timbaigl optics

Observation and Microscopy of New and Weathered Innowood

by

Dr Tim Dabbs

5th April, 2018

Signed ______________________________

EXECUTIVE SUMMARY

The durability of Innowood composite timber was evaluated by inspecting 11 and 12 year old installations at Darling Harbour. In addition, new, 3, 6 and 12 year old weathered samples provided by Innowood were appraised for colour and hardness changes and examined microscopically on their exposed and unexposed surfaces.

The weathered material was found to be in good condition with only minor cosmetic colour changes and surface degradation due to exposure in a temperate environment very close to salt water. Specifically, Innowood was considered appropriate for use as cladding, louvres, decking and screening in that environment. It was confirmed that the material did not appear to corrode, rot or split, seemed resistant to mould, moss and other biological growth and did not facilitate what was assumed to be attack by ants.

Based on these results, Innowood was predicted to remain sound for at least 15 years of exposure to the elements in a temperate coastal environment.

Timbaigl Optics Pty Ltd:
Director Research and Development - Early-stage project management and optical, μ-optical and fibre optic research and development. Consulting in IP management and development of DWDM devices.

Experience and Qualifications:

- Electronic Images - Managing Director -Yachting video production & sales company.
- Nortel Networks (Photonics) - Research and Development Manager - Research, development and technology transfer for the manufacture of μ-optic fibre components for telecommunications.
- James Hardie - Durability Research Manager. Led durability team - durability is James Hardie's competitive advantage. Participated in a range of cross-functional fibre cement product developments. Negotiation and collaboration with businesses, universities and statutory bodies in Australia, NZ, Japan and USA.
- CSIRO - Principal Research Scientist - Laserscan wool fibre diameter measurement - Invention, R&D, tech. transfer and IP protection. Assisted with standards, worldwide introduction and customer feedback. More than 120 instruments sold ($12M) but real value is implementation of dependable, commercially attractive, objective measurement system for pricing Australian wool Fibre optic confocal microscope ideas and development, which resulted in formation of Optiscan Pty Ltd and HBH Technological Industries Led development of astigmatic confocal microscope industrial distance measurement system
- Australian Optical Fibre Research (now part of ADC) - Research Engineer. Assisted with development of optical fibre couplers, now the mainstay of their operation.

Qualifications
PhD (Applied Physics - Strength of Optical Fibres) University of NSW 1986BSc (Hons 1st class) University of NSW 1980

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INDEX

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1. INTRODUCTION

Innowood is a composite timber building material fabricated by extrusion of granulated, powdered, recycled wood fibre (52.5%) bound together with polyvinyl chloride resin (38.2%) and coloured using calcium carbonate (5.8%) and pigments (2.5%). The product is used as internal and external cladding, louvres, decking and screening in residential and commercial buildings. All products have the same composition, do not corrode and are claimed to be highly resistant to rot, splitting and termite attack.

Innowood was first installed in 2006 on the outside of the Wild Life Sydney Zoo and then on buildings and features on Pyrmont Wharves 8 and 9 in 2007, both at Darling Harbour, Sydney. Therefore, inspection of samples that have been exposed for up to 12 years was feasible.

For this study, Timbaigl Optics Pty Ltd was asked to determine whether there was any visible deterioration of Innowood Composite Timber due to weathering and, from this evidence, predict whether significant deterioration in performance would be expected for products exposed to the elements for at least15 years.

Accordingly, Timbaigl Optics carefully inspected and photographed the Darling Harbour installations and took detailed photos and micrographs and qualitatively checked the hardness of new, aged and weathered samples of composite timber provided by Innowood. In this report these observations are described and used to evaluate the performance to date and predict the 15 year durability of Innowood.

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2. METHODOLOGY

A) Sample Descriptions

6 samples of new and weathered Innowood Composite Timber were provided by Innowood:

A. New, unexposed Innowood, shipped (and fabricated) in late 2017. It had been clear coated all over and textured on its display face. Its original colour was 'Tasmanian Oak'.
B. An un-weathered set of Standard Colour panels from the Innovative and Premium Texture Ranges, which are of indeterminate age. They had been clear coated on both sides and a wood-grain texture had been stamped on the display face of the Innovative Texture Range samples.
C. Weathered material installed on 02/11/2015 (2.5 years old). It was initially clear coated and half of the front face had been exposed to the sun and elements while the other half was covered. When new it was 'Golden Oak' in colour.
D. Weathered sample installed in 2012 (6 years old). Application of additional stained coating had occurred at an unknown time on the exposed faces. It was thought to originally be close to 'Tasmanian Oak' in colour.
E. Weathered sample taken from the Wild Life Sydney Zoo installed in 2006 (12 years old), and therefore it had been subjected to salt spray as well as sun, wind and rain. It was uncoated and both the exposed and protected side could be studied. It was believed to have been originally close in colour to 'Weathered Wood' (although the 'Weathered Wood' panel it could be compared with had been clear coated).
F. Weathered sample exposed to the elements since 2006 (approximately 12 years old). It was thought to have been uncoated, and the exposed face had been sanded shortly before this study. The unexposed face was corrugated (5mm period and 2mm depth) and it's colour was not similar to any of the colour display panels.

B) Site Inspections

1) The 2006 (12 years old) façade and exterior ceiling covering on the Wild Life Sydney Zoo at Darling Harbour were inspected using the naked eye and binoculars, photographed and hardness tested where possible by checking indentation depth and material removal (see section 2C.3).

2) The 2007 (11 years old) planter surrounds, wall feature and slatted covering on the lower portion of the building walls at Pyrmont Wharves 8 and 9 at Darling Harbour were inspected using the naked eye, photographed and hardness tested where possible by checking indentation depth and material removal (see section 2C.3).

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C) Sample Observations

1) The front and rear faces of each of the new and weathered Innowood samples described in Section 2A were photographed next to the panel from sample set B that was closest to their presumed initial colour.

2) The front and rear face of each sample was then examined under the microscope and micrographs taken at low (70x) and high (420x) magnification. Extra micrographs were taken to show features of particular interest.

3) The hardness of the surfaces of all of the samples and installations was evaluated by looking at the indentation impression caused by a thumbnail pressed very firmly into the surface and checking for material removal when a thumbnail was scratched across the surface.

D) Durability Evaluation

1) The nature of the available weathered samples was considered with a view to ascertaining what sort of durability conclusions could be drawn.

2) The results of the Darling Harbour site inspections were analysed and the durability implications highlighted.

3) Comparisons were made between the colour of sample set B and the front and rear faces of the new and weathered Innowood samples to determine the effects of weathering on colour.

4) The effects of weathering on the hardness of Innowood was determined, with particular attention paid to the possible development of a chalky surface layer.

5) Comparisons were made between the microscopic appearance of the new and weathered samples as well as between the exposed and unexposed faces of the weathered samples.

6) The appearances of features of particular interest from weathered or eroded areas of the weathered samples were compared with features from unexposed 'pristine' areas from the same sample.

7) The implications for the long-term, 15 year performance of Innowood were predicted from the appearance and hardness of the new and weathered samples and installations.

3. RESULTS

A) Colour Photographs

Figure 1 – Sample A front face (top) held against the Tasmanian Oak colour sample.

Figure 2 – Sample A rear face (top right) held against the Tasmanian Oak colour sample.

Figure 3 – Sample C front face (top) held against the Golden Oak colour sample. The exposed region of the front face of sample C can be seen top right.

Figure 4 – Sample C rear face (top) held against the Golden Oak colour sample.

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Figure 5 – Sample D exposed face (top) held against the Tasmanian Oak colour sample.

Figure 6 – Sample D rear face (left) held against the Tasmanian Oak colour sample. An eroded strip can be seen to the right of Sample D.

Figure 7 – Sample E exposed face held against the Weathered Wood colour sample.

Figure 8 – Sample E unexposed face held against the Weathered Wood colour sample.

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Figure 9 – Sample F front (sanded) face.

Figure 10 – Sample F rear (corrugated) face.

