TEST DATA FOR LIGNIA® MODIFIED PINE

MARCH 2019

CONTENTS

The following provides information about the properties and performance of LIGNIA® modified pine.

Testing was conducted on product modified in pilot scale and commercial scale production facilities using the same processes and raw materials. All modified wood selected for testing was representative of that modified and was from different pilot batches.

Testing was undertaken by independent test houses/ laboratories with expertise and using calibrated equipment. In some instances, LIGNIA® modified pine was tested directly against teak of a quality typically used for yacht deck construction. In other instances, test data was compared against published values for teak. These published values were obtained using the same test methods with testing conducted on Burmese teak and that grown in plantation.

Tests examine properties considered important for use as yacht decking, namely strength (stiffness & bending strength), toughness, wear resistance and hardness, weathering performance, dimensional stability (movement), durability and adhesion to relevant deck substrate.

All test reports are provided in their entirety with a summary of findings provided for each test.

1. POINT BENDING TESTS OF LIGNIA MODIFIED PINE

SUMMARY AND DOCUMENTARY EVIDENCE

Bending strength: BS 373

Sample code [where used]	Modulus of Rupture (N/mm^2)	Modulus of Elasticity (N/mm^2)	Moisture content at test (%)
BD, Radiata pine	80.16 (7.41.sd)	8117 (1425 sd)	12.2
BE, LIGNIA	114.28 (10.07 sd)	12180 (684 sd)	8.4
BG, LIGNIA	100.79 (17.98 sd)	10602 (884 sd)	8.4
Teak	106 (17.1 sd)	10000 1980 sd)	

Mean values for properties determined by three point bending test, standard deviation is shown in parenthesis.

Summary:

The tested batches of LIGNIA performed well in three point bending tests, with strength and stiffness values which were as good as teak, or better.

3-Point Bending Tests of Lignia timber

Work completed for
Lignia Wood Company Limited

14th February 2019

BC Project Reference: BC-1472-2019 part 5

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The BioComposites Centre

The BioComposites Centre have 30 years' experience in research and development for the timber and wood based panels industry. Specialising in industry-facing research, the Centre also provides consultancy, materials testing, product development and technical support for companies in the timber, natural fibre composites, bio-based materials and biopolymer sectors. The Centre also offers assistance to companies in scale up and process development, supported by the Biorefining Technology Transfer Centre.

The BioComposites Centre maintains well-equipped laboratories with calibrated equipment to provide materials testing for the determination of the mechanical and physical properties of wood, wood based panels and other composite materials. This includes British, European and International standard tests for wood based panels (MDF, particleboard, plywood and OSB) and the related adhesives used in this industry. A wide range of mechanical tests can be undertaken on solid wood, for example evaluating new species, new modified wood products and the influence of wood treatments. Weathering, natural durability and determination of resistance to decay by basidiomycete fungi is also routinely undertaken for timber preservative treatments, protective treatments and wood modification systems.

Materials characterisation can also be undertaken at the ultrastructural level, including dynamic vapour sorption, porosimetry, dynamic mechanical analysis, helium pycnometry, differential scanning calorimetry and thermogravimetric analysis.

The BioComposites Centre has specialist testing equipment for polymers, including polymer films, and thermoplastic matrix composites. Injection moulding of test pieces from small batches allows mechanical properties to be evaluated for new products and blends. The Centre also has manufacturing and testing capabilities for thermosetting composites using natural fibre reinforcements, such as hemp, flax, jute and sisal.

The BioComposites Centre annual reports and links to recent scientific publications are available on our website www.bc.bangor.ac.uk

Introduction

Material was supplied by Lignia Wood Company Limited for evaluation and comparison with reference data for teak, which is a commonly chosen species for marine applications.

Testing was performed under BS 373, *Method of testing small clear specimens of timber*, which determines the strength properties of small defect free samples of timber. This data can be compared to published values in Lavers (1969).

Experimental

Material for test

Samples of Lignia from different production conditions were received for test, pre-cut to test specimen dimensions. A reference set of Radiata pine was also received and used as a control set for comparison.

Twenty specimens per batch were supplied for test. Only one sample was rejected prior to test due to recognition of mechanical damage which would unfairly alter the test result. The majority of samples had good alignment of the growth rings with the faces of the test piece, and were tested with the load applied to the radial face.

There were insufficient samples to exclude those with poor alignment of growth rings, an indication of the number of samples with rings at approx. 45° to the faces is also indicated in Table 1.

Sample code	Batch information	Samples tested	Number of non-aligned samples
BD	Radiata pine Untreated control	20	4
BE	Lignia Batch 20, R 17, S4	19	1
BG	Lignia Batch 24, R21, S1 90.23	20	9

Table 1. Materials tested

It was also noted that a significant number of the Radiata pine control samples were possibly from juvenile wood, i.e. with exceptionally wide growth rings. In production, juvenile wood content is observed and restricted for the timber feedstock.

All samples were conditioned at 20°C and 65% relative humidity until their mass stabilised prior to testing. Moisture content at time of test was determined from a sub-set of samples from each batch, immediately after testing.

Bending strength

Samples were tested in three point bending mode (Figure 1) according to the 2cm standard specified in BS 373. The mean and standard deviation for the modulus of rupture (MOR, which is the maximum stress) and the modulus of elasticity (MOE, flexural modulus) are recorded in Table 2.

Figure 1. 3-point bend testing of Radiata pine samples, before and after failure.

Sample code	Modulus of rupture (N/mm^2)	Modulus of elasticity (N/mm^2)	Moisture content at test (%)
BD, Radiata pine	80.16 (7.41 s.d.)	8117 (1425 s.d.)	12.2
BE, Lignia	114.28 (10.07 s.d.)	12180 (684 s.d.)	8.4
BG, Lignia	100.79 (17.98 s.d.)	10602 (884 s.d.)	8.4

Table 2. Mean values for properties determined by three point bending test, standard deviation is shown in parenthesis.

Observations

The Lignia timber batches were stronger than the untreated Radiata pine, i.e had a higher MOR, and demonstrated a significant increase in stiffness, the MOE.

The failure mode of the Lignia samples was typically more brittle than the untreated Radiata pine control, although a higher stress (MOR) was recorded. For the BE and BG Lignia batches, the load-deflection graph showed a period of deformation beyond the limit of proportionality, as is typical for timber. However in some samples this was relatively short.

Examples of failure seen in untreated Radiata pine and Lignia samples are shown in Figures 2 to 4. A typical failure of wood would present a long fingered failure on the tension face (Figure 2). Brittle behaviour is characterised by a brash failure, with the crack propagating more directly between the lower and upper face of the specimen (Figure 3). This was only observed in a portion of the tested Lignia samples from batch BE. The majority of Lignia samples showed a more normal failure mode.

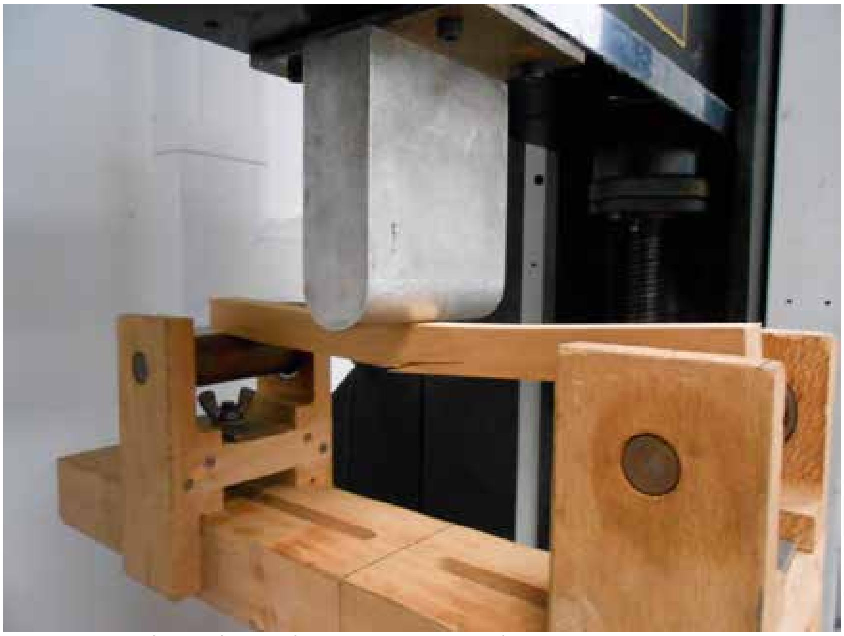


Figure 2. Typical failure of unmodified wood at the tension face, Radiata pine.

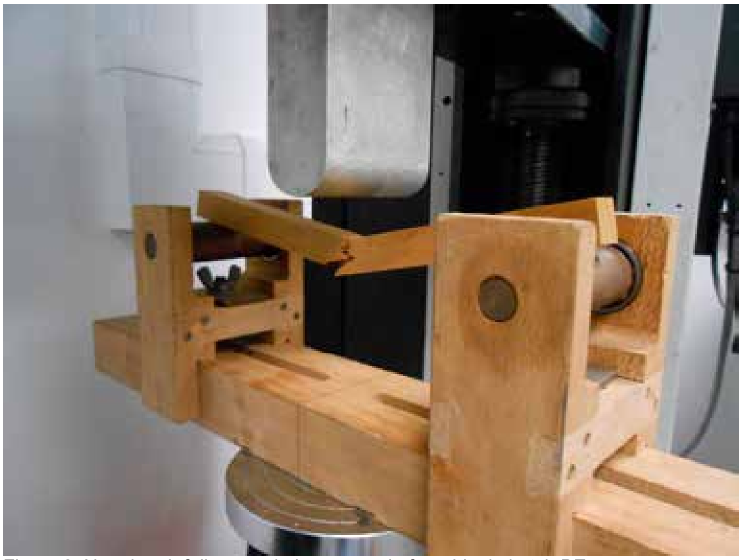


Figure 3. Near brash failure mode in on sample from Lignia batch BE.

Figure 4. Failure of samples of Lignia batch BG, showing crack deflection.

Comparison with teak data

Values for the flexural modulus and maximum stress from these tests were compared with reported data for teak from three different regions, as reported in Lavers (1969) *The strength properties of timbers*, Forest Products Research Bulletin No 50 (see Table 3).

Reference data	Region of origin	Maximum stress, Modulus of Rupture	Stiffness, Modulus of Elasticity
Teak	Burma	106 (17.1 s.d.)	10000 (1980 s.d.)
Teak	Western Nigeria	111 (11.1 s.d.)	11200 (1270 s.d.)
Teak	Northern Nigeria	100 (14.4 s.d.)	10100 (1360 s.d.)

Table 3. Three point bending values from Lavers (1969), note that the numbers of samples tested were 106 (Burma), 28 (W. Nigeria) and 31 (N. Nigeria).

Using the data reported by Lavers (1969), the standard error of the mean was calculated, and used to define the 95% confidence interval. This allows comparison of the data from these experiments with reported data for teak.

The Modulus of Rupture (MOR) is shown in Figure 5. It is clear that batches BE and BG of Lignia have performance which exceeds the untreated Radiata pine, and which is similar to teak. The same observations can be made for the Modulus of Elasticity (MOE, i.e. stiffness), in Figure 6.

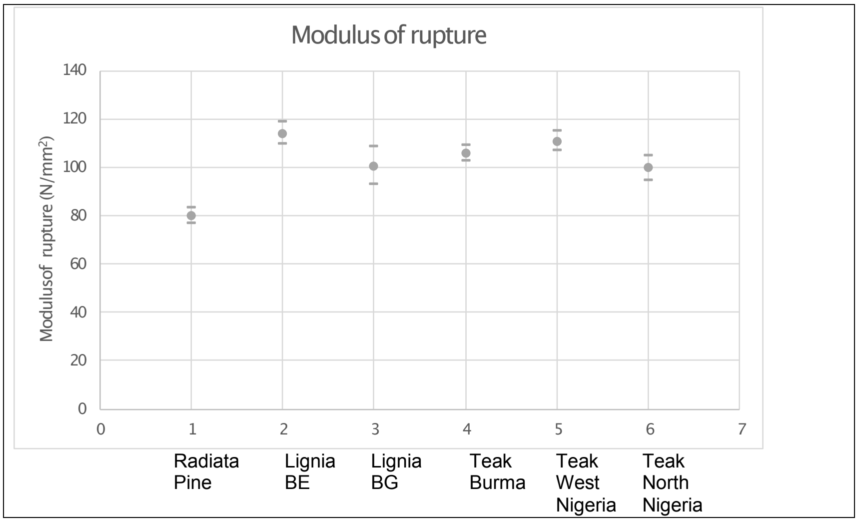


Figure 5. Modulus of rupture for unmodified Radiata pine, Lignia, and teak from three regions of origin. The 95% confidence interval of the mean is indicated by the upper and lower dashes.

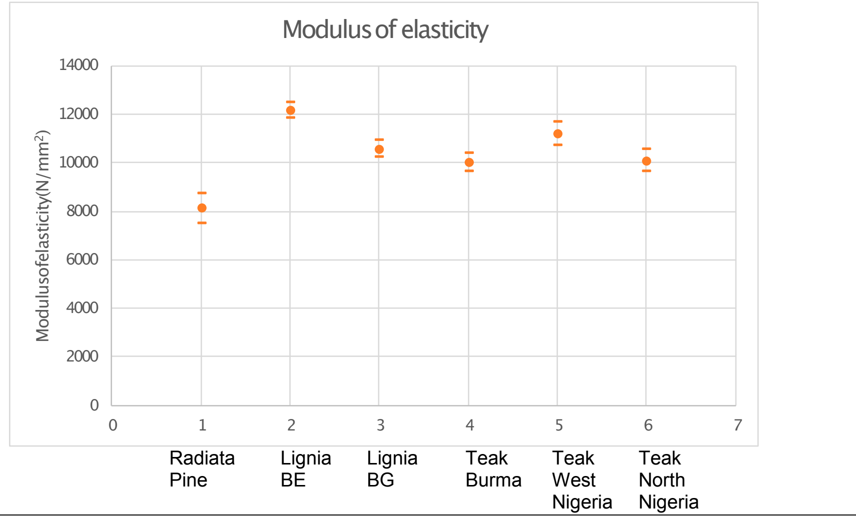


Figure 6. Flexural modulus for unmodified Radiata pine, Lignia, and teak from three regions of origin. The 95% confidence interval of the mean is indicated by the upper and lower dashes.

