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The durability of manufactured structural building materials

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ABSTRACT

The projected market potential for Engineered Wood Products such as CLT (cross laminated timber) is very positive however, potential prolonged rain leakage or moisture exposure during construction and in-service could pose considerable concern for its durability and reputation.

This research was conducted to assess the decay resistance of CLT and OSB (oriented strand board) in an accelerated trial. This testing method is used in establishing the effectiveness of wood products in framing subject to intermittent wetting. The results showed untreated OSB and CLT were very susceptible to decay. However, in the case of CLT, decay can be prevented by surface application of boron preservative.

There is a need to harmonise Standards for CLT and OSB timber used in building.

Keywords: boron, Cross laminated timber, CLT, Engineered Wood Products,EWP, moisture performance, Oriented Strand Board, OSB, Radiata pine

INTRODUCTION

There is a long history of use of Engineered Wood Products (EWP) in New Zealand and around the world. Plywood and glue laminated timbers were some of the first products. EWPs such as laminated veneer lumber (LVL) and oriented strand board (OSB) have also been used for some time (Ozarska 1999). Cross laminated timber (CLT) is a relatively new addition (Gagnon and Pirvu 2011; Brandner et al. 2016) still approximately 15 years old (Espinoza 2016). It can be used for long spans and assemblies like walls, roofs or load bearing linear timber members (Wang and Ge 2016).

Subsequent to the failure of untreated radiata pine in "leaky buildings" (Hunn et al. 2003) and changes in regulations (NZS 3640, 2003), that require preservative treatment of most of the framing used in New Zealand buildings, the use of untreated manufactured products such as oriented strand board (OSB) plywood, laminated veneer lumber (LVL) and cross laminated timber (CLT) in structural situations has been questioned. The New Zealand building standard (NZS 3602:2003 Timber and Wood-based Products for use in Building) requires that plywood used as wall bracing be preservative treated. While the existing standard for framing lists untreated LVL as acceptable (NZS 3602, 2003), amendments to the Australian/New Zealand joint standard related to Engineered Wood Products include requirements for preservative treatment (AS/NZS 1604.4). There are no requirements for the preservative treatment of CLT and OSB although OSB in some structural components such as "I" beam joists and purlins is being preservative treated.

A small test was conducted to determine whether untreated OSB and CLT were susceptible to decay and in the case of CLT whether decay could be prevented by the surface application of a boron preservative.

MATERIALS AND METHODS

1. Oriented strand board (OSB) Test

1.1 Material Preparation

For the OSB test sheets of locally manufactured 10 mm thick "strandboard" was purchased from a local hardware merchant. Imported (U S manufactured) 12 mm thick, OSB strips were supplied by an Auckland based manufacturer of wooden "I" beam joists and purlins. These were cut into 600 mm x 250 mm samples and sealed on all four edges with epoxy paint.

Ten samples for each material type were subjected to a pre-exposure, spray leaching programme and ten were not leached. The leached samples were placed on edge in grooved bearers and exposed to a water spray for one hour each day over a nine day period. The amount of water applied was approximately equivalent to the average amount of rain that falls over three months in the Rotorua area i.e., approximately 300 mm.

Ten samples of New Zealand produced strand board (NZSB) and 10 samples of imported OSB that had not been exposed in the leaching schedule placed in a plastic tank and immersed in water for two hours. This was intended to raise the moisture content of the samples to above 25%.

All samples were weighed and measured for thickness before and after either leaching or soaking.

1.2 Fungal inoculation and exposure

Radiata pine sapwood decay feeder blocks were infected with a pure culture of either *Oligoporus placenta*, or *Antrodia xantha*. Using standard "Sutter Test" methodology, the feeder blocks were then incubated for four weeks at 25^{o} C and 85% RH (Singh et al. 2014a).

Ten samples of each board type from each of the leached and soaked lots were numbered and weighed then swabbed with alcohol on two areas close to the ends. A pre-infected *O. placenta* feeder block was attached to the face in the previously swabbed area and an *A. xantha* feeder block was attached to the equivalent area at the other end on the back. Samples were then placed randomly on edge in slotted H1.2 boron treated radiata pine framing bearers in a lidded plastic tank (Figure 1). Five additional soaked samples of imported OSB were included which did not have decay feeder blocks on them.