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B) Micrographs

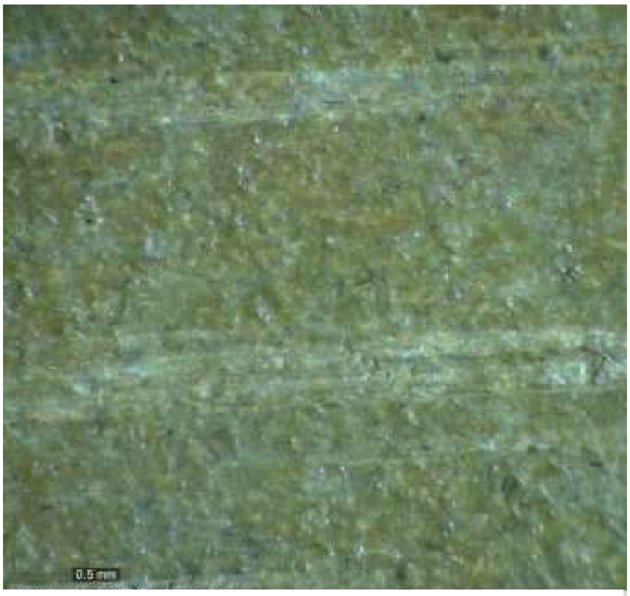

Figure 11 – Micrograph of the front face of Sample A at low magnification.

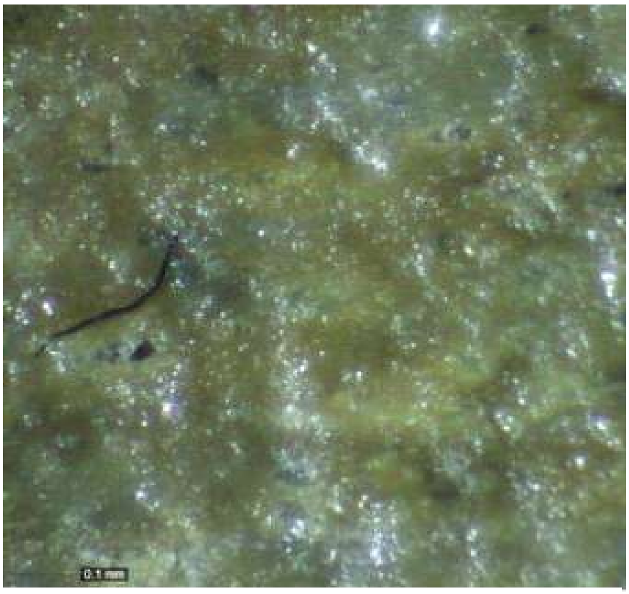

Figure 12 – Micrograph of the front face of Sample A at high magnification.

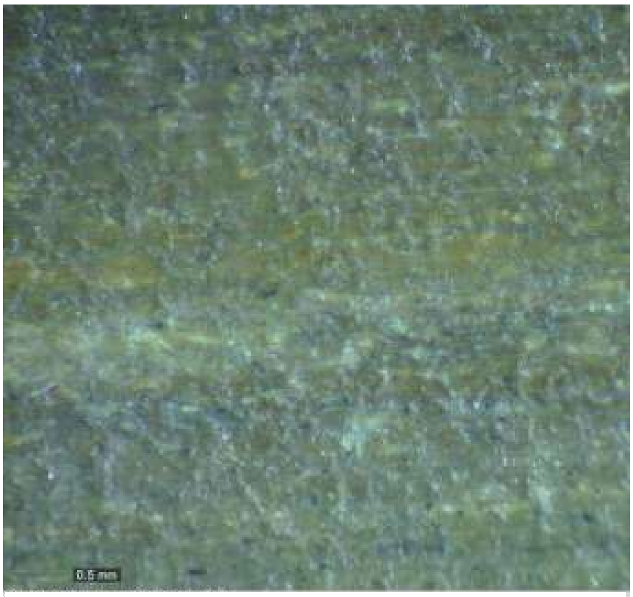

Figure 13 – Micrograph of the rear face of Sample A at low magnification.

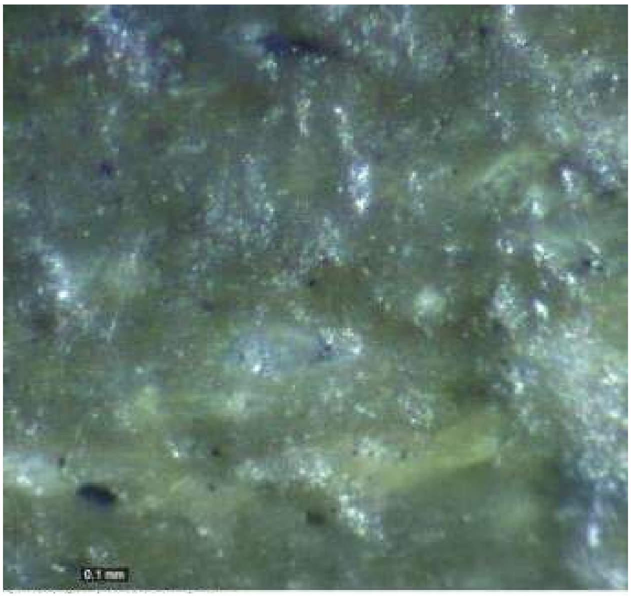

Figure 14 – Micrograph of the rear face of Sample A at high magnification.

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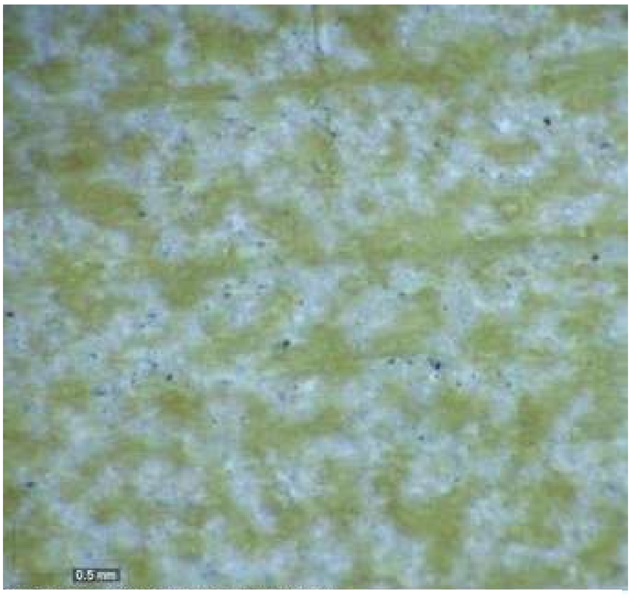

Figure 15 – Micrograph of the exposed region of the front face of Sample C at low magnification.

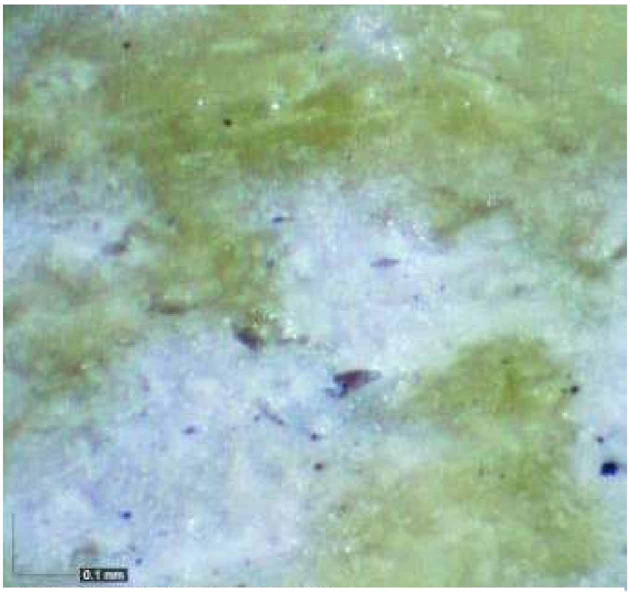

Figure 16 – Micrograph of the exposed region of the front face of Sample C at high magnification.