Summary and Conclusions

The tested batches of Lignia performed well in three point bending tests, with strength and stiffness values which were as good as teak, or better.

2. JANKA HARDNESS TEST

SUMMARY AND DOCUMENTARY EVIDENCE

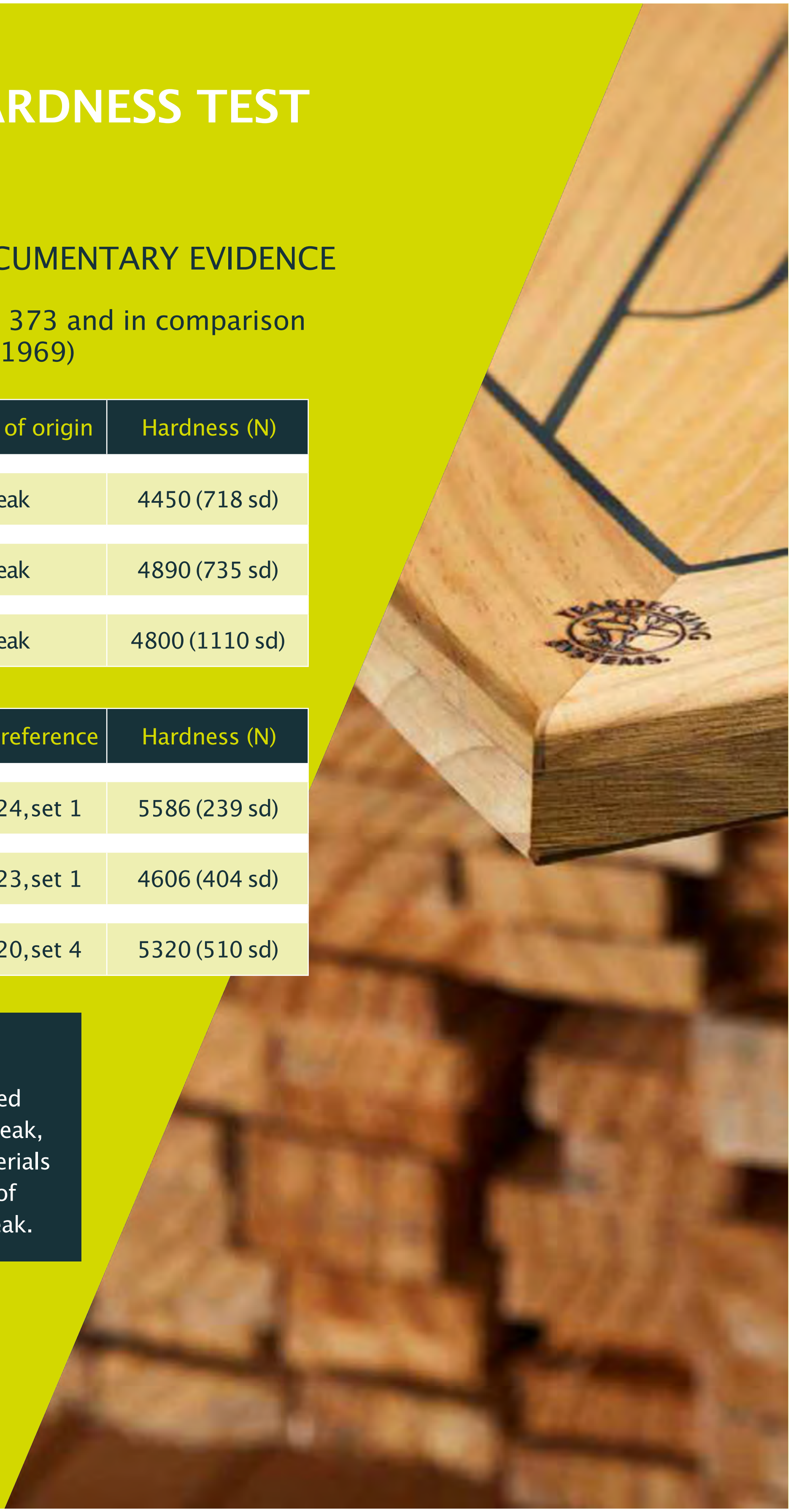
Janka hardness test: BS 373 and in comparison with teak data (Lavers, 1969)

Reference data	Region of origin	Hardness (N)
Teak	Teak	4450 (718 sd)
Teak	Teak	4890 (735 sd)
Teak	Teak	4800 (1110 sd)

Material	Product reference	Hardness (N)
LIGNIA	Batch 24, set 1	5586 (239 sd)
LIGNIA	Batch 23, set 1	4606 (404 sd)
LIGNIA	Batch 20, set 4	5320 (510 sd)

Summary:

The hardness tests revealed that LIGNIA is as hard as teak, and that some of the materials tested have higher levels of hardness than Burmese teak.



Janka Hardness Tests

Work completed for
Lignia Wood Company Limited

5th February 2019

BC Project Reference: BC-1472-2019 part 3

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Materials characterisation can also be undertaken at the ultrastructural level, including dynamic vapour sorption, porosimetry, dynamic mechanical analysis, helium pycnometry, differential scanning calorimetry and thermogravimetric analysis.

The BioComposites Centre has specialist testing equipment for polymers, including polymer films, and thermoplastic matrix composites. Injection moulding of test pieces from small batches allows mechanical properties to be evaluated for new products and blends. The Centre also has manufacturing and testing capabilities for thermosetting composites using natural fibre reinforcements, such as hemp, flax, jute and sisal.

Introduction

Material was supplied by Lignia Wood Company Limited for evaluation. This was from three batches of treatment and an untreated Radiata pine control set of samples.

Testing was performed under BS 373, *Methods of testing small clear specimens of timber*, which determines the strength properties of small defect free samples of timber. The Janka hardness test values allow comparison with reported values for teak, which is a commonly chosen species for marine applications. Teak data published in Lavers (1969) *The strength properties of timbers*, Forest Products Research Bulletin No 50.

Experimental

Janka hardness testing

Samples of 20 x 20 x 60mm were supplied by Lignia Wood Company Limited. These were conditioned at 20°C and 65% relative humidity until a stable weight was recorded, prior to testing.

Sample material	**Code assigned to samples**	**Moisture content at time of test (%)**
Lignia, batch 24, set 1, 90.23	HA	7.8
Lignia, batch 23, set 1, resin 20, 88.04	HB	7.7
Lignia, batch 0, set 4, resin 17	HC	7.8
Control, Untreated Radiata pine	HD	12.9

Table 1. Materials tested and moisture content of samples after conditioning at 20°C and 65% r.h.

Samples were supported within a sample holder during testing on an Instron universal testing machine using the 2cm standard parameters for test. The ball radius was 5.639 mm and cross head speed was 6.35 mm/min.

Ten samples were indented in the tangential face and ten samples were indented in the radial face.

The tested samples were weighed, then oven dried and re-weighed, to determine their equilibrium moisture content at the time of test (20°C 65% r.h.). Values are shown in Table 1 above. The equilibrium moisture content of modified woods is typically lower than unmodified woods, as shown in these samples.

Janka hardness results

The mean hardness values recorded for each material, and the standard deviation (s.d.) are shown in Table 2. All Lignia wood samples recorded higher values than the untreated Radiata pine.

Sample	Tested face	Hardness (N)
HA	Radial	5688 (250 s.d.)
	Tangential	5483 (187 s.d.)
HB	Radial	4476 (309 s.d.)
	Tangential	4735 (460 s.d.)
HC	Radial	5452 (445 s.d.)
	Tangential	5189 (558 s.d.)
HD	Radial	2861 (665 s.d.)
	Tangential	3179 (757 s.d.)

Table 2. Janka hardness values recorded for three supplied Lignia products, tested in the radial and the tangential face. Mean values are shown, with standard deviations in parenthesis.

The hardness values for Lignia were significantly higher than the untreated Radiata pine.

When tested into the tangential face, the Lignia samples had a greater tendency to split than the untreated radiata pine. Splitting was much less frequent in the radial face (Figure 1d), which in practice would be commonly seen in quarter sawn planks.

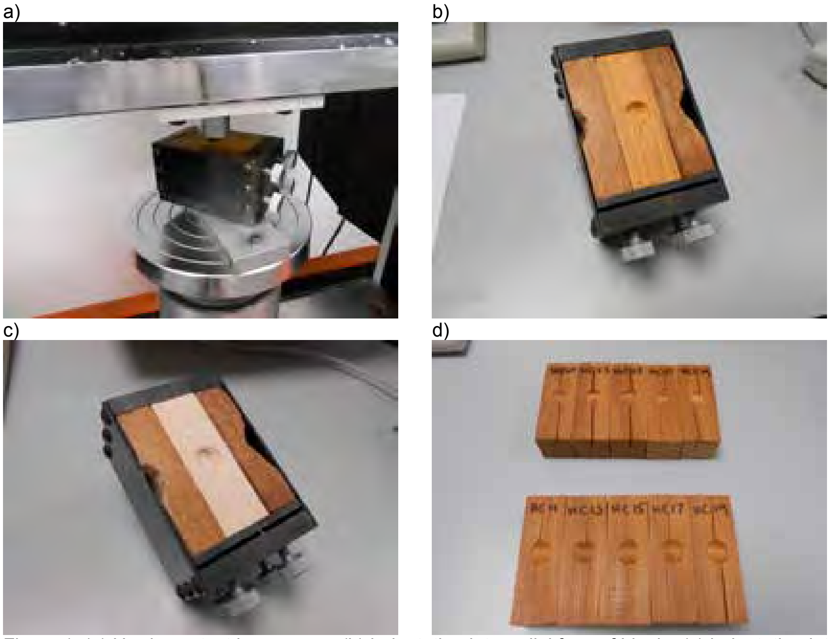

Figure 1. (a) Hardness test in progress. (b) indentation into radial face of Lignia. (c) indentation into radial face of unmodified radiata pine. (d) tested samples of Lignia, upper row tangential face, lower row radial face.

Comparison with teak data (Lavers, 1969)

Reference data	Region of origin	Hardness (N)
Teak	Burma	4450 (718 sd)
Teak	Western Nigeria	4890 (735 sd)
Teak	Northern Nigeria	4800 (1110 sd)

Table 3. Janka hardness values for teak from three sources, reported by Lavers (1969). Note that the teak data were compiled from 109 samples (Burma), 28 samples (W Nigeria) and 33 samples (N Nigeria).

To compare the results from this experiment with the values previously reported for teak, the mean of all samples per treatment was calculated as shown in Table 4.

Material	Product reference	Hardness (N)
HA	Batch 24, set 1	5586 (239 sd)
HB	Batch 23, set 1	4606 (404 sd)
HC	Batch 20, set 4	5320 (510 sd)

Table 4. Mean values for all twenty tested samples per supplied treatment, independent of orientation of testing.

The data in Tables 3 and 4 were used to derive the standard error of the mean, and determine the 95% confidence interval for the populations of material tested. These are shown in Figure 2. It is clear that one of the Lignia products (labelled HB) has a hardness equivalent to teak. The HC material is harder, but its range of values overlaps with the Nigerian teak material, and the HA product is harder than all teak reference materials.

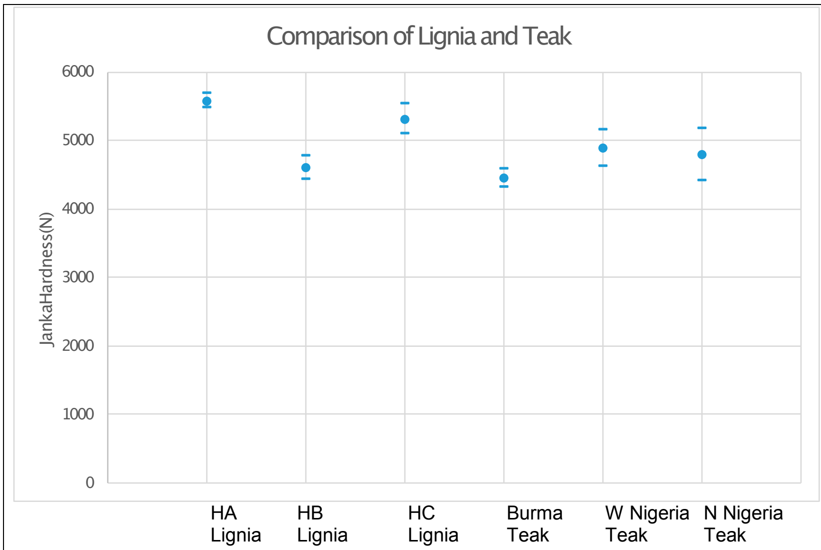

Figure 2. Mean and 95% confidence interval for Lignia and Teak, using standard error of the mean.

Summary and Conclusions

The hardness tests revealed that Lignia is as hard as teak, and that some of the materials tested have higher levels of hardness than Burmese teak.