The tanks have a tight fitting plastic lid and a drain about 20 mm above the bottom which retains some water in the bottom of the tank but allows surplus water to escape. This helps to maintain a humid atmosphere in the tanks (Singh et al. 2014b). The tanks are in the controlled condition room at 25^{o}C and 95% RH. Once a week during the exposure period the lids were removed from the tanks and the samples sprayed with water briefly. This was intended to keep the moisture content of the samples close to or above 25% and to simulate the periodic wetting that is likely to occur in leaky buildings.

1.3 Samples assessment and analysis

After 45 days the tanks were opened and a few of the samples were removed for weighing and assessment. This exercise was repeated after 14 weeks. After 26 weeks exposure all samples were removed from the tanks, weighed, thickness measured and assessed for mycelium spread, decay and mould using standard rating systems (Appendix I). Samples were returned to the exposure tanks after assessment although decay was sufficiently widespread that the decision was made to end the trial at that point.

2. Cross laminated timber (CLT) Test

2.1 Material Preparation and boron application

Three laminate radiata pine CLT, 105 mm thick was cut into 15/601 x 432 mm samples. Offcuts from the samples were weighed, oven dried and reweighed to determine the original moisture content of the samples. Five samples were left untreated and ten were brush coated with a boron/glycol preservative mixture containing approximately 20% boric acid equivalent (BAE). The boron preservative was applied to all surfaces in two coats, with 24 hours between coats. Samples were weighed before and after each coat to measure application rates. One week after treatment two 50 mm diameter holes were bored in one side of each sample about 100 mm from each end, through to mid-depth of the centre laminate.

Five of the preservative treated samples were placed on edge, on bearers in a plastic tank and exposed to a water spray for one hour each day over 12 days. The rate of water application was controlled so that over the leaching period the equivalent of approximately three months rainfall in the Rotorua area was applied to the samples. Wash-off water from the samples was collected in the tanks. Samples of this were sent for chemical analysis to determine how much boron had been lost from the CLT.

One week after the leaching had been completed each set of five samples was placed in a plastic tank and immersed in water. For the untreated samples and the treated but un-leached samples the soaking period was four hours. For the leached samples the soaking period was only two hours. This was intended to raise the moisture content in the samples to above 25%. All samples were weighed before and after soaking and this allowed calculation of the overall moisture content of the samples. An electrical resistance type moisture meter with long insulated probes was used to measure moisture content at about 5 mm and 10 mm from the surface of one sample in each of the sets.

2.2 Fungal inoculation, further unit assembly and exposure

Radiata pine sapwood decay feeder blocks were infected as described above in section 2.1.

Battens using CCA treated radiata pine to H3.2 specification were fixed around the edges on the face and back of each CLT sample. The area between the battens and the holes at the end of each face was swabbed with ethanol. An *Oligoporus placenta* decay feeder block was fixed to the face at one end of the sample, an *Antrodia xantha* block on the face at the other end (Figure 2).

Bituminous building paper and a fibre cement panel were then fixed to the battens on each side of the sample (Figure 3). Assemblies were weighed before and after fixing of the battens and sheathing panels. They were stood on end, on 15 mm thick fillets, on the floor of a controlled condition room. The temperature in the room is 25°C and the relative humidity is 95%. The assemblies were sprayed with water at weekly intervals.

2.3 Samples assessment and analysis

Several assemblies were opened and checked after 18 days and after 12 weeks exposure. After 28 weeks exposure each unit was opened and assessed for decay using a blunt 3 mm diameter probe. The units were weighed so that moisture content could be estimated. The units were photographed and the development of mould and decay mycelium on the surfaces were rated using the relevant scales in Appendix I. The building paper and fibre cement panels were fixed back in place and the units returned to the exposure room. This process was repeated after 12 months although a moisture meter rather than weight was used to determine approximate moisture content

12 months decay
exposure

RESULTS

1. Oriented strand board (OSB) test

Leaching of the OSB/Strandboard samples increased the moisture content of the samples above 25% moisture content before installation but short term soaking did not. However, after six weeks exposure the moisture content of the all the samples had increased to about 30% and there appeared to be little difference between the groups. Moulds became evident on the surface of the leached samples within a few days of the start of leaching.