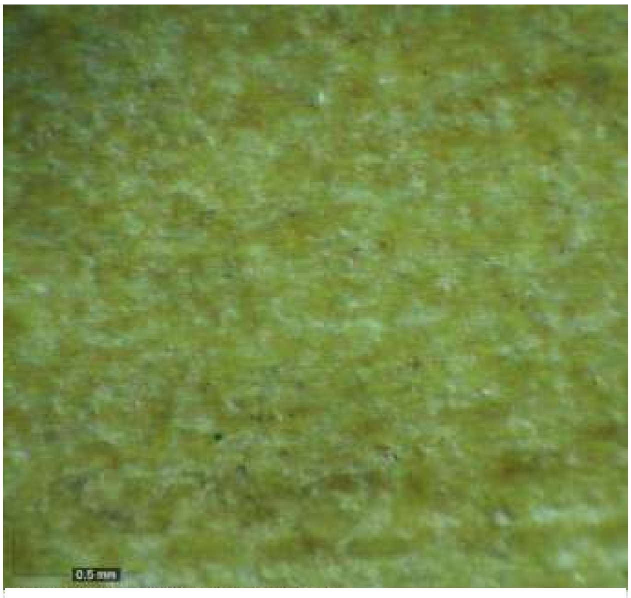

Figure 17 – Micrograph of the unexposed region of the front face of Sample C at low magnification.

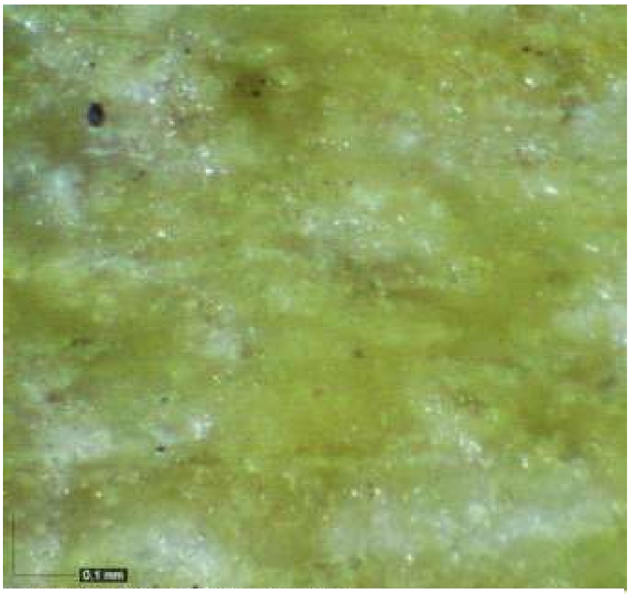

Figure 18 – Micrograph of the unexposed region of the front face of Sample C at high magnification.

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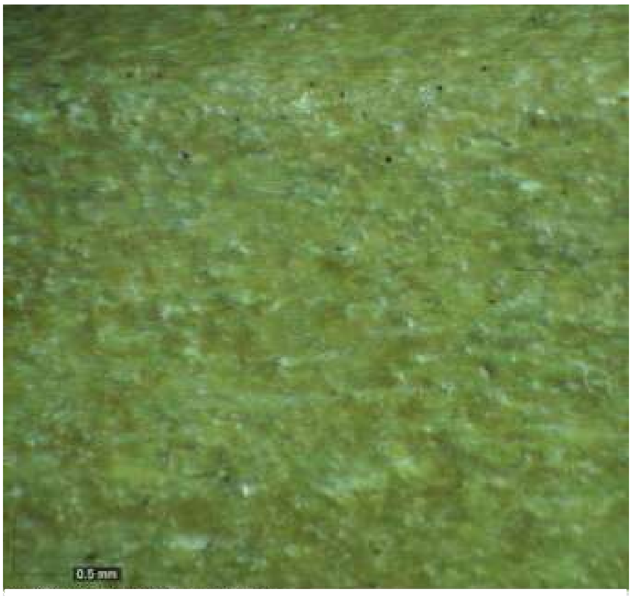

Figure 19 – Micrograph of the unexposed rear face of Sample C at low magnification.

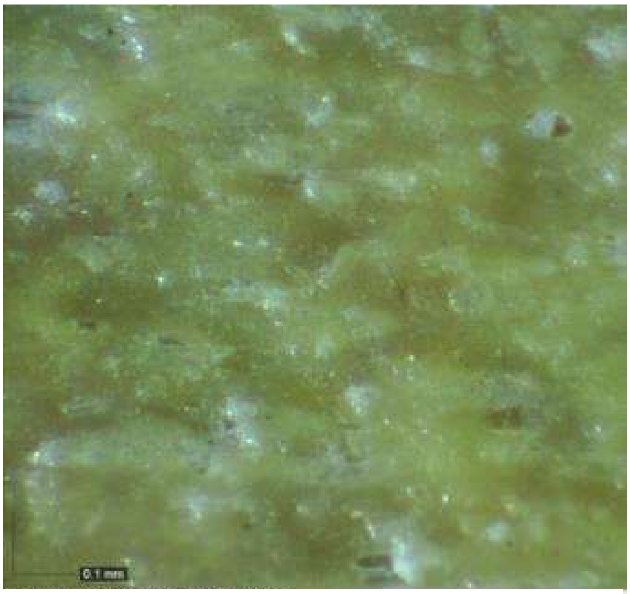

Figure 20 – Micrograph of the unexposed rear face of Sample C at high magnification.

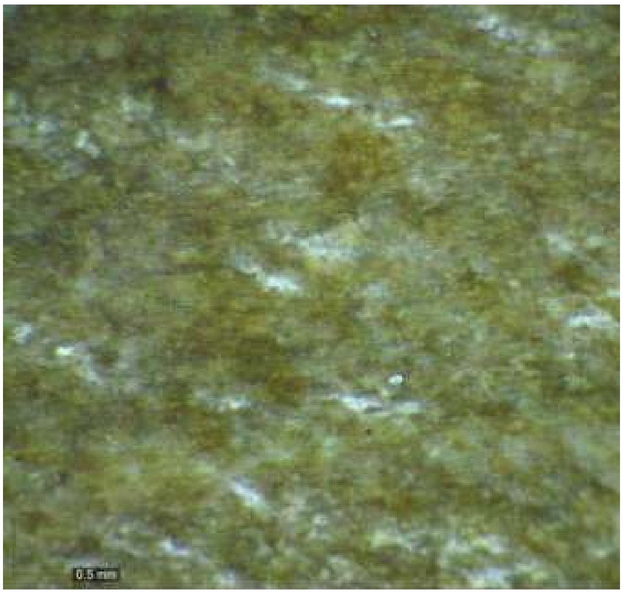

Figure 21 – Micrograph of the exposed front face of Sample D at low magnification.

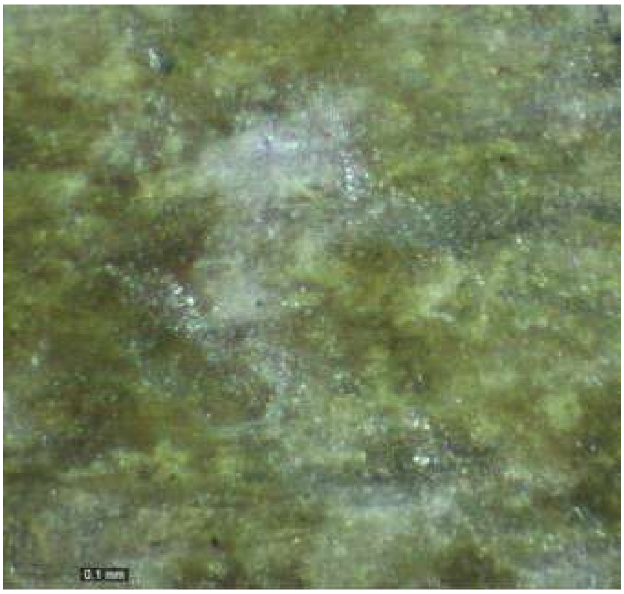

Figure 22 – Micrograph of the exposed front face of Sample D at high magnification.