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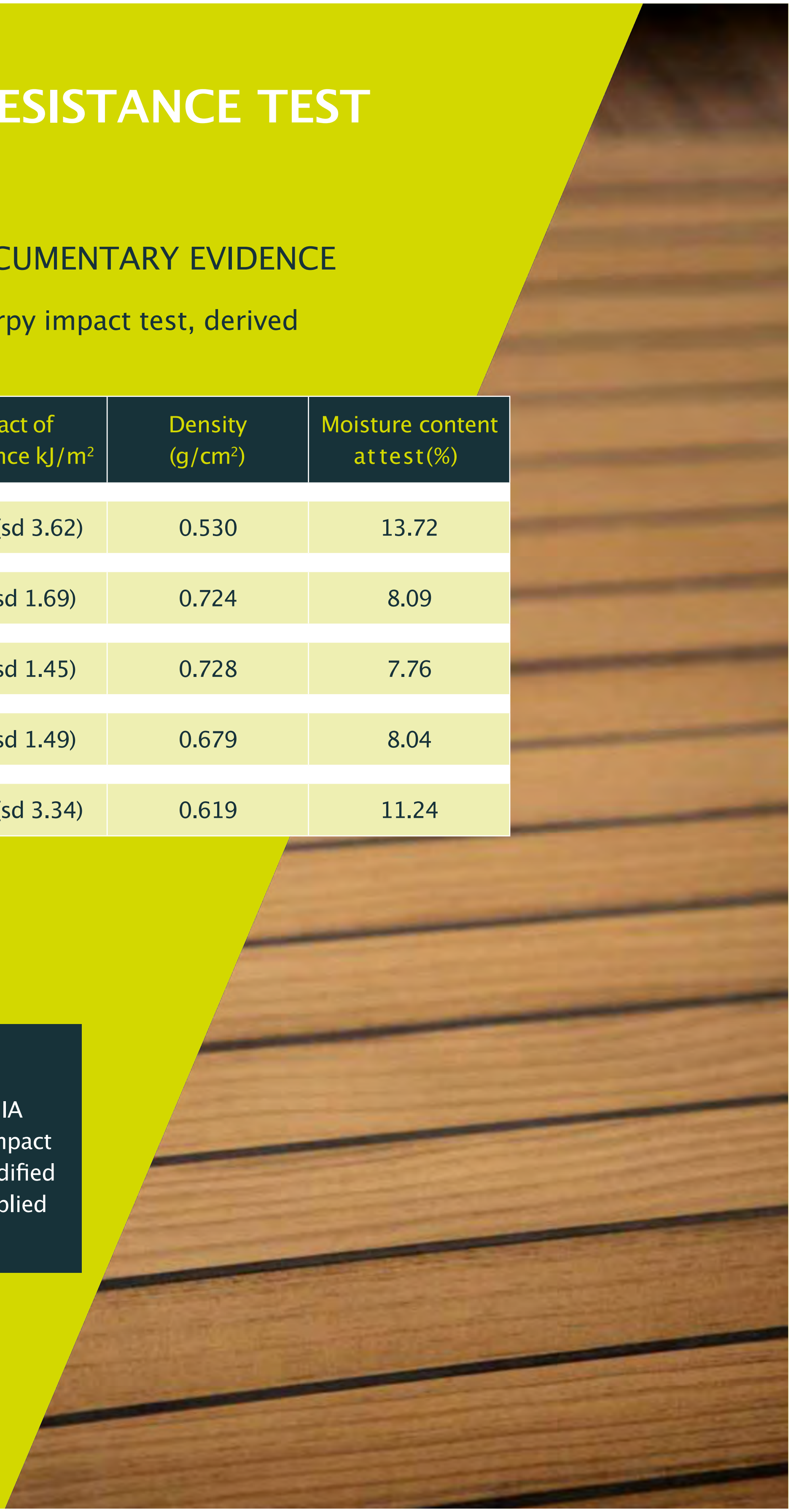
3. IMPACT RESISTANCE TEST

SUMMARY AND DOCUMENTARY EVIDENCE

Impact resistance: Charpy impact test, derived from BS EN ISO 179

Sample code	Impact of Resistance kJ/m^2	Density (g/cm^2)	Moisture content at test (%)
ID Radiata pine	17.48 (sd 3.62)	0.530	13.72
IE LIGNIA	9.53 (sd 1.69)	0.724	8.09
IF LIGNIA	8.51 (sd 1.45)	0.728	7.76
IG LIGNIA	8.96 (sd 1.49)	0.679	8.04
IT TEAK	14.55 (sd 3.34)	0.619	11.24



Summary:

The three batches of LIGNIA showed lower values of impact resistance than the unmodified radiata pine and teak supplied for test.

Impact Resistance Tests

Work completed for
Lignia Wood Company Limited

13th February 2019

BC Project Reference: BC-1472-2019 part 4

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Introduction

Material was supplied by Lignia Wood Company Limited for evaluation and comparison with teak, which is a commonly chosen species for marine applications.

The Charpy impact test was performed according to an in-house method, derived from BS EN ISO 179 which is used in the plastics industry. A 4J anvil was used to strike wood samples in the centre, while supported at each end. The energy consumed in breaking the sample was recorded and used to determine the impact resistance (kilojoules per square metre).

Experimental

Materials supplied for test

Samples of Lignia from three different production batches were supplied, pre-cut for testing. Additionally, samples of untreated Radiata pine and teak were provided to permit comparison of the impact resistance values determined.

All samples were conditioned at 20°C and 65% relative humidity prior to test, and the moisture content at test was determined.

Sample code	Batch information	Samples tested
ID	Radiata pine Untreated control	30
IE	Lignia Batch 20, R 17, S4	30
IF	Lignia Batch 23, R 20, S1	30
IG	Lignia Batch 24, R21, S1	30
IT	Teak	30

Table 1. Materials for test.

Sample dimensions were 100mm (longitudinally aligned) by 10mm (radial direction) by 5mm (tangential direction).

Impact resistance

Impact resistance was tested for each material, as reported in Table 2.

Sample code	Impact resistance kJ/m^2	Density (g/cm^3)	Moisture content at test (%)
ID Radiata pine	17.48 (s.d. 3.62)	0.530	13.72
IE Lignia	9.53 (s.d. 1.69)	0.724	8.09
IF Lignia	8.51 (s.d. 1.45)	0.728	7.76
IG Lignia	8.96 (s.d. 1.49)	0.679	8.04
IT Teak	14.55 (s.d. 3.34)	0.619	11.24

Table 2. Impact resistance recorded for the Lignia, Radiata pine and teak samples.

a) b)

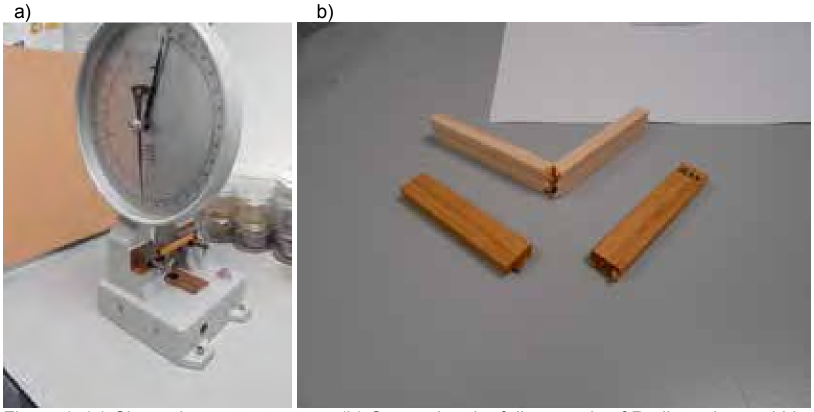

Figure 1. (a) Charpy impact test set up. (b) Comparing the failure mode of Radiata pine and Lignia

Examination of the tested wood specimens indicated a difference in failure mode between the Radiata pine and Lignia (Figure 1b). The Lignia samples showed a more brittle failure mode. The failed teak samples showed behaviour which was more similar to the unmodified Radiata pine.

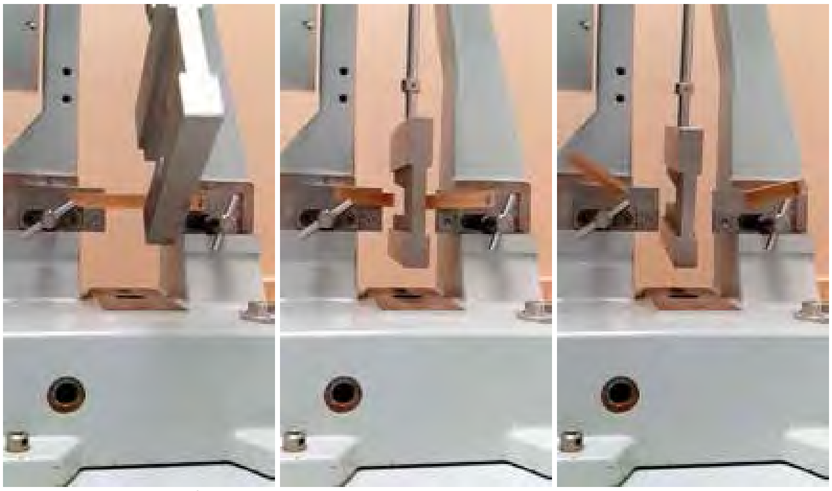

Figure 2. Impact test of a wood sample.

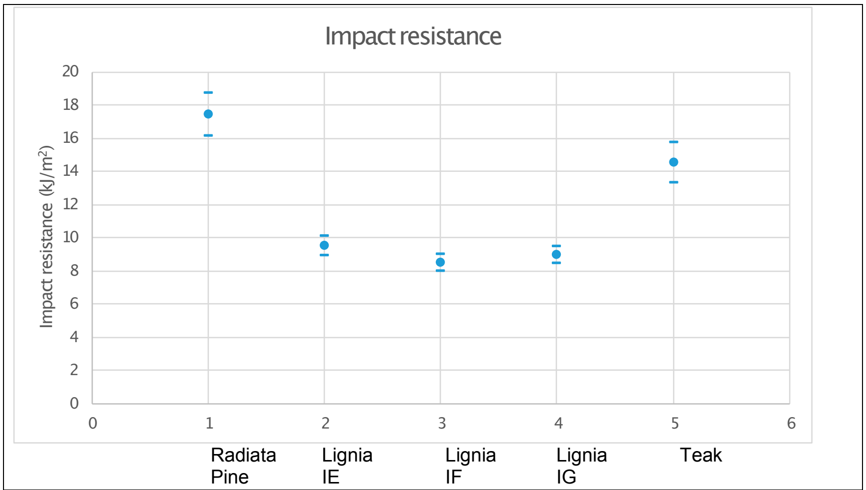

Figure 3. Comparison of the 95% confidence interval of the mean for different batches of Lignia, alongside Radiata pine and teak.

Summary and Conclusions

The three batches of Modified Pine showed lower values of impact resistance than the unmodified Radiata pine and teak supplied for test.

4. THERMAL EFFUSIVITY TEST

SUMMARY AND DOCUMENTARY EVIDENCE

Effusivity test

Thermal Effusivity Results per ASTM 7984 (2 seconds) from 20 °C to 50°C

Sample	Mean Thermal Effusivity ($Ws^{1/2}/(m^2K)$)						
	20 °C	25°C	30°C	35°C	40°C	45°C	50°C
LIGNIA Blank	255.2	3.1.2	303.3	312.1	315.9	329.9	327.0
RSD(%)	5.0	5.3	4.1	3.9	6.2	2.1	6.0
LIGNIA 86.15B24 R21 Set 2	369.6	373.5	377.7	386.4	392.4	402.0	401.1
RSD(%)	0.8	2.4	1.5	1.5	2.0	0.6	1.0
LIGNIA B25 R20 SET 88.25	369.6	353.7	360.1	358.3	378.7	407.7	389.9
RSD(%)	1.8	1.7	1.9	1.6	3.4	0.5	1.9
Teak 1	259.0	275.4	287.2	280.7	289.0	285.5	289.2
RSD(%)	2.0	8.0	3.6	7.7	5.5	2.8	3.5
Teak 2	286.8	305.4	330.0	331.1	353.2	359.1	368.3
RSD(%)	1.4	6.4	8.5	5.6	2.6	1.2	2.6
Teak 3	368.7	379.9	374.9	385.3	391.3	390.9	406.0
RSD(%)	0.4	1.6	2.8	1.4	1.9	2.2	0.5

Summary:

Thermal effusivity provides information about how warm an object feels when touched for a short period and when contact is made over a longer period. It provides a measure of the rate at which a material can absorb heat.

Surfaces of three teak samples taken from different pieces and three pieces of quarter sawn LIGNIA® Yacht from different batches were compared over a range of temperatures and time periods. In most instances, the range of values for both materials are of a similar order of magnitude meaning they feel similar when touched.

Thermtest

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NOTICE:

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SUBJECT:

This report summarizes the measurement of **Thermal Effusivity (W·s$^{1/2}$/(m^2·K))**,of **six wood** samples received from **LIGNIA Wood Company Limited**. All six samples were measured for thermal effusivity using the Hot Disk TPS 2500 S Thermal Constants Analyzer, from **20** to **50°C.**

The ThermTest TPS 2500 S Thermal Constants Analyzer was the instrument used for bulk thermal effusivity measurements. The TPS 2500S meets ISO 22007-2:2015-Plastics – Determination of thermal conductivity and thermal diffusivity – Part 2: Transient plane heat source (hot disc) method.

What is Thermal Effusivity?

Thermal effusivity is a thermal property that governs heat transfer between two objects of different temperatures. To better understand human comfort, the thermal effusivity of the provided wood samples was measured. The thermal effusivity of the samples, or otherwise referred to as the cool to touch effect, will determine the rate at which the material absorbs heat upon contact with the skin.

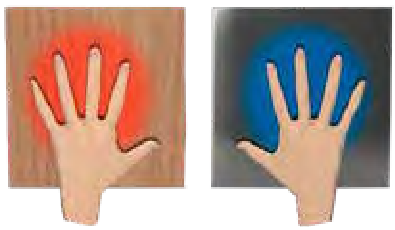

Figure 1. Visual representation of the thermal effusivity between the skin and an object of low effusivity (wood), left, and an object of high effusivity (metal), right.

Figure 1 illustrates the cool to touch effect between the skin and two drastically different materials. An object of lower thermal effusivity, such as wood, is a material that feels warm to the touch. In other words, the material does not quickly absorb heat from the skin upon contact. A material of higher thermal effusivity, such as metal, is a material that will feel cool to the touch. Meaning, the material rapidly absorbs heat from the skin, allowing the body to cool faster upon contact.

Following ASTM D7984, the Hot Disk TPS measures one-dimensional thermal effusivity when testing materials with short test times (typically 1 to 2 seconds). The one-dimensional thermal effusivity is determined by the shape of the heat penetration, at short test times. As the Hot Disk TPS sensor has a large diameter of 14.61 mm and a thickness of 0.01 mm, the sampling of thermal effusivity from the face of the 14.61 mm sensor, has very little lateral heat loss, thus one-dimensional penetration is represented.