At six weeks assessment, mycelium was extending out from the *O. placenta* feeder blocks on all of the boards and had extended through to the other side in most cases but there was no obvious mycelium spreading from the *A. xantha* feeder blocks (Figure 4). There was no decay on the imported OSB samples that had no feeder blocks on them. Moulds had continued to develop and were relatively extensive on all boards.

After 14 weeks exposure the moisture content of the samples had risen to above 30%. Decay mycelium covered more than 50% of the sample surfaces on both sides, all from the *O. placenta* feeder blocks. Decay under the feeder blocks was severe and a 3 mm diameter probe easily penetrated through the samples at the *O. placenta* feeder block end. The *A. xantha* feeder blocks all appeared to be inactive. There was no obvious decay on the imported OSB samples that had been installed without feeder blocks. Moulds were extensive and severe on the leached NZSB (New Zealand OSB) samples but only scattered on most of the imported OSB and the unleached NZSB samples.

Mycelium spread and decay ratings after 26 weeks are summarised in Table 1. Decay mycelium had extended over the whole of both surfaces of the samples with decay feeder blocks on them by the end of the trial (Figure 5). This mycelium appeared to be all from the *O. placenta* feeder blocks and not from the *A. xantha* feeder blocks. Some degeneration of the mycelium close to the *O. placenta* feeder blocks appeared to have occurred over the period between the 14-week and 26-week assessments (Figure 6).

Table 1 – Average Mycelium and Decay Ratings after 26 Weeks Exposure

Group	Mycelium	Decay
NZSB (leached)	6.0	4.0
NZSB (soaked)	6.0	4.0
OSB (leached)	6.0	4.0
OSB (soaked)	5.7	4.2
OSB (Soaked, no FB's)	1.6	9.6

Only one of the imported OSB samples which had no decay feeder blocks on them had decay mycelium on it at the end of the trial. Although *O. placenta* mycelium was widespread on all samples with feeder blocks it had not spread onto the boron treated bearers and there were areas on all samples close to the bearers that were free from mycelium.

Decay was well established in all samples in all groups with decay feeder blocks on them to the point where a 3 mm diameter probe easily penetrated most of the samples and pieces broke off some samples as they were assessed. There appeared to be no difference between these groups.

2. Cross laminated timber (CLT) Test

Boron preservative application rates are in Table 2. These show that application rates were relatively consistent for the two treatment groups and the amount of preservative applied on the surface was approximately equivalent to that required to meet the H1.2 specification for preservative treatment in New Zealand (NZS 3640; 2003).

Table 2 - Average Boron Preservative Application Rates

Treatment group	Preservative application			Calc. Retention
	1st coat (g)	2nd coat (g)	Overall (g/m^2)	(g/100g BAE)
(T) Unleached	113	83	106	0.38
(L) Leached	120	79	108	0.40

Samples of wash-off water taken at three stages during the leaching process indicate that approximately 30% of the boron in the applied preservative was lost during leaching (Table 3).

Table 3 - Average boron loss during leaching

Leaching period	Water applied (l)	Boron in leachate (ppm)	% Loss
5 Days	111	62.6	17.3
6-10 days	118	29.6	8.7
11-12 days	139	12.7	4.4
Total	368		30.5

After 18 days exposure the decay feeder blocks were all still active and scattered spots and patches of mould were developing. On the untreated samples mycelium had spread onto the surface from the decay feeder blocks but this had not occurred on the treated and the leached samples.

