	9.6
Teak	8.8	8.8
Makha	6.4	6.0

[a] *10 = Sound, 0 = Complete failure*

USA test

Summaries of the mean termite and decay ratings for test specimens after exposure in the in-ground graveyard tests at two sites for two years are given in Table 8. At the Gainesville test site all untreated stakes had been destroyed after two years, whilst 20% of the Accoya® stakes had suffered minor nibbling or light attack by termites and moderate levels of decay, with the remainder being sound. At the San Luis test site more than half of the untreated stakes had been destroyed, with the remainder having incurred moderate to heavy attack by both termites and decay fungi. In contrast, only one of the 30 Accoya® stakes had suffered minor nibbling by termites, with the remainder being sound.

Table 8: Mean termite and decay ratings for test specimens after exposure in the graveyard tests (AWPA E7-09) at two sites (Gainesville, Fl. and San Luis, Costa Rica) for two years.

Material Type	Rating[a]			
	Gainesville		San Luis	
	Termite	Decay	Termite	Decay
Accoya® Radiata (NZ)	10.0	9.2	10.0	10.0
Accoya® Radiata (Chile)	9.8	10.0	10.0	10.0
Accoya® SYP	9.7	8.3	10.0	10.0
Radiata pine (NZ)	0.0	0.0	2.7	0.6
Radiata pine (Chile)	0.0	0.0	1.8	1.2
SYP	0.0	0.0	3.2	4.3

[a] *10=Sound, surface nibbles by termites permitted, 9=Light attack, 7=Moderate attack, 4=Heavy attack, 0=Failure*

4. CONCLUSIONS

The results of the laboratory and field studies against decay fungi presented here appear to further confirm that high acetyl WPG timber materials are highly resistant to attack by wood destroying fungi. The field studies against termites have further increased knowledge of the resistance of acetylated timber materials to attack by termites, and it has been demonstrated that both Accoya® and Tricoya® are resistant to attack by the highly destructive Australian termite species *M. darwiniensis*. It would be expected that Accoya® and Tricoya® would exhibit excellent long-term performance against wood destroying fungi and termites in service in most regions in the world.

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