As a natural phenomenon, like the Hot Disk TPS sensor, the skin experiences one-dimensional penetration upon initial contact, due to the large surface area contact, similar to the Hot Disk TPS Sensor. As contact time increases between skin and material, the heat penetration becomes more three-dimensional. By extending test times, one can determine the level of human comfort, or the effective thermal effusivity of the material, with respect to prolonged exposure times. Test times from 2 to 40 seconds were performed to mimic this prolonged exposure.

SAMPLE DESCRIPTION:

Sixwood samples were received from LIGNIA Wood Company Limited for thermal effusivity measurements. The samples were identified as follows:

Figure 2. LIGNIA Blank. Thermtest Identifier: TT-001-501.

Figure 3. LIGNIA B25 R20 SET 88.25. Thermtest Identifier: TT-001-502.

Figure 4. LIGNIA B24 R21 SET 2. Thermtest Identifier: TT-001-503.

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Figure 5. Teak 1. Thermtest Identifier: TT-001-504.

Figure 6. Teak 2. Thermtest Identifier: TT-001-505.

Figure 7. Teak 3. Thermtest Identifier: TT-001-506.

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EXPERIMENTAL:

Thermal Effusivity was measured using the **TPS Single-Sided Standard Analysis Module**. With this test module and using the TPS 2500 S Thermal Constants Analyzer, effective thermal effusivity of a variety of samples, with varying sample geometries can be easily determined.

To mimic the feeling from the hand, thermal effusivity tests were performed single-sided. With this approach, an insulating backing material of known thermal properties is placed in contact with the TPS sensor on the opposite face to the unknown sample.

In the process of calculations, the thermal properties of the backing material are accounted for, leaving the thermal properties of the unknown sample. Multiple thermal effusivity measurements were performed at each test time, to confirm precision.

RESULTS:

Thermal Effusivity Per ASTM 7984 (2s) from 20 to 50°C

To demonstrate the cool to touch sensation, per ASTM 7984, a test time of 2 seconds was performed at each temperature. Results can be found below.

Table 1. Thermal Effusivity Results per ASTM 7984 (2s) of the six Wood Samples (TT-001-501to-506), from 20 to 50°C.

Sample	Mean Thermal Effusivity ($Ws^{1/2}/(m^2K)$)						
	20°C	25°C	30°C	35°C	40°C	45°C	50°C
LIGNIA Blank	**255.2**	**301.2**	**303.3**	**312.1**	**315.9**	**329.9**	**327.0**
RSD (%)	5.0	5.3	4.1	3.9	6.2	2.1	6.0
LIGNIA 86.15 B24 R21 Set 2	**369.6**	**373.5**	**377.7**	**386.4**	**392.4**	**402.0**	**401.1**
RSD (%)	0.8	2.4	1.5	1.5	2.0	0.6	1.0
LIGNIA B25 R20 SET 88.25	**369.6**	**353.7**	**360.1**	**358.3**	**378.7**	**407.7**	**389.9**
RSD (%)	1.8	1.7	1.9	1.6	3.4	0.5	1.9
Teak 1	**259.0**	**275.4**	**287.2**	**280.7**	**289.0**	**285.5**	**289.2**
RSD (%)	2.0	8.0	3.6	7.7	5.0	2.8	3.5
Teak 2	**286.8**	**305.4**	**330.0**	**331.1**	**353.2**	**359.1**	**368.3**
RSD (%)	1.4	6.4	8.5	5.6	2.6	1.2	2.6
Teak 3	**368.7**	**379.9**	**374.9**	**385.3**	**391.3**	**390.9**	**406.0**
RSD (%)	0.4	1.6	2.8	1.4	1.9	2.2	0.5

Notes: For each sample, five measurements of thermal effusivity were conducted at each temperature – the mean results are reported. Measurements were made using the TPS Single-Sided Standard Analysis Method.TPS sensor #4922 (14.61 mm radius; Kapton insulation), 2 second test times and 0.1 Watts of power were selected for measurement parameters.

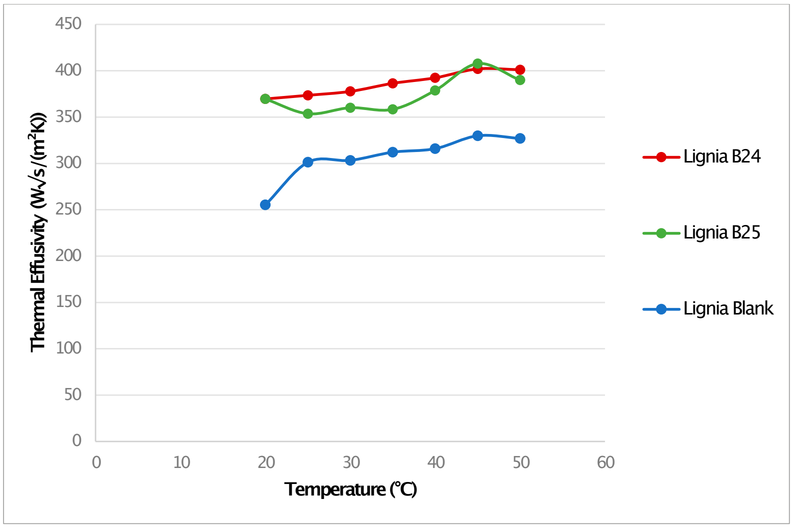

Figure 8. Thermal Effusivity per ASTM 7984 (2s), of the three LIGNIA Samples (TT-001-501to-503), from 20 to 50°C.

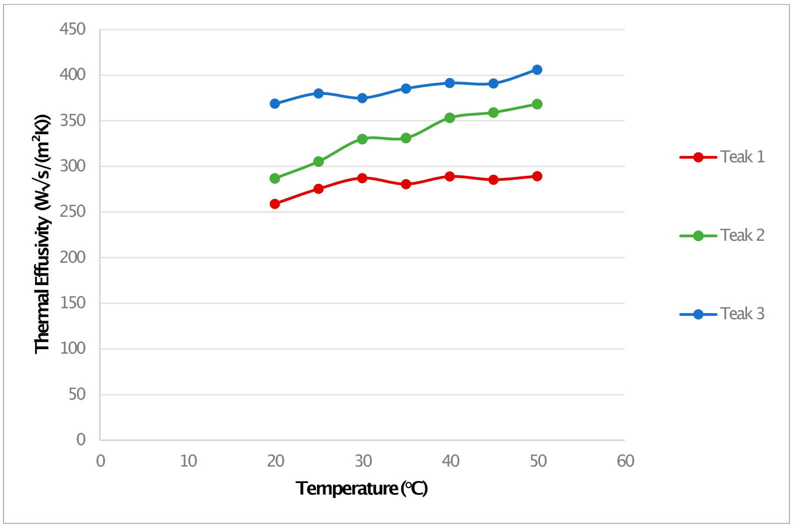

Figure 9. Thermal Effusivity per ASTM 7984 (2s), of the three Teak Samples (TT-001-504to-506), from 20 to 50°C.

Thermal Effusivity with Prolonged Exposure Time (10s) from 20 to 50°C

To demonstrate the cool to touch sensation, with a prolonged exposure time, a test time of 10 seconds was performed at each temperature. Results can be found below.

Table 2. Thermal Effusivity Results with Prolonged Exposure Time (10s) of the six Wood Samples (TT-001-501to -506), from 20 to 50°C.

Sample	Mean Thermal Effusivity ($Ws^{1/2}/(m^2K)$)						
	20°C	25°C	30°C	35°C	40°C	45°C	50°C
LIGNIA Blank	**325.6**	**330.4**	**330.6**	**337.7**	**345.2**	**346.1**	**360.1**
RSD (%)	0.1	0.1	1.3	0.2	0.2	0.1	0.5
LIGNIA 86.15 B24 R21 Set 2	**371.3**	**372.4**	**369.4**	**380.7**	**382.1**	**391.8**	**401.7**
RSD (%)	1.5	1.4	1.2	1.2	1.3	0.7	0.6
LIGNIA B25 R20 SET 88.25	**372.6**	**374.9**	**372.5**	**375.9**	**394.0**	**392.3**	**401.8**
RSD (%)	0.7	1.1	0.9	1.8	1.1	1.6	2.6
Teak 1	**330.3**	**335.5**	**339.4**	**341.3**	**356.4**	**352.7**	**354.7**
RSD (%)	1.0	0.3	1.6	0.4	0.5	0.5	4.3
Teak 2	**334.4**	**346.8**	**355.0**	**366.0**	**367.3**	**362.4**	**375.0**
RSD (%)	0.3	0.2	0.3	0.2	0.1	0.4	0.5
Teak 3	**367.8**	**382.2**	**383.7**	**389.9**	**388.7**	**397.7**	**404.3**
RSD (%)	1.7	0.9	1.8	1.5	1.7	1.2	0.4

Notes: For each sample, five measurements of thermal effusivity were conducted at each temperature - the mean results are reported. Measurements were made using the TPS Single-Sided Standard Analysis Method.TPS sensor #4922 (14.61 mm radius; Kapton insulation), 10 second test times and 0.1 Watts of power were selected for measurement parameters.

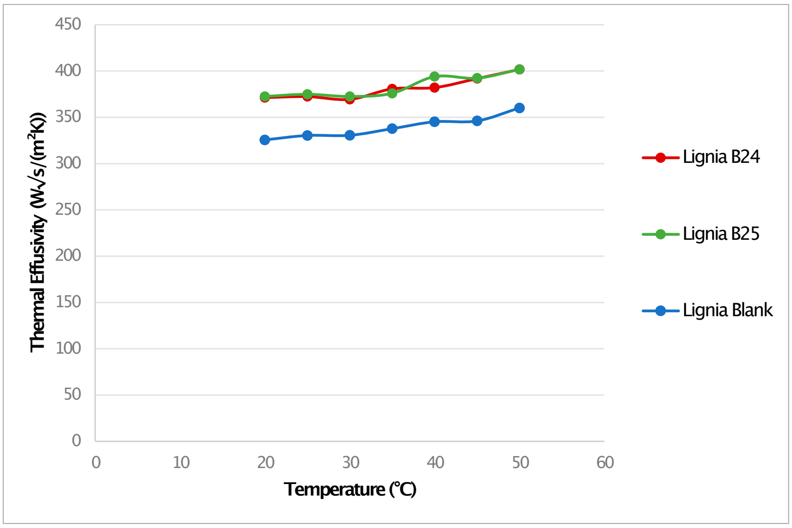

Figure 10. Thermal Effusivity with Prolonged Exposure Time (10s), of the three LIGNIA Samples (TT-001-501 to -503), from 20 to 50°C.

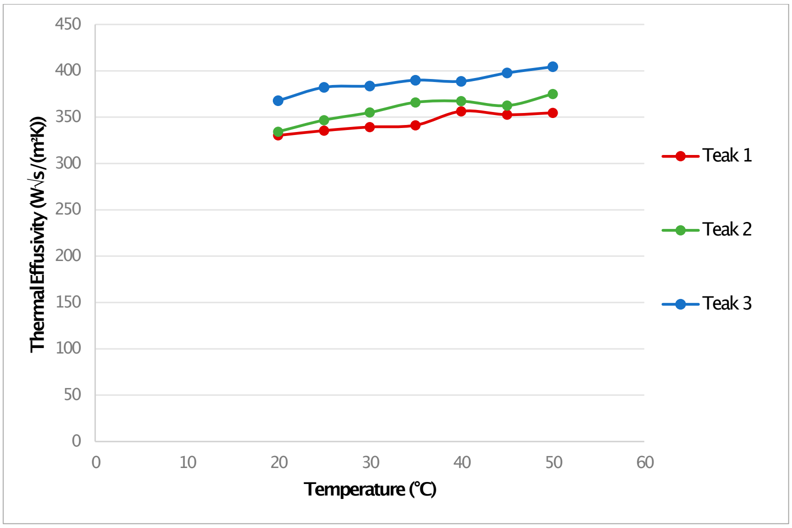

Figure 11. Thermal Effusivity with Prolonged Exposure Time (10s), of the three Teak Samples (TT-001-504 to -506), from 20 to 50°C.

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Thermal Effusivity with Prolonged Exposure Time (40s) from 20 to 50°C

To demonstrate the cool to touch sensation, with a prolonged exposure time, a test time of 40 seconds was performed at each temperature. Results can be found below.

Table 3. Thermal Effusivity Results with Prolonged Exposure Time (40s) of the six Wood Samples (TT-001-501to -506), from 20 to 50°C.

Sample	Mean Thermal Effusivity ($Ws^{1/2}/(m^2K)$)						
	20°C	25°C	30°C	35°C	40°C	45°C	50°C
LIGNIA Blank	**333.0**	**339.9**	**346.5**	**350.2**	**356.2**	**360.3**	**367.2**
RSD (%)	0.1	0.1	0.1	0.1	0.1	0.1	0.1
LIGNIA 86.15 B24 R21 Set 2	**354.5**	**360.7**	**366.2**	**372.0**	**377.6**	**384.3**	**390.1**
RSD (%)	0.3	0.2	0.5	0.3	0.1	0.3	0.5
LIGNIA B25 R20 SET 88.25	**368.1**	**372.6**	**377.4**	**385.9**	**389.9**	**394.8**	**401.7**
RSD (%)	0.3	0.2	0.4	0.1	0.3	0.4	0.3
Teak 1	**342.2**	**348.9**	**352.0**	**357.6**	**362.7**	**368.1**	**374.6**
RSD (%)	0.2	0.1	0.4	0.1	0.3	0.3	0.2
Teak 2	**345.6**	**352.0**	**356.5**	**361.5**	**366.7**	**370.9**	**373.1**
RSD (%)	0.1	0.1	0.4	0.2	0.1	0.3	0.2
Teak 3	**373.5**	**379.0**	**381.5**	**387.4**	**392.5**	**396.8**	**399.9**
RSD (%)	0.1	0.1	0.3	0.1	0.1	0.1	0.3

Notes: For each sample, five measurements of thermal effusivity were conducted at each temperature - the mean results are reported. Measurements were made using the TPS Single-Sided Standard Analysis Method.TPS sensor #4922 (14.61 mm radius; Kapton insulation), 40 second test times and 0.1 Watts of power were selected for measurement parameters.