After 12 weeks, assembly weight indicated that the moisture content was in the range of 22-34%. In the untreated units mycelium from the *O. placenta* feeder blocks was visible on the outside of the assemblies (Figure 7). Under the exterior covers there was extensive mycelium and established decay in the CLT from the *O. placenta* feeder blocks. The *A. xantha* feeder blocks appeared largely inactive and mouldy. In the treated units, both leached and unleached there were patches of mould or mould spots on individual boards and there was no mycelium spread from the feeder blocks.

At the 28-week assessment all of the untreated units had extensive *O placenta* decay mycelium over the outer surface but no decay was evident on the outside of the leached and unleached boron treated units. Unit weights indicated that the moisture content was only slightly increased from when the units were installed. After 28 weeks mould in the untreated units was obscured where extensive decay mycelium had spread from the *O. placenta* feeder blocks. There was extensive patchy mould on all treated units, most severe on the boron treated units that had not been leached.

Oligoporus placenta mycelium was widespread on the face and back of the untreated units and was associated with decay to 15 mm deep. In two of the samples fine black lacy mycelium similar to *Coniophora puteana* was also widespread (Figure 8). There was no mycelium development or decay in any of the treated leached and treated unleached units (Figure 9).

After 56 weeks the moisture content of the samples was taken on the exposed edges of the samples plus on the face and back once the exterior panels had been removed. This showed that the moisture content on the exposed edges of the panels was in the range of 26-58% whereas the moisture content under the panels was less variable and within the range of 35-54%.

A summary of mycelium and decay rating is shown in Table 4. All of the untreated units contained severe decay, particularly at the lower end which remained wetter due to close proximity to the wet concrete floor (Figure 10). *Oligoporus placenta* appeared to be responsible for most of the decay although there was also widespread fine, dark, lacy mycelium in three units. This is infection was from an outside source and appeared to be predominant on the back of the units where there was less mycelium from *O. placenta*.

All of the boron treated units were free from decay (Table 4) but had severe mould (Figure 11). Also, some darkening in the treated samples, both leached and unleached, suggested the early stages of soft rot fungi infection in the wettest areas.

Table 4 - Decay mycelium and decay ratings summary after 56 weeks exposure

Treatment Group	Mycelium spread			Decay		
	O. p.	A. x.	Reverse	O. p.	A. x.	Reverse
Untreated	5.2	3.6	5.6	6.0	7.0	6.2
Treated leached	1.0	1.0	1.0	10	10	10
Treated unleached	1.0	1.0	1.0	10	10	10

After 56 weeks, all 15 surface treated CLT samples were free from decay. The samples were surface treated with a boron based preservative to the retention requirements of H1.2, but the penetration was not measured.
Tripti concludes that this surface treatment provides good protection in situations where the CLT is wet during construction or in situations where some leakage occurs and the wood becomes wet for a period of at least up to 12 months.

DISCUSSION

By six week exposure, moisture content differences between the various treatment groups had largely disappeared and all groups had an average moisture content around 30%. Hence the initial low moisture content did not obviously severely affect decay development. Clearly imported OSB, NZSB and untreated CLT have little resistance to *O. placenta* decay in damp conditions. The rate of deterioration was similar to that which could be expected with the same fungi in untreated radiata pine framing.

Decay development from the *O. placenta* feeder blocks and not from the *A. xantha* blocks indicated OSB had some resistance to the *A. xantha* fungi. This same problem occurred in the CLT test established about the same time and the original culture of *A. xantha* that the feeder blocks were infected with appeared, some weeks later, to be lacking in vigour. The culture was later replaced therefore the lack of decay from the *A. xantha* blocks could be regarded as due to the poor viability of the culture used rather than resistance to the decay fungi in the sample material. Degeneration of the *O. placenta* mycelium close to feeder blocks has been observed in other long-term framing tests once severe decay has developed in the substrate (Hedley et al. 2009; Singh et al. 2014a) hence it is not a phenomenon solely associated with OSB.

Although *O. placenta* mycelium was widespread on all samples with feeder blocks, it had not spread onto the boron treated bearers and there were areas on all samples close to the bearers that were free from mycelium. This suggested that there had been boron diffusion from the bearers into the samples sufficient to restrict mycelium development (Dirol 1988; Hedley et al. 2009) and that boron treatment would be adequate to prevent decay in OSB for at least six months.