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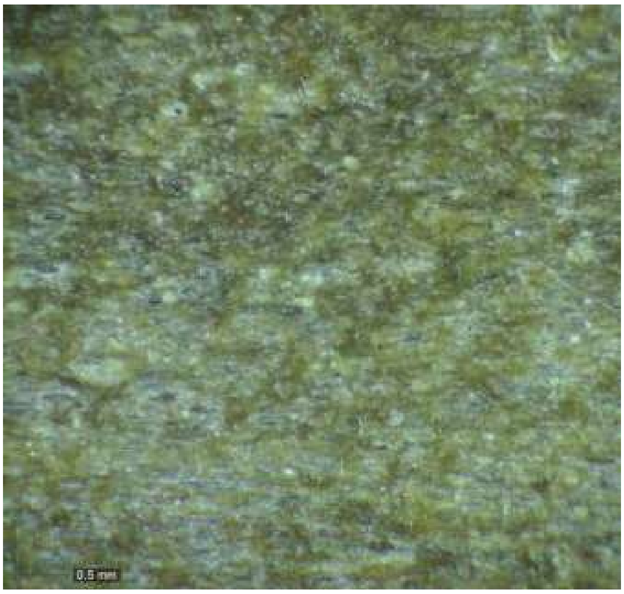

Figure 23 – Micrograph of the unexposed rear face of Sample D at low magnification.

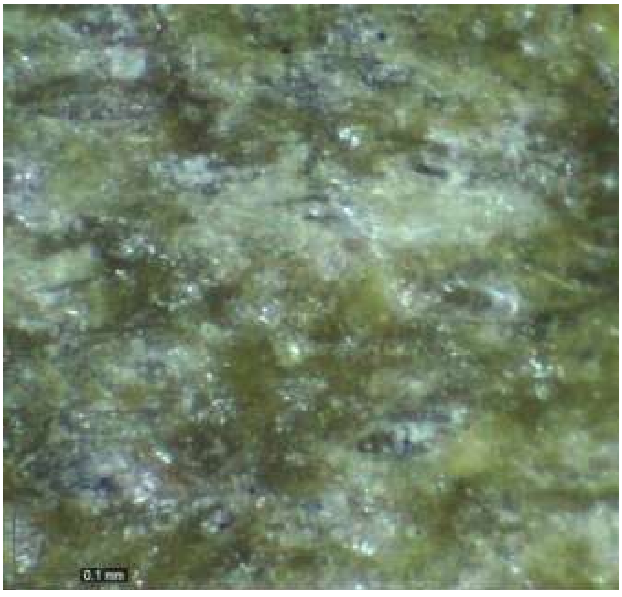

Figure 24 – Micrograph of the unexposed rear face of Sample D at high magnification.

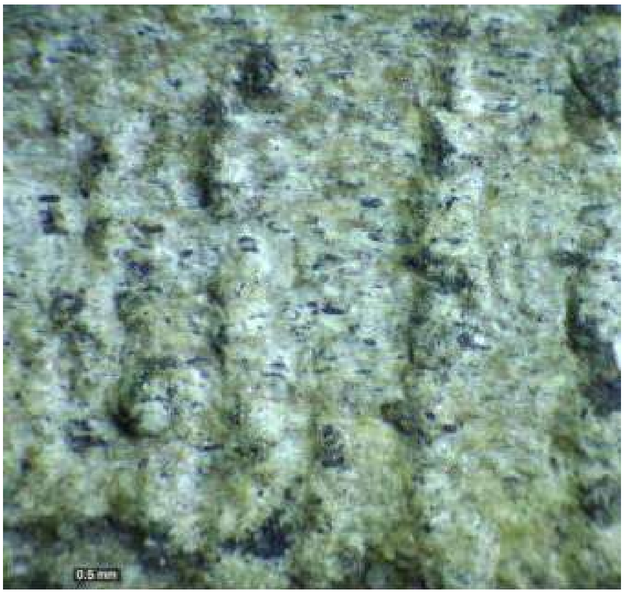

Figure 25 – Micrograph of the rear face of Sample D at low magnification in the region of the edge where grooves appear to have been formed in the surface.

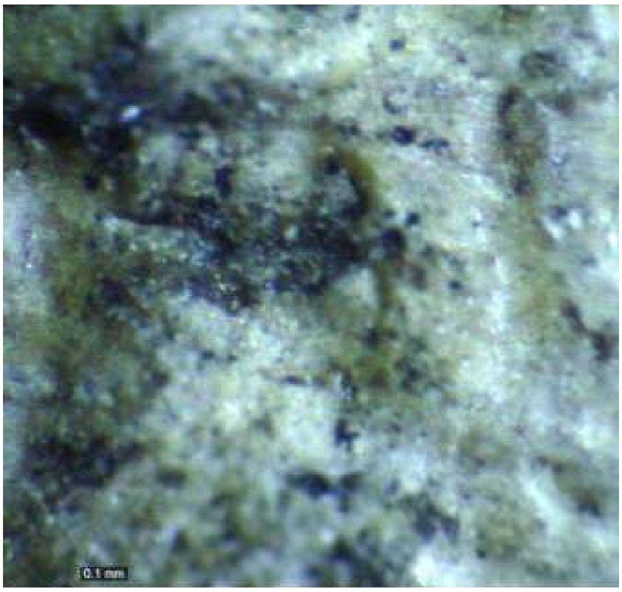

Figure 26 – Micrograph of the rear face of Sample D at high magnification in the region of the edge where grooves appear to have been formed in the surface.

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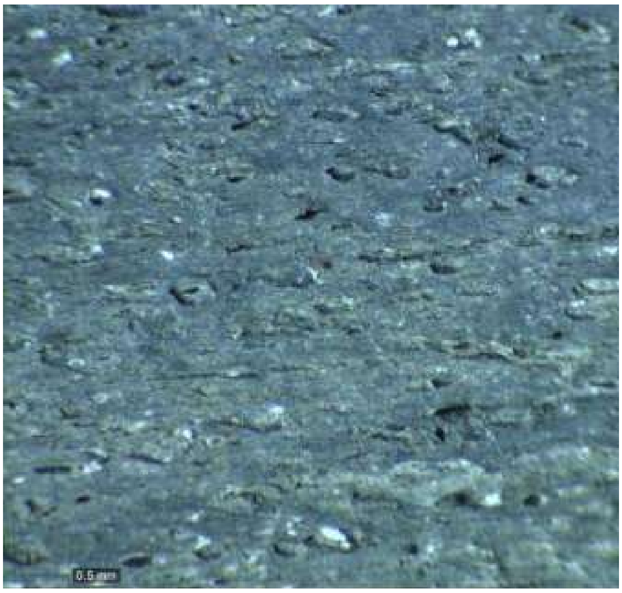

Figure 27 – Micrograph of the exposed front face of Sample E at low magnification.

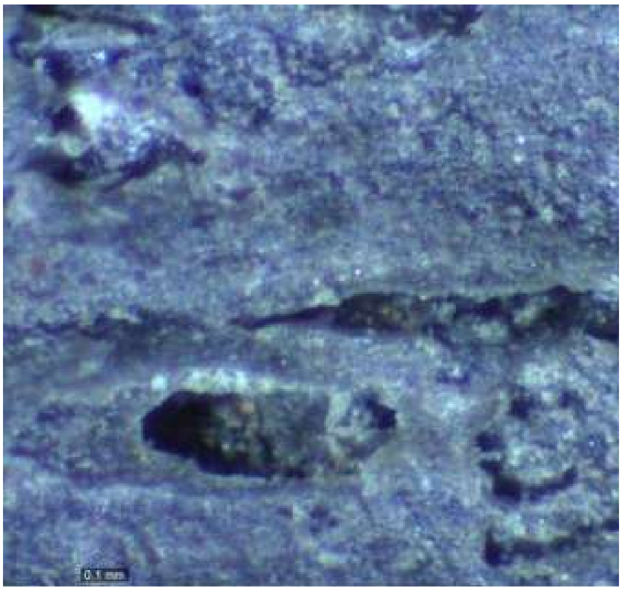

Figure 28 – Micrograph of the exposed front face of Sample E at high magnification.