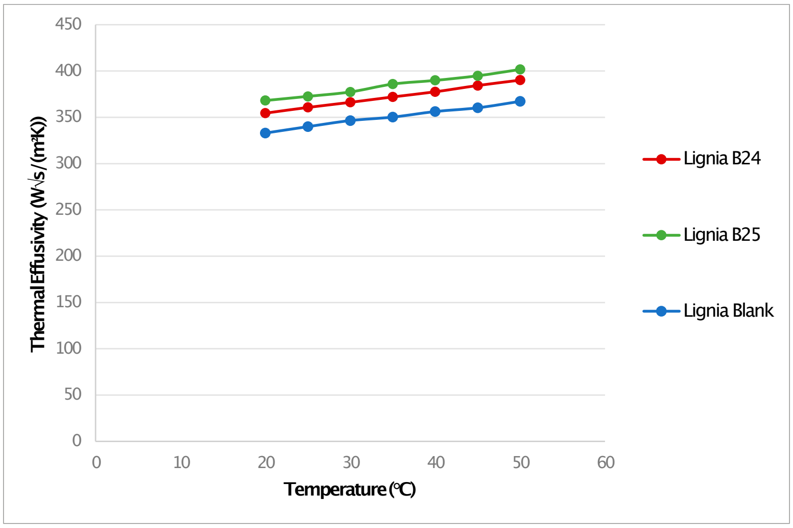

Figure 12. Thermal Effusivity with Prolonged Exposure Time (40s), of the three LIGNIA Samples (TT-001-501 to -503), from 20 to 50°C.

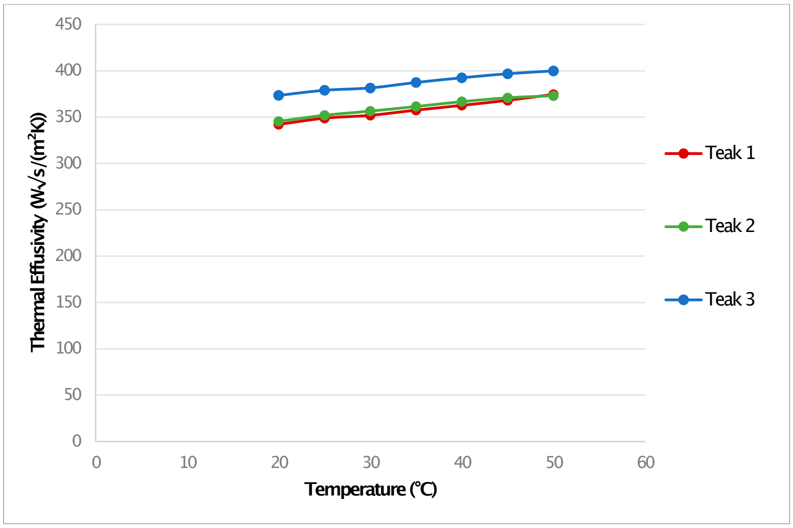

Figure 13. Thermal Effusivity with Prolonged Exposure Time (40s), of the three Teak Samples (TT-001-504 to -506), from 20 to 50°C.

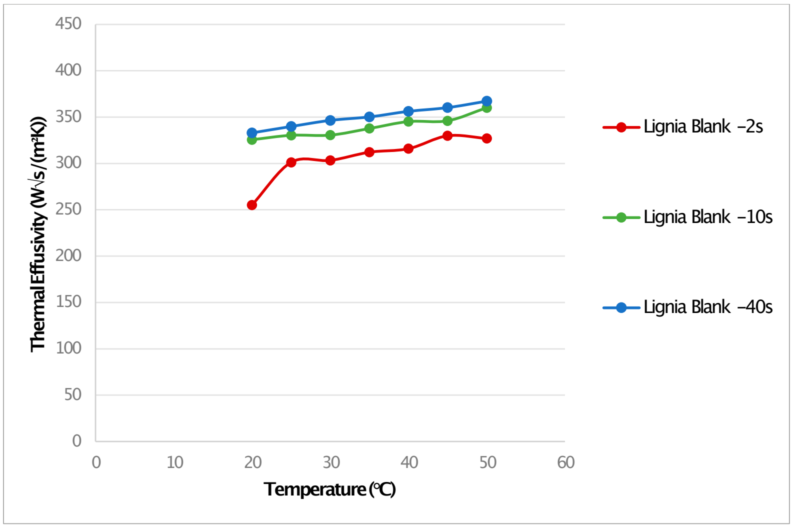

Figure 14. Thermal Effusivity with Exposure Time (2s, 10s and 40s), of the LIGNIA Blank Sample (TT-001-501), from 20 to 50°C.

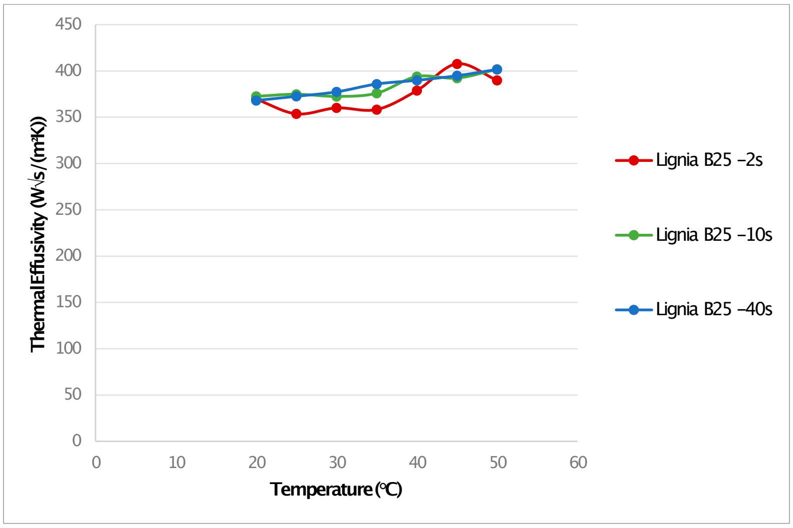

Figure 15. Thermal Effusivity with Exposure Time (2s, 10s and 40s), of the LIGNIA B25 R20 SET 88.25 Sample (TT-001-502), from 20 to 50°C.

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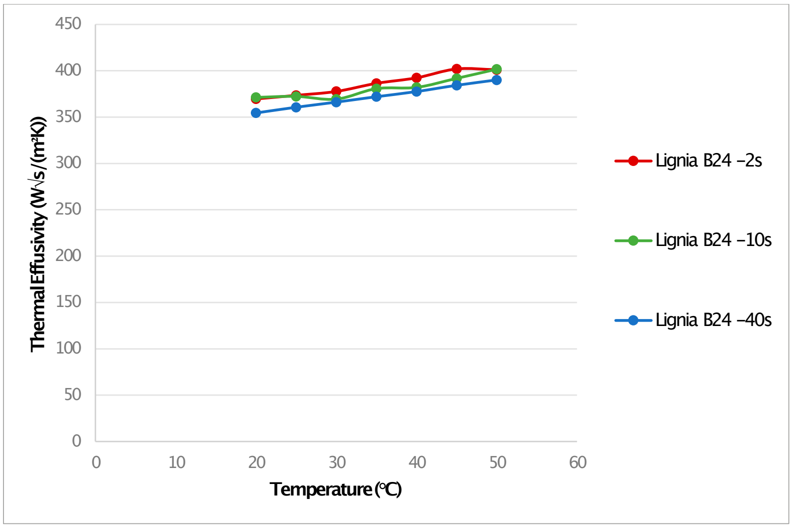


Figure 16. Thermal Effusivity with Exposure Time (2s, 10s and 40s), of the LIGNIA B24 R21 SET 2 Sample (TT-001-503),from 20 to 50°C.

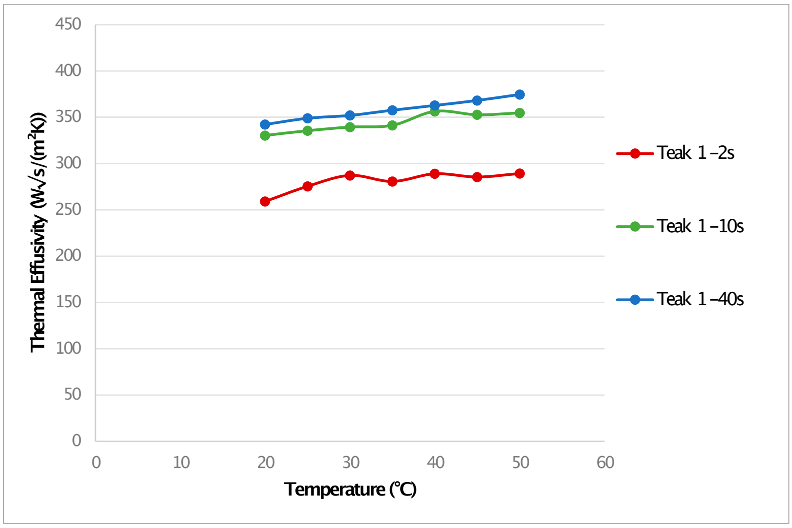


Figure 17. Thermal Effusivity with Exposure Time (2s, 10s and 40s), of the Teak 1 Sample (TT-001-504), from 20 to 50°C.

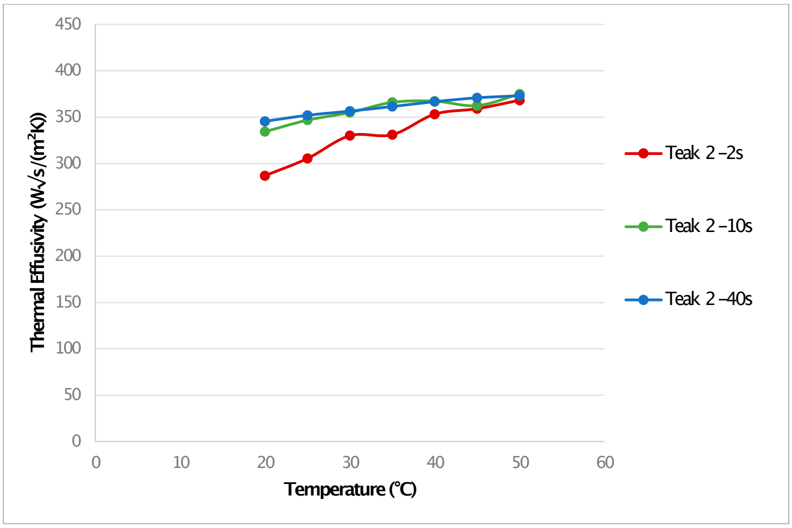


Figure 18. Thermal Effusivity with Exposure Time (2s, 10s and 40s), of the Teak 2 Sample (TT-001-505), from 20 to 50°C.

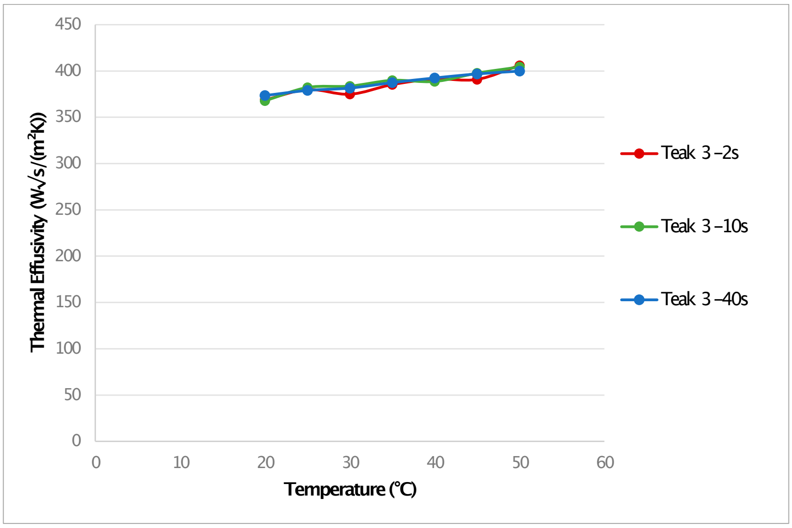


Figure 19. Thermal Effusivity with Exposure Time (2s, 10s and 40s), of the Teak 3 Sample (TT-001-506), from 20 to 50°C.

5. SURFACE BURNING CHARACTERISTICS

SUMMARY AND DOCUMENTARY EVIDENCE

Surface burning test results: ASTM –E 84

Approx. time to ignition (seconds)	Maximum flame front distance	Time to maximum flame front (s)	Flame Spread Index (FSI)	Smoke Developed Index (SDI)
74	(ft): 5.9 (m): 1.80	307	25	110

Summary:

Industry documents such as the International Building Code (IBC) or NFPA 101 Life Safety Code refer to ASTM E 84 (UL 723, NFPA 255) test results using the following material classification categories:

Class	Flame-Spread Index (FSI)	Smoke Development Index (SDI)
Class 1 or Class A	0–25	450 Maximum
Class 2 or Class B	26–75	450 Maximum
Class 3 or Class C	76–200	450 Maximum

LIGNIA falls into the Class 1 or Class A rating.

ASTM E 84 Surface Burning Characteristics of "LIGNIA® Modified Wood (Radiata Pine)"

A Report To:	**Fibre 7 U.K. Limited** Unit 10, Atlantic Trading Estate Barry, Vale of Glamorgan United Kingdom CF63 3RF
Phone:	+44 1446 502957
Attention: E-mail:	Steve Rogers steve.rogers@fibre7.com
Submitted by:	Exova Warringtonfire North America
Report No.	18-002-430(B) 4 Pages
Date:	August 9, 2018

ACCREDITATION To ISO/IEC 17025 for a defined Scope of Testing by the International Accreditation Service

SPECIFICATIONS OF ORDER

Determine the Flame Spread and Smoke Developed Indices based upon a single test conducted in accordance with ASTM E 84-18, as per Exova Warringtonfire North America Quotation No. 18-002-561,263 RV2 dated July 3, 2018.