In the CLT test, boron retention on the treated samples was close to that required in the H1.2 specification for treatment of radiata pine framing in New Zealand. Penetration of the preservative was not measured in any of the samples although it is likely that the preservative had not fully penetrated the samples (Singh et al. 2016). The holes bored in the face of the samples were intended to expose wood beyond the initial penetration zone. The loss from the leached samples was about 30%, similar to the loss from conventional framing exposed to a similar leaching regime (Singh et al. 2014a). While this is a substantial amount it is likely that the retention in the samples would have remained above 0.2% BAE, regarded as an approximate threshold for preventing brown rot fungi (Hedley et al. 2009; Singh et al. 2014a.).

Severe decay development from the *O. placenta* feeder blocks on the untreated samples over the 56 weeks exposure shows that CLT is vulnerable to decay if it becomes wet and remains wet for a prolonged period. CLT does not change basic wood characteristic and its durability (Espinoza 2016). The development of decay mycelium on three of the untreated samples from a source other than the feeder blocks indicates that it is susceptible to infection by brown rots other than those introduced artificially. This indicates that building designs, in which untreated CLT produced from Radiata pine or other non-durable species is an important structural component, must prevent the CLT from getting wet throughout the buildings lifetime.

The potential to absorb and trap water deading development of decay is influence by type of wood species, amount of sapwood/heartwood present, gaps within and between laminates, needs further investigation. A recent study in Europe on 'status and research needs for CLT' calls for better understanding on moisture performance along with structural performance (Espinoza 2016).

No decay has developed on the boron treated samples regardless of whether they were leached or not. The suggestion that darkening similar to the early stages of soft rot was present after 56 weeks on several of the treated samples, including some that had not been leached, indicates that boron cannot be relied upon to prevent decay in prolonged, consistently wet conditions. It also indicates it provides good protection in situations where the CLT is wet during construction or in situations where some leakage occurs and the wood becomes wet for a period of at least up to 12 months.

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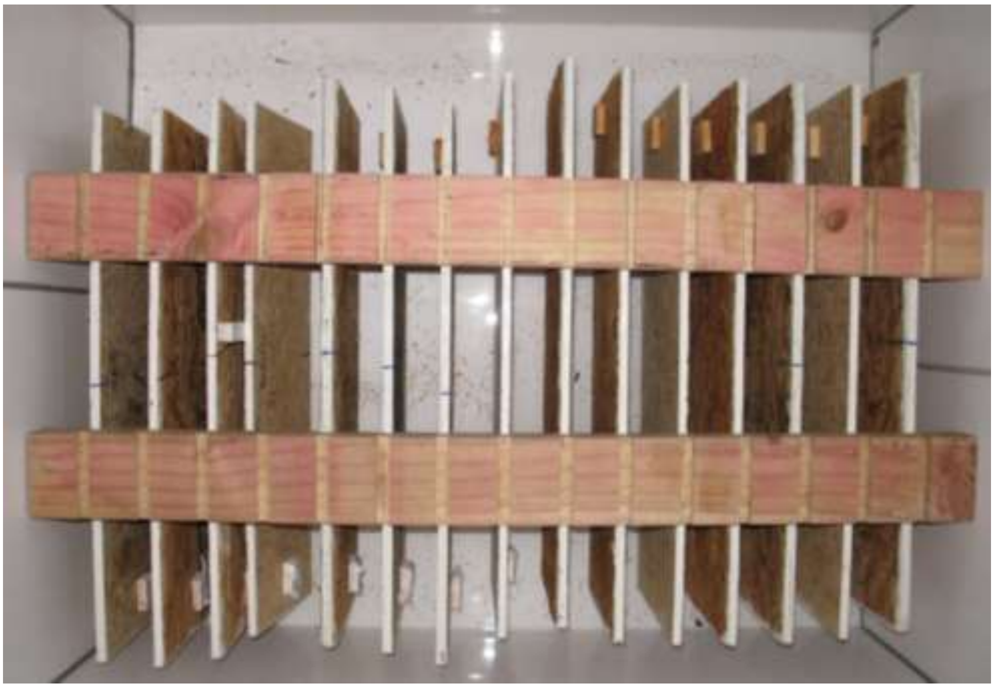

Figure 1 – Samples of OSB in slotted bearers in the exposure tanks. The *O. placenta* feeder blocks were on one face at one end of the samples, the *A. xantha* feeder blocks were on the reverse side at the other end.