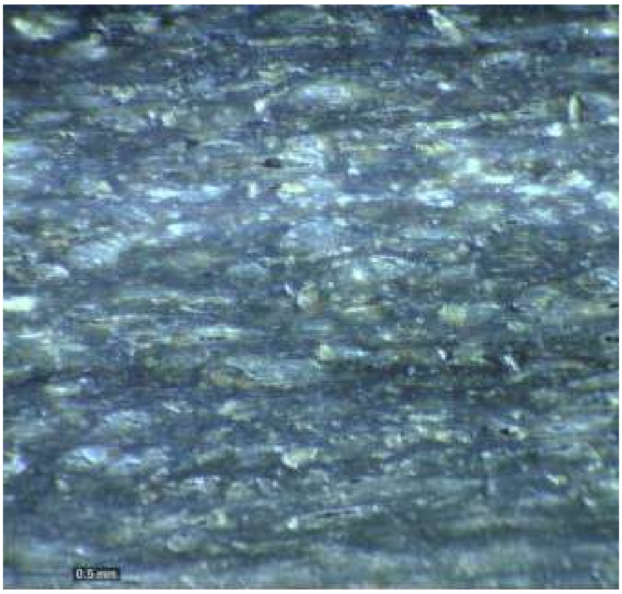

Figure 29 – Micrograph of the unexposed rear face of Sample E at low magnification.

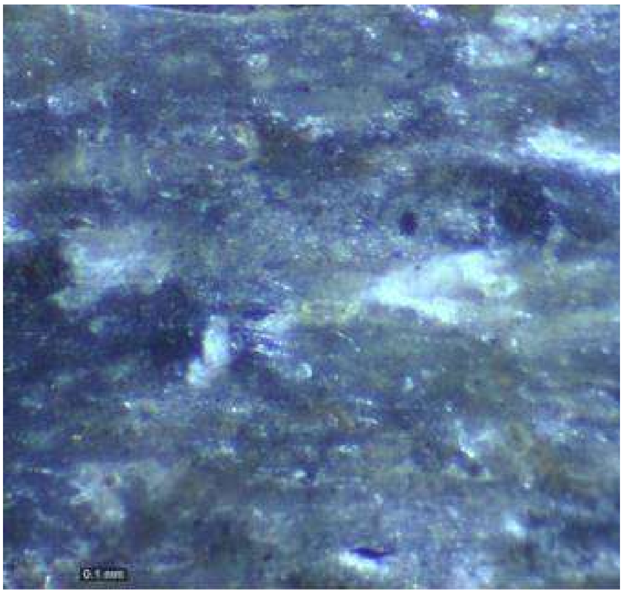

Figure 30 – Micrograph of the unexposed rear face of Sample E at high magnification.

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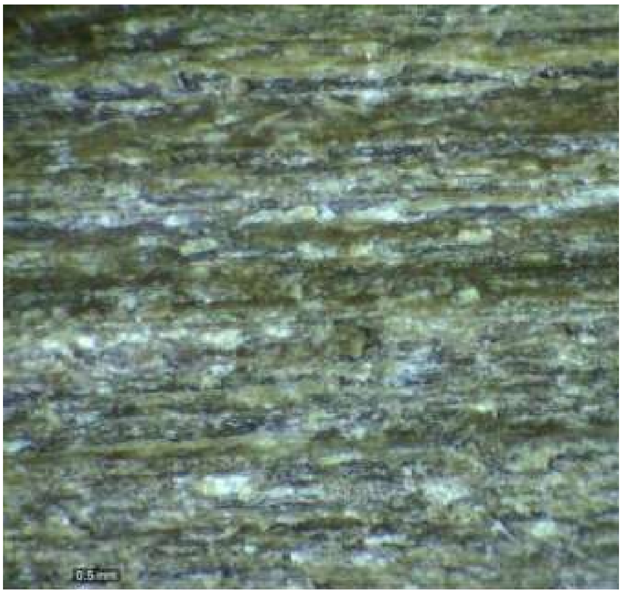

Figure 31 – Micrograph of the exposed and sanded front face of Sample F at low magnification.

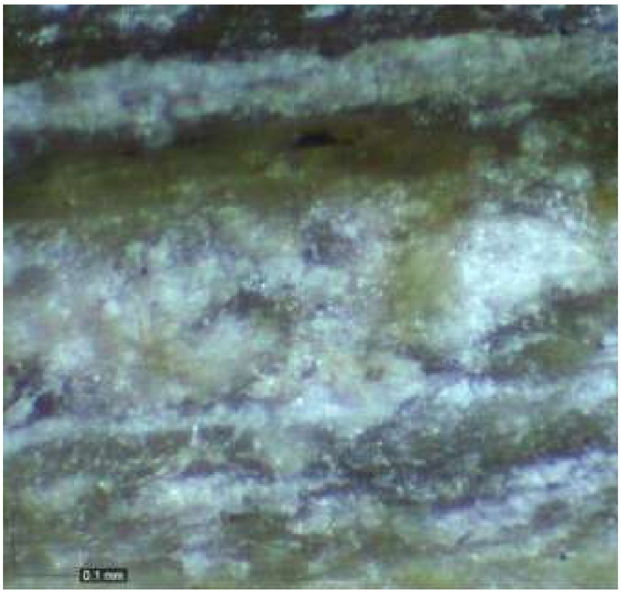

Figure 32 – Micrograph of the exposed and sanded front face of Sample F at high magnification.

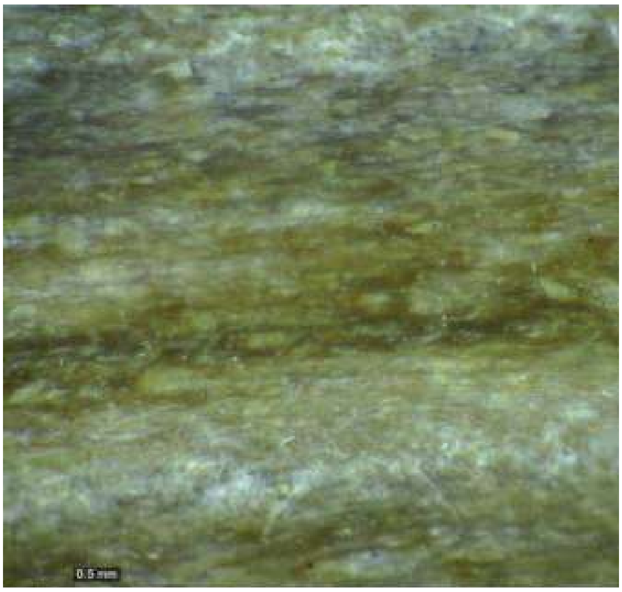

Figure 33 – Micrograph of the unexposed corrugated rear face Sample F at low magnification.

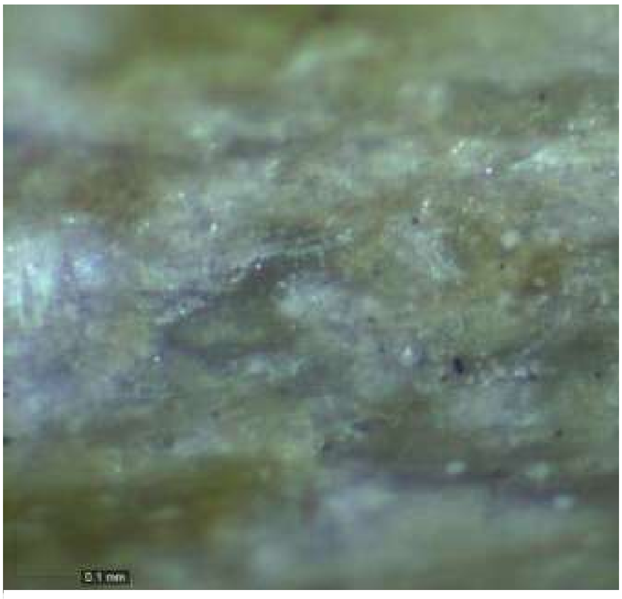

Figure 34 – Micrograph of the unexposed corrugated rear face Sample F at high magnification.

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C) Darling Harbour Site Inspections

Figure 35 – General view of the Wild Life Sydney Zoo Façade.

Figure 36 – Detailed view of the Wild Life Sydney Zoo Façade shade slats.

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Figure 37 – Detailed view of 45˚ joins in a vertical section of the Wild Life Sydney Zoo Façade.