SAMPLE IDENTIFICATION (Exova sample identification number 18-002-S0430)

Modified wood material described as, "LIGNIA is a densified timber through use with Cascophen P3026 Resin impregnation. Average density is 650 kg/m^3 and moisture content is below 11%", identified as: "LIGNIA® Modified Wood (Radiata Pine)"

TEST PROCEDURE

The method, designated as ASTM E 84-18 "*Standard Method of Test for Surface Burning Characteristics of Building Materials*", is designed to determine the relative surface burning characteristics of materials under specific test conditions, where the material under test is mounted so that it forms the ceiling of a horizontal fire tunnel. A specified airflow is introduced through the tunnel and a specified flame is applied to one end. Observations are then made regarding the rate of flame spread along the specimen. Results are expressed in terms of Flame Spread Index (FSI) and Smoke Developed Index (SDI). There is no established relationship between those two values.

Although the procedure is applicable to materials, products and assemblies used in building construction for development of comparative surface spread of flame data, the test results may not reflect the relative surface burning characteristics of tested materials under all building fire conditions.

SAMPLE PREPARATION

The specimen was supplied in plank sections, each approximately 0.79 inches (20 mm) in thickness by 5.26 inches (134 mm) mm in width. The planks were described as "Tongue and groove v jointed one side siding board". For testing purposes, the planks were constructed into manageable deck sections, using the tongue and groove edges as well as cross battens on the unexposed side. The test specimen consisted of a total of three prepared sections, each approximately 96 inches (2438 mm) in length. The sections were butted together to create the requisite specimen length. Prior to testing, the specimen was conditioned to constant weight at a temperature of 73 ± 5°F (23 ± 3°C) and a relative humidity of 50 ± 5%. During testing the specimen was self-supporting.

The testing was performed on: 2018-08-09

SUMMARY OF TEST PROCEDURE

The tunnel is preheated to 150 ± 5°F (66 ± 2.8°C), as measured by the floor-embedded thermocouple located 23.25 feet (7087 mm) downstream of the burner ports, and is allowed to cool to 105 ± 5°F (40.5 ± 2.8°C), as measured by the floor-embedded thermocouple located 13 feet (3962 mm) from the burners. The tunnel lid is then raised and the test sample is placed along the ledges of the tunnel so as to form a continuous ceiling 24 feet (7315 mm) long, approximately 12 inches (305 mm) above the floor. Three 8 foot (2438 mm) sections of 0.25 inch (6 mm) cement board are then placed on the back side of the sample and the lid is then lowered into place.

SUMMARY OF TEST PROCEDURE (continued)

Upon ignition of the gas burners, the flame spread distance is observed and recorded every second. Flame spread distance versus time is plotted. Calculations ignore all flame front recessions and Flame Spread Index (FSI) is determined by calculating the total area under the curve for the test sample. If the area under the curve (A) is less than or equal to 97.5 min·ft, then FSI = 0.515·A; if greater, FSI = 4900/(195-A). FSI is then rounded to the nearest multiple of 5.
Smoke Developed Index (SDI) is determined by dividing the total area under the obscuration curve by that of red oak, and multiplying by 100. SDI is then rounded to the nearest multiple of 5 if less than 200. SDI values over 200 are rounded to the nearest multiple of 50.

TEST RESULTS

SAMPLE: "LIGNIA® Modified Wood (Radiata Pine)"

Approx. Time to Ignition (s)	Maximum Flame Front Distance	Time to Maximum Flame Front (s)	Flame Spread Index (FSI)	Smoke Developed Index (SDI)
74	(ft.): 5.9 (m): 1.80	307	**25**	**110**

Observations of Burning Characteristics

The specimen ignited approximately 74 seconds after exposure to the test flame.

Interpretation of Test Results

Industry documents such as the International Building Code (IBC) or NFPA 101 Life Safety Code refer to ASTM E 84 (UL 723, NFPA 255) test results using the following material classification categories:

	Flame-Spread Index (FSI)	Smoke Development Index (SDI)
Class 1 or Class A	0 - 25	450 Maximum
Class 2 or Class B	26 - 75	450 Maximum
Class 3 or Class C	76 - 200	450 Maximum

Results Classification (if applicable):	Class 1 or Class A

Francis Williams,
Technician

Ian Smith,
Technical Manager

Note: This report and service are covered under Exova Canada Inc. Standard Terms and Conditions of Contract which may be found on the Exova website (www.exova.com), or by calling 1-866-263-9268.

ASTM E 84-18 Test Charts

Sample: "LIGNIA® Modified Wood (Radiata Pine)"

Chart 1. FLAME SPREAD

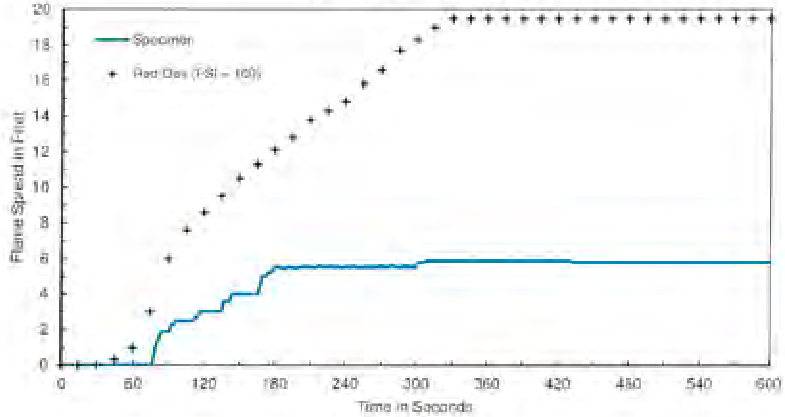
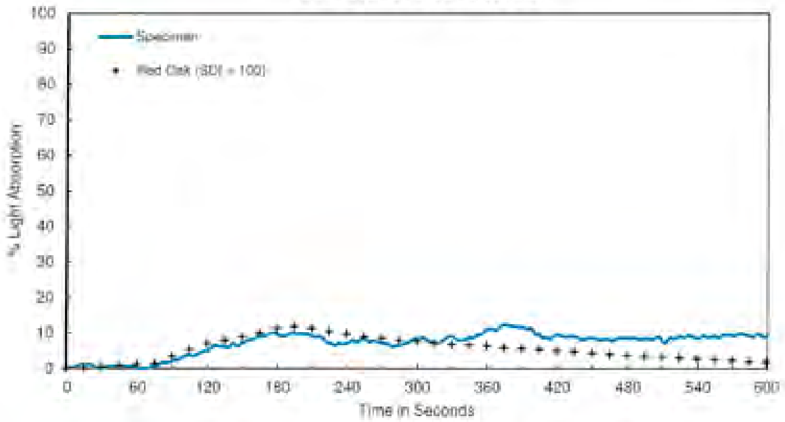


Chart 2. SMOKE DEVELOPED



Calculated Flame Spread (CFS)	Rounded Flame Spread Index (FSI)	Calculated Smoke Developed (CSD)	Rounded Smoke Developed Index (SDI)	Maximum 23' Air Temperature (°F)
23.8	**25**	112.0	**110**	569

6. MOISTURE MOVEMENT PROPERTIES

SUMMARY AND DOCUMENTARY EVIDENCE

Movement classes, conditioning and equilibrium moisture content

The Movement Class for each timber in this publication was assigned by taking the sum of the radial and tangential movements between these humidities. Small movement species are those where the sum of the radial and tangential movements are less than 3%, medium movement species are those where the sum of radial and tangential movements is between 3.0–4.5% and large movement class or more than 4.5%.

Radial and tangential cumulative movement (six samples per board).

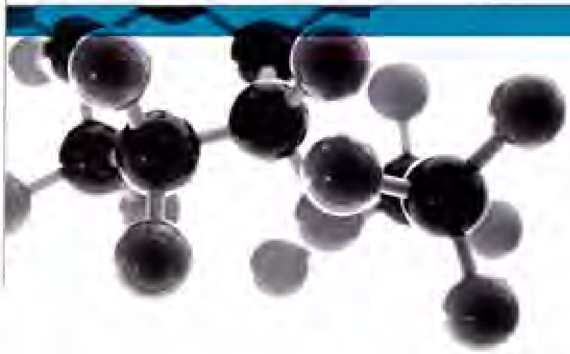
Batch No.	Radial and tangential cumulative movement 94% to 65% RH (%)			
	No. Boards	Average	Minimum	Maximum
Batch 2 (LIGNIA)	6	0.94	0.46	1.38
Batch 4 (LIGNIA)	6	1.66	1.33	2.28
Batch 9 (LIGNIA)	6	1.25	0.49	1.90
Batch 11 (LIGNIA)	6	1.06	0.82	1.44
Radiata pine	5	2.31 (3.2)	1.73	3.31
W red cedar		(1.35)		

Summary:

The moisture movement properties test demonstrate that LIGNIA® falls into the 'small movement' category.

Exova BM TRADA

Determination of the moisture movement properties of four batches of Lignia®, modified radiata pine



A Report To:
Fibre 7 UK Limited
Unit 10 Atlantic Trading Estate
Barry
Wales
CF63 3RF

Document Reference:
TC 17251

Date: 16/01/2018

Copy: 1

Issue No.: 2

Page 1

Exova – the new name for BM TRADA

On December 1st 2015, Chiltern International Fire Ltd and TRADA Technology Ltd (both trading as BM TRADA) commenced trading under the name Exova.

To coincide with this change, our Technical Reports, Test Reports, Product Assessments, company stationery and marketing collateral have been updated to reflect the Exova branding.

The validity of all documents previously issued by Chiltern International Fire Ltd and TRADA Technology Ltd including certificates, test reports and product assessments is unaffected by this change. A letter to this effect is available upon request by e-mailing europe@exova.com

About Exova

Exova is part of the Exova Group one of the world's leading laboratory-based testing groups, trusted by organisations to test and advise on the safety, quality and performance of their products and operations. Headquartered in Edinburgh, UK, Exova operates 143 laboratories and offices in 32 countries and employs around 4,500 people throughout Europe, the Americas, the Middle East and Asia/Asia Pacific. With over 90 years' experience, Exova specialises in testing across a number of key sectors from health sciences to aerospace, transportation, oil and gas, fire and construction.

Be assured that while the name will change, your service provision and primary contacts have not. What will be available to you is a wider team of testing experts and an extended range of testing capabilities.

If you have any questions, please do not hesitate to contact a member of the team and we will do our best to answer them. We appreciate your business to date and we look forward to working with you in the future.

Kind regards

Exova

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Document No.	TC 17251	Page No.	2 of 9
Author	Aron Searle	Issue Date	16/01/2018
Client	Fibre 7 UK Limited	Issue No.	2

Exova
BMTRADA

Contents

1 Introduction

Dr Andy Pitman, Technical Director at Fibre 7 UK Limited, contacted Exova BM TRADA in November 2017 to request testing of modified radiata pine samples to assess the movement properties of the modified wood.

A scope of works and fee proposal with terms and conditions was prepared and issued by Exova BM TRADA. The signed contract, Reference TC 17251, was returned by Dr Pitman on the 27th November 2017.

2 Scope of Work

To carry out testing of modified radiata pine timber samples taken from three production batches (later changed to four), to indicatively assess the movement properties of the modified wood. Testing methods will be based upon the standard method set out in *BRE 1982, Technical Note No. 38, The movement of timbers.*

- The test method requires 50mm long by 6mm thick by 150mm to 225mm wide radial and tangentially machined samples. Sample widths for this test will be determined by the limitations of the available material, in particular, radially sawn samples are likely to be only 20mm to 25mm wide.
- The Client is to supply 6, approximately 1 metre long boards from each of the four different batches for Exova BM TRADA to machine samples from.
- A minimum of three samples from each board will be tested (54 samples).
- A number of unmodified radiata pine (supplied by the Client), and Wester red cedar samples (supplied by Exova BM TRADA) will be used as controls.
- The dimensional change of samples in the radial and tangential direction will be measured between conditioning of the samples at 85% RH to 60%RH at 25°C.
- To carry out oven dry testing to determine the moisture content values attained in each environment.
- To provide a written report summarising our findings.

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3 Limitations

1. The findings of this report are based solely upon the information and evidence provided and made available to Exova BM TRADA by the Client and/or the Client's representative(s) at the time that this report was written. Should subsequent information be made known to us we reserve the right to amend our findings.

2. Any information or evidence provided to Exova BM TRADA for the preparation of this report by the Client or the Client's representative(s), or by any third party, has been taken by us at face value, unless we state specifically that we have validated it and include in this report evidence of such validation.

3. This report cannot be used for any purpose other than that for which it is expressly authorised within the contract under which it has been agreed and produced.

4. All advice offered by Exova BM TRADA is offered on the basis that it represents the principles of good practice and that it has not necessarily been validated by Exova BM TRADA.

5. Statements which appear in this report, which address current or likely future risks, and which project or estimate outcomes, are based on reasonable assumptions from empirical evidence. Such statements by their nature involve uncertainties, which themselves carry the risk that actual outcomes may differ materially from any predicted outcomes. Exova BM TRADA does not guarantee or warrant any projections or estimates of risks or outcomes contained within this report.

6. Any contracted rights to confidentiality will be considered null and void should the report be modified in any way by any party without express permission of Exova BM TRADA.

4 Procedures

4.1 Sampling and referencing

Twenty nine boards nominally 25mm by 140mm by 1000mm were supplied for testing by Fibre 7, and 5 reference boards of Western red cedar were supplied by Exova BM TRADA, as follows:

- Twenty four modified radiata pine boards supplied by the Client from four different batches, with six boards per batch as shown in Table 1 below.
- Five Unmodified radiata pine boards supplied by the Client as control samples from the same source.
- Five radially cut Western red cedar boards supplied by Exova BM TRADA as control samples.

Three radially and three tangentially cut samples were machined from each radiata pine board and three radially cut samples were machined from the Western red cedar boards. Movement characteristics were determined by measuring changes in the width of samples.

Samples were machined from boards so that the growth ring orientation was as close to either true radial or tangential across their width as possible. Samples were machined 50mm long and 5mm to 7mm thick. Pieces were machined so as to maximise their width which resulted in varying widths of samples depending upon the growth ring orientation.

As most of the boards supplied were 'flat sawn' most radially cut pieces were limited in width to between 20mm to 40mm. The control western red cedar samples were cut to be 38mm wide to closely match the size of the test samples.

The modified boards were referenced by the Client as per Table 1 below.

Table 1: Lignia® boards and sample referencing as per Fibre 7.