Figure 2 – A sample of CLT showing fungal inoculum of *O. placenta* and *A. xantha* at the opposite end close to 50 mm diameter holes that were bored after treatment.

Figure 3 – Unit preparation of a CLT sample after fungal inoculation. Fibre cement panels and building paper were fixed on top of H3.2 treated CCA battens on each side of the sample.

Figure 4 – *A. xantha* decay feeder block near the right end on the reverse of a leached NZSB sample SL8 after six weeks exposure. There was no mycelium development from the feeder block but mycelium from the *O. placenta* feeder block on the other side of the sample had penetrated the sample towards the left end. There were extensive moulds over the whole of the sample.

Figure 5 – Widespread *O. placenta* mycelium covering the reverse of sample SO3, imported OSB which had not been leached, after 26 weeks exposure. The mycelium had completely covered the *A. xantha* feeder block. There was no mycelium or decay in the areas immediately adjacent to where the sample was in contact with the boron treated bearers

Figure 6 - Widespread *O. placenta* mycelium covering the face of sample SL2, NZSB which had been leached before exposure, after 26 weeks exposure. The mycelium around the feeder block had degenerated since the 14-week assessment. Severe decay was present throughout the board, except close to the bearers.

Figure 7 – The lower end of untreated unit (U2) after 12 weeks in the exposure room. The mycelium from the *O. placenta* feeder block had penetrated under the treated batten and was developing on the outer surface of the assembly.

Figure 8 – The reverse side of untreated, assembly U1 after 28 weeks exposure. The fibre cement sheathing and building paper have been removed. Decay mycelium had spread across the whole of the surface. While the white mycelium appeared to be from the *O. placenta* feeder blocks there was dark, lace-like mycelium also on the surface suggesting infection by an outside decay fungus, possibly *Coniophora puteana*.

Figure 9 – Treated, unleached assembly T2 after28 weeks exposure. There was no decay mycelium from the feeder blocks but there was extensive mould on the surface and the feeder blocks.

Figure 10 – The face of untreated unit (U5) after 56 weeks in the exposure room. There was extensive decay mycelium and deep decay over the whole of the face.

Figure 11 – The face of treated (not leached) unit (T2) after 56 weeks in the exposure room. There was no decay but there was extensive mould across the face and on the decay feeder blocks.

Appendix 1

<u>Description of assessment rating's</u>

Mycelium spread

- **1** No mycelium development onto the sample surface from the feeder block
- **2** Mycelium growth from the feeder block onto the surface, spread less than 5 mm
- **3** Mycelium from the feeder block on the surface, spread 5-50 mm
- **4** Active mycelium from the feeder block on the surface, spread greater than 50 mm
- **5** Extensive mycelium over the sample surface, less than 50% of the surface area
- **6** Extensive mycelium over the sample surface, more than 50% of the surface area

Decay ratings

- **10** No decay or insect damage
- **T** Trace, discolouration, mycelium or softening, not positively identified as decay
- **9** First stages of decay, small areas, not more than 1 mm deep
- **8** Lightly established decay, patches 1-5 mm deep
- **7** Well established decay, extensive surface decay or patches to 20 mm deep
- **6** Established and progressive decay over wide areas with patches greater than 20 mm deep
- **4** Severe decay over the majority of the surface with patches more than 40 mm deep
- **0** Failed. Decay completely through the sample.

Mould ratings

- **1** No perceivable mould
- **2** Light mould in small patches or widely scattered spots
- **3** Extensive mould as numerous scattered spots or widespread light mould
- **4** Severe mould, up to 50% of the surface covered
- **5** Severe mould, more than 50% of the surface covered