Figure 38 – Detail of (rare instance of) surface peeling in the Wild Life Sydney Zoo Façade

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Figure 39 – General view of the slatted ceiling at the Wild Life Sydney Zoo

Figure 40 – More detailed view of the slatted ceiling at the Wild Life Sydney Zoo

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Figure 41 – General view of the slatted covering on the lower portion of the building walls at Pyrmont Wharves 8 and 9.

Figure 42 – View of the slatted covering on the lower portion of the building walls at Pyrmont Wharves 8 and 9 showing its close proximity to the high water level.

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Figure 43 – Close-up of the slatted covering on the lower portion of the building walls at Pyrmont Wharves 8 and 9.

Figure 44 – Close-up of slatted covering corners on the lower portion of the building walls at Pyrmont Wharves 8 and 9.

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Figure 45 – Close-up of the slatted covering expansion joins on the lower portion of the building walls at Pyrmont Wharves 8 and 9.

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Figure 46 – General view of the planter surrounds and wall feature in front of Pyrmont Wharves 8 and 9.

Figure 47 – Planter surrounds in front of Pyrmont Wharves 8 and 9.

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Figure 48 – Matt top surface of the wall feature in front of Pyrmont Wharves 8 and 9.

Figure 49 – Shiny under surface of the wall feature in front of Pyrmont Wharves 8 and 9, revealed by reflection of a door.

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Figure 50 – Close-up of pits in the top surface of the wall feature in front of Pyrmont Wharves 8 and 9. The plank gap is ~5mm wide.

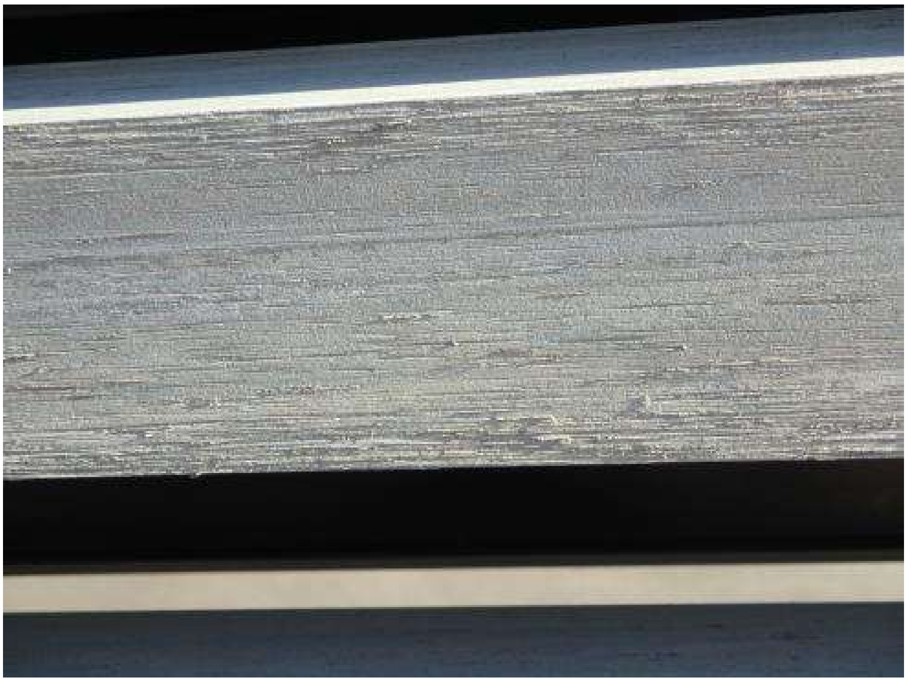

Figure 51 – Close-up of (a rare instance of) minor surface peeling in the side surface of the wall feature in front of Pyrmont Wharves 8 and 9.

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Figure 52 – Damage in part of the East planter surround in front of Pyrmont Wharves 8 and 9.

Figure 53 – Damage in part of the East planter surround in front of Pyrmont Wharves 8 and 9.

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Figure 54 – Corner damage in the West planter surround in front of Pyrmont Wharves 8 and 9.

Figure 55 – Tyre marks and impact indentation in the East planter surround in front of Pyrmont Wharves 8 and 9.

Figure 56 – Corner scrape in the East planter surround in front of Pyrmont Wharves 8 and 9.

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D) Hardness Estimation

The (rough) surface density and compressibility for all but the 12 year old Sample E was identical; where a thumbnail had been pressed very firmly into the surface, an indentation 'line' of compressed material could be seen. This deformation was plastic in nature as it appeared unchanged after a few days.

While the back, unexposed surface of Sample E had the same apparent hardness as the other samples, the front surface of sample E was much harder with a substantially smaller, shallower indentation due to compression caused by very firm thumbnail pressure.

The same relatively high hardness seen in Sample E was found for the weathered surfaces during the field inspections at both the Wild Life Sydney Zoo and the planter surrounds and wall feature in front of Pyrmont Wharves 8 and 9.

For all samples, no surface material, front or back, exposed or unexposed, could be removed using a thumbnail scraped perpendicular or parallel to the 'grain' of the Innowood.

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4. DURABILITY EVALUATION

A) General Considerations

Ideally, to draw definitive conclusions from material exposed to the weather one would compare the properties of new material, weathered material and aged but unexposed material of the same type. In reality, it is rarely possible to find aged and weathered samples that are identical to available, newly fabricated material. For the present study, the samples of weathered material were reported to have the same formulation and were fabricated using the same extrusion method as the available new material, but all had different extrusion cross-sections and coatings and uncertain initial colours. This allowed the hardness and some but not all aspects of the appearance of the new material to be compared with aged material. Because of the differing extrusion cross-sections it was not possible to whether changes in additional properties such as water absorption and strength had occurred.

Of particular advantage, all of the weathered samples provided by Innowood had exposed and unexposed areas which could be compared, which enabled reliable inferences about the effects of exposure to the weather to be drawn. In particular, by observing the surfaces it was possible to determine whether any visible degradation in the structure and surface integrity had occurred due to the effects of exposure to the elements.

With regard to colour comparisons in particular, the colours of weathered or even new samples are not expected to be exactly the same as the colour display panels due to variations in batch mixes, changes in mixing due to different types of extrusion dies and, for the older samples, discontinued batch mixes and extrusion shapes. However cosmetic changes in colour, which are typically caused by exposure to sunlight, could be determined by comparing the colour of the exposed and unexposed surfaces.

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B) Site Inspection Analysis

Wild Life Sydney Zoo, Darling Harbour

As shown in Figure 36, most of the Wild Life Sydney Zoo façade constructed from Innowood was fully exposed to the weather. Not shown in the photo, the building is located on a wharf adjacent to Darling Harbour, so in addition to sunlight, rain and wind, some exposure to salt spray would also have been expected.

The Innowood on this installation was in excellent condition despite 12 years of full exposure to the weather, as shown in Figures 36 and 37. In particular, there was no evidence of significant bleaching, surface erosion or shrinkage, the 45° and right-angle joins remained flush and the overall appearance was one of well-preserved weathered timber.

Careful, close inspection through the binoculars revealed a couple of instances of peeling of very thin surface layers (Figure 38), but this was very rare, required a very careful inspection of all surfaces and did not detract from the overall appearance of the façade.

Some areas of the façade were able to be hardness tested using very firm thumbnail pressure and scraping along and across the 'grain'. Virtually no indentation could be effected, and it was not possible to remove any material from the surface. As found subsequently, this behavior was identical to that of Sample E, represents an increase in surface hardness and could be interpreted as an improvement in the properties due to weathering.

Figures 39 and 40 show the area under the roof extending around the Wild Life Sydney Zoo, which was covered by thin ceiling slats of Innowood. Despite careful scrutiny, no evidence of degradation or damage could be seen in this less exposed material.

Pyrmont Wharves 8 and 9

Figures 41 and 42 detail the Innowood slats that were placed over the lower walls of the residential buildings at Pyrmont Wharves 8 and 9 in 2007. As shown in Figure 42, the bottom slats are only just above the high water mark. Therefore, in addition to 11 years of exposure to sunlight, wind, rain and salt water spray, the lower slats would be expected to be regularly immersed in salt water due to wave action at high tide. This is a particularly aggressive weathering environment!