Batch No	2	4	9	11
Board No.	2.1	4.1	9.22	13.04
	2.17	4.11	9.24	13.05
	2.3	4.12	9.25	13.06
	2.4	4.14	9.27	13.07
	2.6	4.17	9.28	12.15
	2.8	4.7	10.05	12.16

Note: After testing, Exova BM TRADA was informed by the Client that board 10.05 was part of Batch 9, and that boards 13.04 to 13.07 and 12.15 and 12.16 formed Batch 11.

4.2 Measurement methodology

The width of the samples were measured using a steel rig with flat and parallel circular faces on the horizontal fitted with a calibrated digital dial gauge. A vertical steel back plate was fitted to the rig as a fixed reference surface for the insertion of samples between measurements. The steel rig was used in a temperature controlled environment with a set temperature of 20°C, and calibrated prior to taking each set of measurements with calibration gauge blocks. The calibration certificates for the micrometre and for the steel rig are for an accuracy of ±0.01mm.

Prior to full testing of the samples a number of repeatability trails were conducted to determine the margin of error introduced by the manual insertion of samples into the rig. Off-cut wood samples measuring 50mm long by 5-7mm thick by 20mm to 60mm wide were used. Multiple samples were measured, removed, and re-measured in a different order. The repeatability of measurement accuracy attained fell to within ±0.01mm in around 80% of measurements or ±0.02mm for the remaining 20%.

Therefore, based upon the above factors we have assumed a conservative cumulative accuracy of ±0.03mm measurement for these trials.

4.3 Movement classes, conditioning and equilibrium moisture content

The movement classifications given in *Technical Note No. 38* are based upon conditioning from 90% RH and 60% RH at 25°C (i.e. a 30% reduction in humidity).

The *Movement Class* for each timber in this publication was assigned by taking the sum of the radial and tangential movements between these humidities. Small movement species are those where the sum of the radial and tangential movements are less than 3%, medium movement species are those where the sum of radial and tangential movements is between 3.0-4.5% and large movement class or more than 4.5%.

These exact conditions were not matched but test conditions achieved a comparable fall in humidity at temperature ranges close to those set out above.

All specimens were first conditioned at 94% relative humidity (RH) and 25°C and weighed until a consistent mass was achieved, demonstrating they had reached equilibrium with the ambient conditions. Radial and tangential dimensions were then measured.

All samples were then conditioned at 65% RH and 20°C to constant mass and their radial and tangential dimensions re-measured.

The radial and tangential shrinkages were determined for each block as percentages of their dimensional changes from 94% RH down to 65% RH at (i.e. a 29% fall in humidity) based on their dimension at 65% RH.

The equilibrium moisture content of samples at 94% RH and 65% RH were determined using the oven dry method.

5 Findings and discussion

Tables 2 to 5 below provide a summary of the movement results. Tables 6 and 7 in the appendix provide the full data of the testing.

Table 2: Summary of moisture contents

Batch No.	Moisture content at 94% RH	Moisture content at 65% RH
Batch 2	12	9
Batch 4	12	9
Batch 9	12	9
Batch 11	11	9
Radiata pine	17	13

Whilst the movement Results returned for the Western red cedar were comparable to *Technical Note No. 38*, the radiata pine control samples had a cumulative movement value of >38% less than the published data. This may be due to variability in the radiata pine and the statistically small number of samples. However, even if the modified wood sample values are increased by 38% then the movement values would still remain below the threshold required for a 'small movement' classification.

Note: In the below tables the shrinkage values given in *Technical Note No. 38* for radiata pine and Western red cedar from conditioning at 90% RH to 60% RH at 25°C have been shown in brackets for comparative purposes.

Table 3: Radial and tangential cumulative movement (six samples per board)

	Radial and tangential Cumulative movement 94% to 65% RH (%)			
Batch No.	**No. Boards**	**Average**	**Minimum**	**Maximum**
Batch 2	6	0.94	0.46	1.38
Batch 4	6	1.66	1.33	2.28
Batch 9	6	1.25	0.49	1.90
Batch 11	6	1.06	0.82	1.44
Radiata pine	5	2.31 *(3.2)*	1.73	3.31
W red cedar		*(1.35)*		

Table 4: Radial movement (three samples per board)

	Radial movement 94% to 65% RH (%)			
Batch No.	**No. Boards**	**Average**	**Minimum**	**Maximum**
Batch 2	6	0.50	0.24	0.82
Batch 4	6	0.65	0.43	0.92
Batch 9	6	0.64	0.41	1.38
Batch 11	6	0.51	0.24	0.67
Radiata pine	5	0.82 *(1.2)*	0.62	0.94
W red cedar	6	0.49 *(0.45)*	0.39	0.66

Table 5: Tangential movement (three samples per board)

	Tangential movement 94% to 65% RH (%)			
Batch No.	**No. Boards**	**Average**	**Minimum**	**Maximum**
Batch 2	6	0.46	0.30	0.60
Batch 4	6	1.01	0.77	1.67
Batch 9	6	0.69	0.49	1.09
Batch 11	6	0.55	0.32	0.81
Radiata pine	5	1.49 *(2.0)*	0.84	2.57
W red cedar		*(0.95)*		

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6 Conclusions

Exova BM TRADA conclude the following:

i) The humidity range used for these tests differed slightly from *Technical Note No. 38* but a comparable fall in humidity at a comparable temperature was achieved.

ii) The equilibrium moisture content of the modified wood samples was lower than the unmodified radiata pine indicating a reduction in atmospheric moisture absorption of the modified wood. Whether the wood has an improved resistance to liquid moisture has not been tested as part of this works.

iii) The modified wood samples all returned a cumulative movement value significantly lower than the unmodified radiata pine and three of four batches returned a value lower than that of Western red cedar, a well recognised and used small movement timber.

iv) *Technical Note No. 38* sets out that 'Not less than six, *and generally considerably more*, quarter-sawn and plain-sawn representative samples of good quality material are employed' (i.e. at least 12 separate pieces). It also sets out that samples should be cut to a width of between 150 to 225mm.

v) *Technical Note No. 38* does not state if the samples should be from separate boards and whether these boards should also be from separate trees. However, given that the properties of any timber species are known to vary both between individual trees and between the same species of timber grown in different geographic locations, we would consider it appropriate to assume that the samples should be taken from a number of boards from a number of different batches of timber.

vi) Given that the number of boards provided from each batch was low, and the size of the samples which could be machined from the boards provided was small, the actual test results should be considered as indicative only.

vii) However, whilst the precise movement properties of a modified wood cannot be determined with great confidence by such small scale testing of small samples the results do show that the modified wood would be classed as 'small movement'.

7 Authorisation

	Issued by:	**Under the authority of:**
Signature:	Searle	
Name:	Aron Searle	Philip O Leary
Title:	**Technical Officer**	**Section Leader, Timber Technology Investigations**

Appendix

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Measurements

Document No.:	TC 17251		
Author:	Aron Searle	Issue Date:	15/01/2018
Client:	Fibro 7 UK Limited	Issue No.:	2

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Table 6: Radial measurements

Sample No.	94% RH Weight (g)	94% RH Moisture %	94% RH Width mm	65% RH Weight (g)	65% RH Moisture %	65% RH Width mm	Shrinkage %
2.17A	5.94	12	30.05	5.77	10	29.92	0.43
2.17B	7.68	12	30.72	7.48	9	30.56	0.52
2.17C	7.48	12	31.05	7.29	10	30.89	0.52
2.1A	5.63	13	29.44	5.47	10	29.2	0.82
2.1B	5.24	13	28.69	5.08	10	28.47	0.77
2.1C	4.84	13	28.65	4.68	10	28.46	0.67
2.3A	3.64	12	18.76	3.55	9	18.68	0.43
2.3B	3.73	12	18.81	3.63	9	18.74	0.37
2.3C	3.76	11	18.83	3.69	10	18.76	0.37
2.4A	4.49	11	24.61	4.42	9	24.55	0.24
2.4B	6.12	11	24.84	6.01	9	24.65	0.77
2.4C	5.62	11	24.53	5.52	9	24.44	0.37
2.6A	invalid test/sample						
2.6B	6.24	11	25.09	6.1	9	24.98	0.44
2.6C	5.82	11	24.98	5.69	9	24.87	0.44
2.8A	8.21	11	32.1	8.02	9	31.95	0.47
2.8B	8.13	11	32.29	7.96	9	32.15	0.44
2.8C	7.4	11	30.74	7.26	10	30.62	0.39
4.10A	8.64	12	31.9	8.39	10	31.61	0.92
4.10B	10.01	12	31.79	9.76	10	31.6	0.60
4.10C	9.11	12	32.34	8.91	10	32.19	0.47
4.11A	9.57	12	34.55	9.29	10	34.29	0.76
4.11B	9.02	12	34.06	8.79	10	33.82	0.71
4.11C	8.92	12	34.43	8.66	10	34.22	0.61
4.12A	4.34	12	25.34	4.23	10	25.14	0.80
4.12B	5.68	12	25.25	5.53	10	25.09	0.64
4.12C	5.5	12	25.13	5.33	9	24.96	0.68
4.14A	9.66	12	36.22	9.37	10	35.96	0.72
4.14B	9.87	12	35.63	9.57	10	35.34	0.82
4.14C	9.51	12	35.95	9.23	9	35.71	0.67
4.17A	5.11	12	25.4	4.96	9	25.29	0.43
4.17B	5.22	12	25.39	5.07	9	25.27	0.47
4.17C	5.6	12	25.27	5.43	9	25.15	0.48
4.7A	6.08	12	30.58	5.92	10	30.38	0.66
4.7B	6.66	12	30.03	6.48	9	29.87	0.54
4.7C	6.35	12	30.8	6.18	10	30.59	0.69
9.22A	5.04	13	29.55	4.9	10	29.42	0.44
9.22B	6.61	12	30.26	6.45	10	30.09	0.56
9.22C	6.45	12	30.29	6.29	10	30.16	0.43

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Sample No	84% RH Weight (g)	Moisture %	Width mm	65% RH Weight (g)	Moisture %	Width mm	Shrinkage %
9.24A	6.14	12	24.81	5.99	10	24.64	0.69
9.24B	5.66	11	23.59	5.5	9	23.4	0.81
9.24C	6.32	12	24.96	6.15	9	24.77	0.77
9.25A	4.8	12	19.77	4.66	10	19.5	1.38
9.25B	4.61	12	19.12	4.48	9	18.94	0.95
9.25C	4.91	12	20.13	4.77	9	19.97	0.80
9.27A	5.73	12	25	5.58	9	24.89	0.44
9.27B	6.32	12	25.13	6.16	9	25	0.52
9.27C	6.02	12	24.99	5.87	10	24.86	0.52
9.28A	10.11	11	32.85	9.89	9	32.68	0.52
9.28B	9.75	11	32.82	9.51	9	32.58	0.74
9.28C	10.12	11	32.82	9.9	9	32.66	0.49
13.04A	9.04	12	34.65	8.81	9	34.47	0.52
13.04B	8.2	11	33.88	8.01	9	33.67	0.62
13.04C	9.17	11	34.89	8.95	9	34.69	0.58
13.05A	8.95	11	35.5	8.73	9	35.33	0.48
13.05B	8.89	11	34.4	8.69	9	34.23	0.50
13.05C	7.6	11	32	7.44	9	31.87	0.41
13.06A	21.75	11	60.34	21.18	9	59.94	0.67
13.06B	21.3	11	60.29	20.81	9	59.91	0.63
13.06C	21.94	11	60.81	21.39	9	60.43	0.63
13.07A	25.51	11	69.45	24.92	9	69.05	0.58
13.07B	25.17	11	69.36	24.53	9	68.97	0.57
13.07C	24.71	11	69.2	24.11	9	68.85	0.51
12.15A	7.51	11	31.21	7.36	10	31.05	0.52
12.15B	5.4	13	29.58	5.25	10	29.45	0.44
12.15C	5.68	12	29.66	5.54	10	29.58	0.27
12.16A	invalid test/sample						
12.16B	5.07	12	25.12	4.9	9	25.06	0.24
12.16C	4.56	11	25.17	4.48	10	25.04	0.52
10.05A	6.18	11	24.27	6.05	10	24.17	0.41
10.05B	6.02	11	24.05	5.9	9	23.94	0.46
10.05C	5.23	11	24.3	5.13	10	24.18	0.50
Radiata 1A	14.92	17	60.2	14.09	13	59.65	0.92
Radiata 1B	13.42	16	60.21	12.84	13	59.71	0.84
Radiata 1C	15.22	17	60.17	14.46	13	59.68	0.82
Radiata 2A	4.65	17	24.74	4.45	13	24.53	0.86
Radiata 2B	4.87	17	25.06	4.65	13	24.84	0.89
Radiata 2C	4.16	17	24.54	3.99	14	24.39	0.62
Radiata 3A	4.7	17	24.6	4.47	13	24.37	0.94

Sample No.	84% RH Weight (g)	Moisture %	Width mm	65% RH Weight (g)	Moisture %	Width mm	Shrinkage %
Radiata 3B	3.28	17	24.21	3.14	14	24.04	0.71
Radiata 3C	4.3	16	24.52	4.14	13	24.35	0.70
Radiata 4A	19.05	17	71.28	18.11	13	70.63	0.92
Radiata 4B	20.53	17	71.22	19.62	13	70.61	0.86
Radiata 4C	19.44	17	70.25	18.51	13	69.63	0.89
Radiata 5A	3.16	17	24.1	3.04	13	23.91	0.79
Radiata 5B	2.98	17	24.27	2.87	14	24.09	0.75
Radiata 5C	4.35	17	24.56	4.17	13	24.38	0.74
Cedar 11A	5.29	16	38.36	5.08	12	38.18	0.47
Cedar 11B	5.19	15	38.54	4.98	11	38.39	0.39
Cedar 11C	5.31	16	38.44	5.07	12	38.26	0.47
Cedar 1A	6.13	14	38.44	5.87	10	38.24	0.52
Cedar 1B	6.76	14	38.21	6.48	10	38.03	0.47
Cedar 1C	6.78	14	38.54	6.52	11	38.37	0.44
Cedar 3A	6.78	17	38.4	6.48	13	38.15	0.66
Cedar 3B	6.99	16	38.64	6.73	13	38.43	0.55
Cedar 3C	7.02	17	38.53	6.74	13	38.31	0.57
Cedar 4A	5.63	16	38.25	5.39	12	38.06	0.50
Cedar 4B	5.78	16	38.26	5.54	13	38.05	0.55
Cedar 4C	5.88	16	38.61	5.64	12	38.39	0.57
Cedar 5A	6.44	16	38.2	6.16	13	38.04	0.42
Cedar 5B	6.46	16	38.26	6.2	13	38.1	0.42
Cedar 5C	6.43	16	38.43	6.19	12	38.28	0.39