Despite very careful scrutiny, there was no evidence of surface erosion or significant bleaching as evidenced by Figures 43 to 45, and the composite timber still gave the appearance of weathered, natural timber in good condition. (Note that natural timber was highly unlikely to have survived that well after 11 years in that environment). Indeed, the slight darkening seen in the bottom corner of the slat covering shown in Figure 42 was typical of the worst of the discolouration observed, and much more appealing than the appearance of the concrete surface it covered. No significant mould, moss or other biological growth could be seen on the surface of the Innowood slats. Figure 45 details what was thought to be an expansion join between the slats covering the walls; any shrinkage would have been masked by the expansion join gap.

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Because of their location, it was not feasible to get closer than about 1 metre from the slats on the lower walls. Therefore it wasn't possible to examine the surface of the slats more closely or to test their hardness.

Figures 46 and 47 show the general siting of the Innowood planter surround and wall feature between Pyrmont Wharves 7 and 10 and Wharves 8 and 9. These constructions, erected in 2007, would have been exposed to the full effects of sunlight, wind, rain and salt spray for 11 years, and water would be expected to lie on the horizontal surfaces for a while after rain. Because of their location, these features were accessible to the public and both planter surrounds were of a height that they would have been expected to be regularly used as seats (which may have been an inappropriate use for this form of Innowood).

In the main, as can be seen in Figures 46 and 47, the Innowood used in the planter surround sand wall feature still looks like weathered timber in good condition. Figures 48 and 49 show images of the top and bottom surfaces of the top of the wall feature taken at an oblique angle looking towards a door. In the photo of the bottom surface, a reflection of the door can be seen, indicating that the Innowood surface is still shiny (as both surfaces presumably were when initially installed) while the top surface now has a matt surface (which is probably more akin to the weathered timber it simulates). The matt finish to the top surface is due to the formation of very small pits, which can be seen in the close-up photo of the surface shown in Figure 50; these pits are only visible if the surface is examined very closely. A small proportion of the vertical surfaces have also suffered minor surface peeling, as shown in Figure 51, which is also only evident upon very close examination, looks very like splinters of timber and, despite appearances, could not be scratched off.

Unexpectedly, the surface pitting and minor surface peeling was not accompanied by poor hardness or surface integrity. Specifically, it was virtually impossible to create an observable indentation using very firm thumbnail pressure which, compared to new material, represents a significant increase in hardness. As for all new and weathered Innowood tested during this study, no material could be scratched off using a thumbnail scraped perpendicular or parallel to the 'grain'. In summary, despite 11 years of exposure, the surface integrity of this Innowood installation has been maintained and appeared harder than when first installed; it was not chalky.

While the general condition of the planter surrounds and wall feature was very good, some damage to part of the Eastern planter surround was evident, as shown in Figures 52 to 56. Figures 52 and 53 show broken areas in the top surface of the Eastern planter surround, revealing the approximately 5mm wall thickness of the hollow-section plank. The material around the break was very tough, and it was not possible to break off additional material by hand. It may be relevant that the regions where material had been removed (Figures 52 and 54) were at joins, where it would have been possible to insert a lever. Figure 55 shows what looks like a tyre scrape mark and impact damage by an approximately 15mm circular implement while Figure 56 shows another tyre mark and edge scrape, both in the walls of the Eastern planter surround near the damage to the top surface.

Note that while it appeared that the weathered Innowood was still very tough, to be definitive and properly compare its strength characteristics with that of new material a proper, calibrated 3-point bend test would have to be conducted.

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Nevertheless, the apparent toughness of the material in the region of the damage shown in Figures 52 to 56, the very good condition of the remainder of the planter surrounds, wall feature and slats on the lower walls of the Wharf 8 and 9 buildings, the location of the damage in Figures 52 and 54 and evidence of tyre marks in Figures 55 and 56 all suggest that the damage is due to significant force; tentatively attributed to a combination of impact by heavy gardening equipment, determined vandalism and its use as a 'BMX bike obstacle'. More importantly, it seems unlikely that the damage in part of the Eastern planter surround was due to deterioration of the Innowood as a result of weathering.

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C) Colour Changes Due to Weathering

The wood grain appearance seen in Innowood products are created by placing dyes in extruder where they don't fully mix, giving rise to 'streaking'. Thus, while the overall colour is the same 'on average', it does not take the form of a single, reproducible colour (ie. it is similar to natural timber). Clearly demonstrated in figures 1 and 2 of the front and back of sample A, the colouring was similar to the target 'Tasmanian Oak' colour panel but had significant variations such as the top right portion seen in Figure 2. Since this variation had clearly occurred during manufacture of new material, it made it difficult to be definitive when drawing conclusions about changes in colour due to weathering.

The weathered portion in sample C (Figure 3) was clearly lighter in shade than both the un-weathered front and rear portions of sample C, which seemed very close in colour to the 'Golden Oak' colour panel. As discussed later, this bleaching could have been related to UV induced breakdown of the coating. No similar whitening was apparent in fresh material (sample A) or on the exposed or unexposed faces of weathered samples D, E and F; the observation of whitening was confined to a single sample and thus it was postulated that the bleaching was probably an anomaly related to a particular batch of coating or the technique or type of coating prevalent late in 2015.

It was difficult to draw conclusions about colour changes due to weathering for sample D (Figure 5) as it had been recoated with a stained coating. If the back face of sample D was originally 'Tasmanian Oak' in colour, ageing, whether it had been exposed to the elements or was unexposed, may have led to a lightening in tone and greying in hue. Based on evidence from the other samples, it seemed more likely that Sample D was not originally 'Tasmanian Oak' in colour.

The best evidence regarding colour change was provided by the front and rear face of sample E (Figures 7 and 8), which was thought to be initially similar in colour to the 'Weathered Wood' panel. It can be seen that the (uncoated) rear face had light and dark regions and streaks of colour which, on average, match the colour and tone of the (coated) 'Weathered Wood' panel. In contrast, the front face had less variation in both colour and tone and was, on average, lighter than the 'Weathered Wood' panel. Thus, it may be inferred that exposure had bleached the colour and lightened the tone of this sample, although the changes were relatively small.

For sample F, the original colour was unknown and the front face had recently been sanded, so it was impossible to determine whether the colour of sample F had changed due to exposure. The closeness of the colours of the front and back face did show that even if the colour of weathered material had deteriorated, it could be returned to it's original appearance through surface sanding.

In summary, it can be stated that while there may have been colour changes due to weathering, such changes were quite small and, unless placed next to a new piece of Innowood, would probably not be noticeable. Moreover, because all Innowood is now clear-coated, which should minimize fading due to UV exposure, even the possible colour changes observed for the 12 year old sample may be minimised for new material. Finally, the observation that sanding returns the surface to its original colour showed that it would be relatively easy to fully resurrect the surface colour should it be considered necessary.

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D) Effect of Weathering on Hardness

Hardness indentations due to surface compression resulting from very firm thumbnail pressure on all samples but the front surface of Sample E were similar to that seen in hard, high density timber such as Ash and Mahogany, shallower than would be seen in medium density timbers such as Maple and significantly shallower than would be expected in low density timbers such as Radiata Pine or Western Red Cedar. The weathered Innowood on the front surface of Sample E, other material on the Wild Life Sydney Zoo façade and the surface of the planter surrounds and wall features in front of Pyrmont Wharves 8 and 9 all appeared to be as hard as the highest density timber. Thus, the hardness of Innowood was found to be relatively high and either unaffected or increased by weathering.

The inability to scratch material from the surface of any of the Innowood tested is unlike, and superior to the properties of most timber, for which material can be readily removed from an (uncoated) surface using a thumbnail scratched across the timber grains. This behavior in natural (uncoated) timber leads to erosion, the development of splinters and allows water to penetrate under the surface. Thus, Innowood probably has an advantage over traditional, natural timber materials, particularly when used as decking.

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E) Microscopic Examination of New and Weathered Surfaces

Figures 11 to 14 show the front and rear faces of the new material of Sample A, which look identical at their respective magnifications. This was not necessarily expected as the front and back of the extrusion die may not have produced the same conditions of pressure or may have had different frictional properties, for example. While it must be borne in mind that this sample was fabricated using a different extrusion die to the other samples, and had a different coating regime, it suggests that the exposed front and unexposed back faces of the weathered samples began with a similar appearance. Therefore, if differences are observed between the exposed and unexposed regions of the weathered samples, they should be attributable to the effects of the weather.

Clear differences can be seen between the exposed and unexposed regions of the front face of the 2.5 year old Sample C in Figures 15 to 18. Specifically, the exposed region of the front face shown in Figures 15 and 16 has bleached 'splotches' which, as previously noted, has resulted in a lighter colour when viewed without magnification. Similar bleaching was not apparent in the new Innowood of Sample A. Examination under the microscope (Figures 15 and 16) suggests that the colour change in Sample C was due to whitening in regions of the coating, and not due to changes in the underlying composite structure. Inspection of the micrographs of the un-weathered surfaces of the same sample (Figures 17-20) indicates that the beginnings of similar bleaching had occurred, albeit to a significantly lesser extent. No bleaching is discernable on the unexposed rear face of Sample C (Figures 19 and 20). The fact that examination of other older, sometimes uncoated samples does not reveal similar bleaching strengthens the hypothesis that the effect is confined to the coating, and is not indicative of deterioration of the composite timber structure. The bleaching is worst where the surface has been exposed to the elements, including sunlight, barely visible on the unexposed front face where the sunlight would have a very low intensity and not apparent on the rear face where sunlight is unlikely to penetrate, so it seems most probable that the bleaching is due to UV induced breakdown of the coating. As mentioned in section 4C, this deterioration is probably an anomaly related to a particular batch of coating or the technique or type of coating prevalent late in 2015.

Bearing in mind the masking effect of the coatings, no significant differences can be seen between the rear and re-coated front faces of the six year old Sample D shown in Figures 21 to 24, both of which are similar to Sample A. In particular, there is no evidence of pitting or other surface erosion in the exposed, coated face of Sample D and even the distribution of pigment looks similar, particularly at the higher magnification. While this suggests that no deterioration in the Innowood has occurred due to exposure to the elements, because the front face has been recoated it is impossible to determine whether this would have been the case if it had been left without additional protection. On the other hand, this sample indicates that recoating Innowood protects or rejuvenates the surface to achieve an appearance very similar to that of fresh material (and the un-exposed rear surface).

Figures 6, 25 and 26 show evidence of mechanical, chemical or biological erosion of small grooves in one back edge of Sample D; attack by ants seems most likely. The erosion is confined to less than 1 mm of depth, the surface of the erosion grooves was still sound, as hard as the rest of the sample (as measured by the depth of the indentation caused by very firm thumbnail pressure) and looked similar to the remainder of the sample (albeit without a coating). This suggests that while the Innowood had not prevented any damage from occurring, it can be considered resistant to such attack (as claimed in the on-line literature).

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When combined with the inspections at the Wild Life Sydney Zoo and Pyrmont Wharves, examination of the front and rear face of Sample E in Figures 27 to 30 gave a good indicator of the effects of weathering as the sample had been exposed for 12 years. Firstly, although this material had not been coated there was what appeared to be a glossy finish to the rear, unexposed face of the sample which looked similar to new, coated Innowood. In contrast the exposed surface of the sample had a matt appearance, although it was not as rough and pitted as the surface shown in Figure 50, which had a horizontal installation orientation and thus would have been covered with water after rain. Under the microscope, the source of the glossy sheen on the unexposed face of Sample E was due to what looked like excess PVC resin at the surface (Figures 29 and 30), which was no longer visible on the exposed front face shown in Figures 27 and 28. As it is probable that both surfaces were exposed to rain and salt-laden wind, the most likely cause of the loss of gloss would be exposure to UV light from the sun, which is known to discolour and break the chemical bonds in PVC. The weathered surface had a high hardness, indicating that the surface breakdown had halted, possibly due to UV light blocking by pulp and dye, leaving behind a durable surface that was harder than the original, PVC-laden surface; this hypothesis could be tested by doing a chemical analysis across a section through new and weathered material.

The other feature evident in the weathered surface of Figures 27 and 28 was the appearance of small pores. Under the microscope it appeared as if the pores were an infrequent close-surface feature so it was unlikely that the weathered material was porous for any depth. This theory is supported by the fact that the surface was hard, not friable, and could be quantified in future by conducting vacuum-assisted water absorption measurements. No pits or surface peeling, such as portrayed by Figures 38, 50 and 51, were present in Sample E so these features could not be examined microscopically.

More significantly for Sample E, it was observed during inspection at the slightly younger Pyrmont Wharves installation that additional material could not be broken off by hand from the periphery of the damaged region. Similarly, Sample E was too tough to break by hand and maintained a degree of plasticity with no indication of brittleness. These strength characteristics appeared similar to those of the new material of Sample A, although proper strength testing would be needed to be definitive.

Turning finally to Sample F, which was also 12 years old, micrographs of the front, sanded surface and the back, corrugated surface can be seen in Figures 31 to 34. While it was unfortunate that the weathered surface of Sample F was not available for observation, a comparison between Figures 31 and 33 and Figures 32 and 34 indicate that the sanded surface looks similar to the back face (and that of new Innowood) and there was no evidence for breakdown of the composite timber. (As a follow-up, it may be advantageous to compare this sanded material with that of the new material after sanding, as the coating on new material partially masks the structure under the unexposed surface.) The implications of the apparent soundness of the weathered Innowood after sanding is two-fold; firstly it indicates that weathering has not affected the underlying integrity of the material, and secondly it shows that weathered material can be sanded to provide an as-new surface.

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F) Overall Conclusions and Extrapolation to 15 Years

Overall, Innowood composite timber does not appear to have deteriorated significantly, even after up to 12 years of exposure in a relatively aggressive coastal temperate environment. Indeed, a substantially greater change would be expected to be seen in analogous, uncoated natural products such as wood, or materials that are generally considered durable such as concrete or fibre cement.

Extrapolating into the future, based on site inspections, qualitative hardness measurements and unmagnified and microscopic observations of the surfaces of new and weathered Innowood, it seems highly likely that this product would survive largely unchanged after an additional 3 years. Therefore, Innowood may be considered a durable building material that would survive at least 15 years of exposure to the elements in a temperate coastal environment.

G) Possible Future Work

This study has been confined to an examination, albeit a very close examination, of the surface of new Innowood and Innowood exposed to a temperate coastal environment for up to 12 years.

Sample F, which had been sanded, turned out to be more useful than had been expected, as it could be used to draw conclusions about the (lack of) deterioration in the subsurface material. Similarly, it might be instructive to sand all the samples and thereby determine the condition of subsurface material which is, after all, possibly of greater interest than the mostly cosmetic surface changes. Additionally, a microscopic examination of, and chemical analysis across the polished cross-section of a weathered sample could ascertain whether there is a significant change in the structure and composition of the surface, and how far below the surface such a change might extend.

The hardness evaluation carried out for this study was qualitative; a quantitative test would be a better determinant of the tentative conclusions drawn here and should allow any hardness change to be confidently extrapolated to longer timescales.

It would also be valuable to look at quantitative changes in other physical properties, and in particular strength, porosity and water absorption, as a result of weathering. Assuming that formulations and extrusion pressures and temperatures have not changed over time, this might be best accomplished using new and weathered samples with the same initial density, which implies an identical, or at least very similar extrusion pressure and cross section.

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5. CONCLUSION

While there may have been small cosmetic colour changes and surface degradation as a result of weathering of the Innowood in the Darling Harbour installations and samples of Innowood provided, these changes appear to be minor in nature and would not be expected to significantly impact the performance of this material when used as cladding, louvres, decking or screening. Specifically, it was confirmed that the material did not appear to corrode, rot or split, seemed resistant to mould, moss and other biological growth and was not conducive to what was assumed to be attack by ants.

Thus, Innowood was found to be a durable building material that should survive at least 15 years of exposure to the elements in a temperate coastal environment.

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