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Table 7: Tangential measurements

Sample No.	94% RH			65% Rh			
	Weight (g)	Moisture %	Width mm	Weight (g)	Moisture %	Width mm	Shrinkage %
2.17A	21.73	11	78.17	21.25	9	77.81	0.46
2.17B	21.26	11	78.52	20.77	9	78.14	0.49
2.17C	23.07	12	78.52	22.17	9	78.12	0.51
2.1A	16.05	11	60.5	15.7	9	60.25	0.41
2.1B	18.85	11	60.21	18.44	9	60.03	0.30
2.1C	17.45	11	61.55	17.11	9	61.27	0.46
2.3A	31.57	12	97.08	30.49	9	96.62	0.48
2.3B	36.32	14	98.08	34.04	9	97.64	0.45
2.3C	29.94	10	98.48	29.35	9	97.99	0.50
2.4A	27.43	13	95.56	26.11	8	95.08	0.50
2.4B	26.13	11	94.84	25.57	9	94.27	0.60
2.4C	26.12	11	95.13	25.54	9	94.67	0.49
2.6A	28.41	15	92.6	26.55	9	92.18	0.46
2.6B	31.08	12	91.89	29.89	9	91.43	0.50
2.6C	28.69	14	92.84	27.06	9	92.49	0.38
2.8A	27.64	10	88.22	27.08	9	87.85	0.42
2.8B	29.04	11	88.91	28.44	9	88.53	0.43
2.8C	26.95	12	88.29	25.89	9	87.84	0.51
4.10A	24.97	12	83.96	24.24	9	83.31	0.78
4.10B	28.68	12	84.99	26.65	6	83.59	1.67
4.10C	24.21	12	83.39	23.54	10	82.43	1.16
4.11A	21.24	11	71.23	20.72	9	70.56	0.95
4.11B	23.29	11	72.86	22.75	9	72.3	0.77
4.11C	22.87	12	73.35	22.34	9	72.74	0.84
4.12A	29.68	12	93.57	28.74	9	92.62	1.03
4.12B	29.56	13	93.73	28.37	9	92.72	1.09
4.12C	29.46	12	93.79	28.59	9	92.87	0.99
4.14A	23.39	12	77.43	22.72	9	76.59	1.10
4.14B	23.74	12	77.07	23.09	9	76.3	1.01
4.14C	23.42	12	75.76	22.76	10	75.04	0.96
4.17A	42.12	12	147.13	40.9	9	145.82	0.90
4.17B	43.12	12	147.9	41.92	9	146.63	0.87
4.17C	45.07	16	147.7	41.6	9	146.24	1.00
4.7A	22.67	12	77.42	21.98	9	76.63	1.03
4.7B	24.28	15	77.64	22.85	9	76.84	1.04
4.7C	26.2	16	77.57	24.25	9	76.75	1.07
9.22A	30.4	11	94.89	29.73	9	94.32	0.60
9.22B	29.56	12	96.12	28.87	10	95.64	0.50
9.22C	31.21	16	95.08	30.48	14	94.55	0.56

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Sample No.	94% RH Weight (g)	Moisture %	Width mm	65% RH Weight (g)	Moisture %	Width mm	Shrinkage %
9.24A	29.13	11	89.98	28.44	9	89.17	0.91
9.24B	32.05	14	90.17	30.39	9	89.2	1.09
9.24C	30.09	11	90.79	29.34	9	90.01	0.87
9.25A	invalid test/sample						
9.25B	31.22	14	98.9	29.32	9	98.28	0.63
9.25C	29.36	13	97.98	27.95	9	97.32	0.68
9.27A	25.28	11	92.88	24.66	9	92.28	0.65
9.27B	26.36	11	93.26	25.71	9	92.65	0.66
9.27C	25.71	11	92.81	25.11	9	92.16	0.71
9.28A	28.92	11	91.73	28.29	9	91.17	0.61
9.28B	26.75	11	91.67	26.24	9	91.22	0.49
9.28C	invalid test/sample						
13.04A	19.09	10	67.77	18.76	9	67.48	0.43
13.04B	17.86	10	67.69	17.56	9	67.43	0.39
13.04C	20.63	10	67.99	20.28	9	67.77	0.32
13.05A	25.91	11	89.53	25.39	9	89.18	0.39
13.05B	27.11	11	90.9	26.36	8	90.4	0.55
13.05C	29.63	11	91.89	28.99	9	91.32	0.62
13.06A	26.84	11	83.45	26.26	9	82.85	0.72
13.06B	26.21	11	83.86	25.56	9	83.19	0.81
13.06C	26.92	11	84.06	26.36	9	83.54	0.62
13.07A	22.71	11	75.03	22.23	9	74.72	0.41
13.07B	23.96	13	75.53	22.85	9	74.97	0.75
13.07C	21.92	11	74.96	21.46	9	74.49	0.63
12.15A	29.97	13	96.98	28.58	9	96.49	0.51
12.15B	27.81	11	96.82	27.25	10	96.33	0.51
12.15C	28.3	11	96.67	27.8	9	96.14	0.55
12.16A	31.59	12	94.07	30.37	9	93.45	0.66
12.16B	35.22	11	93.13	34.44	9	92.54	0.64
12.16C	33.73	11	92.36	33.05	9	91.96	0.43
10.05A	55.18	12	144.72	51.1	5	143.71	0.70
10.05B	57.35	12	143.03	50.83	0	142.1	0.65
10.05C	53.18	13	141.85	50.83	9	140.84	0.72
Radiata 1A	22.89	17	97.51	21.89	13	96.52	1.03
Radiata 1B	22.21	17	97.98	21.09	13	96.72	1.30
Radiata 1C	20.31	18	98.35	19.24	13	97.15	1.24
Radiata 2A	15.42	17	74.18	14.72	14	73.25	1.27
Radiata 2B	15.63	17	73.83	14.91	13	73.07	1.04
Radiata 2C	13.91	18	72.91	13.19	13	72.04	1.21
Radiata 3A	19.7	18	96.16	18.65	13	94.47	1.79

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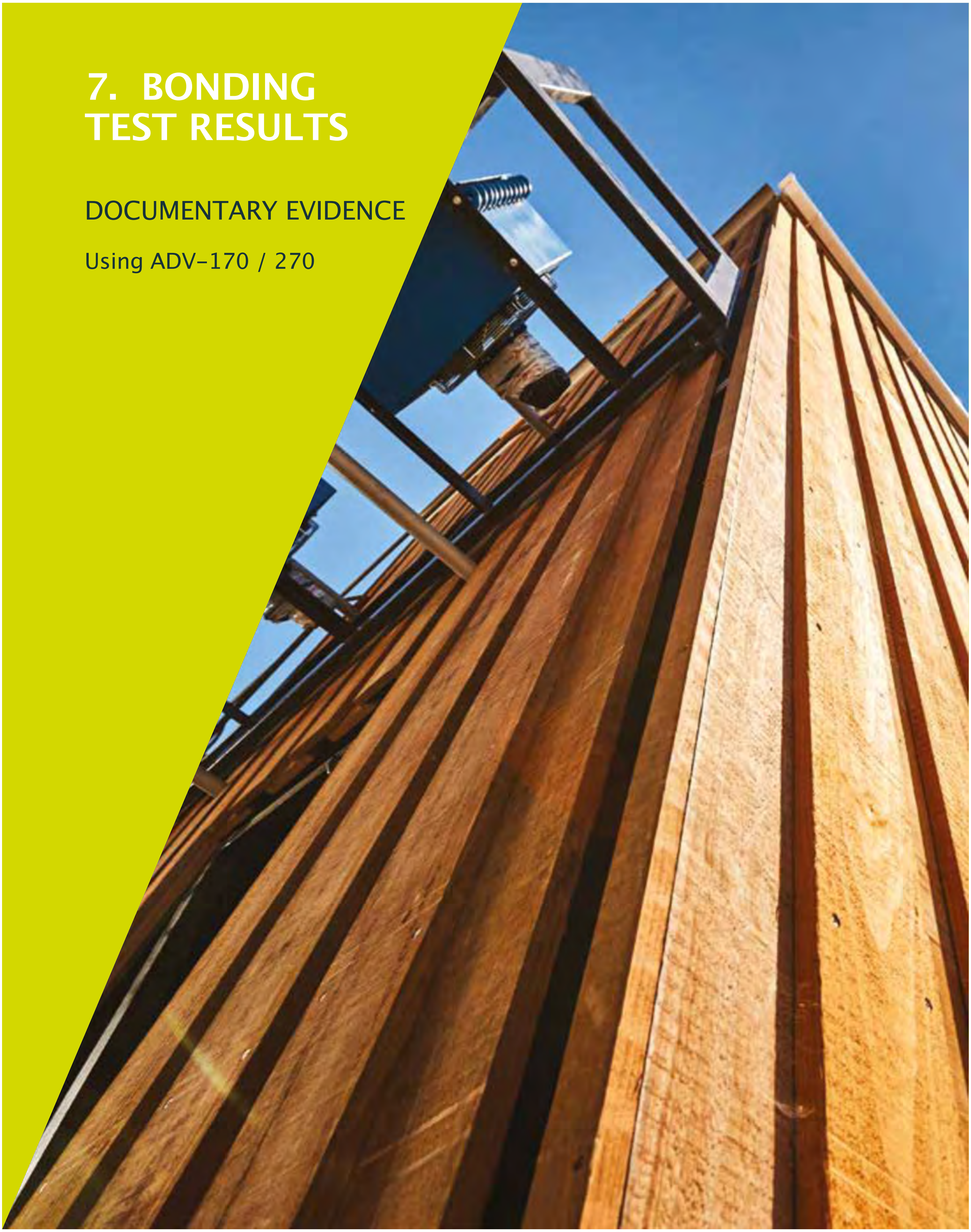
Sample No.	94% RH Weight (g)	Moisture %	Width mm	65% Rh Weight (g)	Moisture %	Width mm	Shrinkage %
Radiata 3B	20.25	18	95.95	19.17	13	94.27	1.78
Radiata 3C	23.21	17	95.15	22.02	13	93.76	1.48
Radiata 4A	20.97	17	97.27	20.04	13	96.29	1.02
Radiata 4B	21.3	17	98.22	20.28	13	97.13	1.12
Radiata 4C	23.46	17	98.13	22.42	13	97.31	0.84
Radiata 5A	15.63	18	87.31	14.84	13	85.33	2.32
Radiata 5B	14.82	17	87.56	14.11	13	85.5	2.41
Radiata 5C	14.99	17	87.4	14.24	13	85.21	2.57

7. BONDING TEST RESULTS

DOCUMENTARY EVIDENCE

Using ADV-170 / 270



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4 March 2019

Please find below pull-off adhesion test results using ADV-170/270 on Lignia Yacht Decking manufactured by D.A Watts.

	Pull-off Adhesion (MPa)	
	Wood face	Laminate face
1	2.93	5.74
2	4.31	5.36
3	4.81	5.46
4	3.80	5.31
5	4.37	4.98
6	3.45	5.66
7	3.63	5.94
8	4.86	6.71
Min	2.93	4.98
Max	4.86	6.71
□	1.93	1.73
Average	4.02	5.65
Median	4.06	5.56
□	0.64	0.49

Both faces of the sample was tested, the plain untreated wood and the laminated face.

We have tested teak decking manufactured in a similar fashion and seen typical adhesion figures in the range of 4 – 8 MPa.

I also attach two images which show the failure observed in each case.

For the wood face –100% cohesive failure of the wood throughout.

For the laminate face – 100 % laminating adhesive failure throughout. Worth noting however than upon failure the studs remained firmly attached to the underlying glass cloth and not inconsiderable force was required to detach them.

The images illustrate a clear failure of wood fibre against the A face of the deck and the laminate failing against the wood in an area surrounding the bonded stud on the B face (laminate face).

We would expect such a bond to indicate wood fibre as the weakest component of the joint.

8. LIGNIA MODIFIED PINE MAINTENANCE ADVICE

PRODUCT CHARACTERISTICS

LIGNIA Yacht has a density similar to Burmese Teak, and the surface has a similar wear resistance (see third party test results). It is harder due to the modification process (JANKA test 5.7 Kn), which results in the product's grain structure remaining flat during exposure to UV, water, salt and wind.

Over a five-year test period in the USA, it has been proven that eco-friendly acid-free cleaners that are designed to be thorough, yet gentle work best on LIGNIA. DO NOT USE CHLORINE BLEACH in an attempt to bleach the decks. Chlorine will attack most caulking products, breaking them down.

The LIGNIA deck can be scrubbed across or along the grain with a 3M scotchbrite scrubbing pad or a polypropylene bristle brush. With Teak decks traditionally scrubbing with the grain tears the soft grain out of the planks, leaving the surface rough. However, with a LIGNIA deck you do not get grain tear because the surface is harder. A rough, weathered deck exposes more of the wood to environmental deterioration. On larger areas, use of rotary cleaning machines with dispenser tanks and polypropylene bristle brushes is appropriate.

Even with care, in time the surface of LIGNIA may become uneven and the colour will change from a golden brown to a sliver grey due to the effects of UV, wind, rain and sea water. The product may exhibit signs of fine surface checking, similar to Burmese Teak, when this happens, the decks should be lightly sanded with a sanding machine to smooth the surface and remove the surface checks. This will increase the life of the deck by exposing less wood to the elements and preventing the grain from trapping dirt or air carried corrosives.

LIGNIA has been proven to provide a longer period between maintenance than Burmese Teak, on average twice as long, before remedial sanding is required.