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MOISTURE INTRUSION PATTERNS IN SMALL-SCALE MASS PLY PANEL FLOORS

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ABSTRACT: Mass timber elements have gained increased global interest as builders seek more carbon neutral materials. These products are primarily intended for interior uses where the risk of wetting is minimal. Moisture can have many detrimental effects on engineered wood products including swelling, cracking, delamination and, if prolonged, fungal decay. These products are manufactured using dry wood (<15 % depending on the product), but wetting can occur in between manufacturing and final building closure. Understanding the rates and degree of moisture intrusion can guide moisture management strategies to mitigate the risk of wetting and ensure performance. Water uptake was assessed over 24 days in Douglas-fir mass ply panels. Moisture contents exceeded 40 % in the upper four plies after 1 day of wetting but increased more slowly further inward. Prolonged wetting (24 days) resulted in moisture levels above 20 % deeper in the panel. The results highlight the speed with which wood moisture content can increase in MPP with rainfall and can be used to develop mitigation methods to minimise the risks of wetting.

KEYWORDS: *moisture, decay, mass ply panels, Douglas-fir*

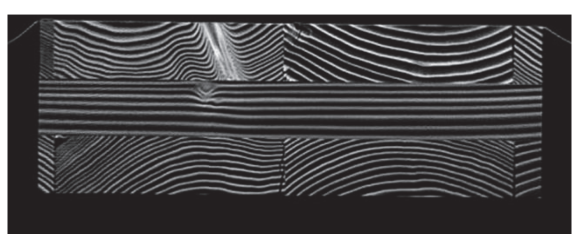
1 – INTRODUCTION

Timber has gained increased interest due to its positive environmental attributes including low embodied energy, recyclability and ability to sequester carbon. A major driver of this interest has been the emergence of larger engineered wood products, termed mass timber. Mass timber is not a new concept as laminated timbers have been used for decades, but the emergence of cross laminated timber and, more recently, mass ply panels (MPP) have sparked considerable interest in the engineering and architectural communities. While the focus has been on very visible high-rise structures, each vying to be the tallest or the largest, there is considerable opportunity for mass timber in mid-rise structures [1].

In most instances, mass timber elements are intended for interior applications where there is minimal risk of wetting that might lead to biodeterioration [2-4]. These products are produced at moisture levels well below 20 % moisture content and thus, present minimal risk of biodeterioration once installed. However, there is a considerable risk of moisture intrusion in mass timber elements between manufacturing and building completion. Prolonged moisture accumulation will invariably support the development of fungal decay that will sharply reduce the material properties of the timber [5-7]. There are an increasing number of reports of decay in mass timber buildings either through poor detailing or failure to control wetting during construction [8-15] Moisture intrusion can lead to wood swelling, delamination along the gluelines and, if prolonged, to fungal decay. Unlike traditional stick-frame buildings where the frame can be subjected to rapid drying to remove any moisture that accumulated during construction, mass timber elements are much more sensitive to rapid drying and can experience cracking, delamination and other physical degradation as the wood equilibrates to an in-service moisture level.

Understanding the rates and degree of moisture intrusion during construction can help encourage moisture exclusion measures. Many manufacturers work to minimise the risk of wetting by covering panels in plastic to exclude water and using just-in-time delivery to minimise storage on site. There remains, however, a time interval between installation and completion of building enclosure when water intrusion can occur. Even here, builders have worked to minimise wetting by capping walls with plastic to minimise end-grain exposure to rainfall, taping floor joints and application of water repellent coatings. However, moisture can still accumulate on floors, especially during periods of heavy rainfall. Understanding the extent of moisture intrusion can help guide both the extent to which moisture exclusion procedures are undertaken as well as the amount of post-construction drying needed.

Previous studies used mass gain and computer tomography (CT)-scans to examine moisture accumulation and distribution in Douglas-fir CLT panels exposed outdoors for 30 days as a simulated floor [10]. Panels gained nearly 30 % mass over the exposure, while CT scans suggested that moisture accumulation was highly variable but was concentrated in the non-edge-glued joints (Figure 1). Post-drying examination revealed the presence of numerous internal cracks (Figure 2). These results highlighted the risk of moisture intrusion for this product, but these risks need to be understood for new products entering the market.



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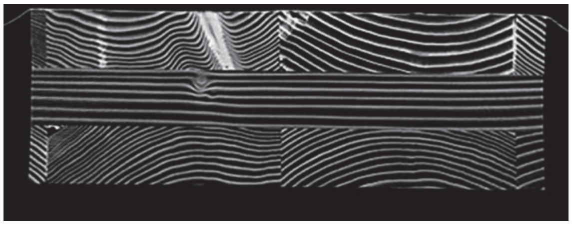

Figure 1. CT-Scans showing a cross section of a Douglas-fir CLT panel before and after 30 days of exposure to natural rainfall. Note the brighter areas at the non-edge-glued joints after wetting indicating higher density (Morrell et al., 2018).

Mass ply panels (MPP) are just one such material. Although MPP is not completely new, development of production capacity has stimulated renewed interest in this product in commercial construction in North America. Unlike non-edge-glued CLT where the pathways for moisture intrusion are primarily from the upper surface and the non-edge-glued areas, the multiple bondlines in MPP create a more complex pathway for moisture intrusion. However, wood is still hygroscopic and lathe checks, small gaps in the gluelines and scarf joints all present pathways for moisture intrusion into the panel. Understanding how moisture migrates into this material will help manufacturers and builders develop best-practices for managing moisture during construction.

Figure 2. Example of a Douglas-fir CLT panel section exposed to natural rainfall for 30 days and allowed to dry for 2 years showing checking and delamination.

The objective of this study was to assess moisture movement into Douglas-fir MPP panels exposed to wetting for 1 to 24 days.

2- MATERIALS AND METHODS

MPP (75 mm thick with 27 plies) were cut into 100 mm by 153 mm long sections that were conditioned to stable mass at 23 °C and 65 % relative humidity. A test matrix is shown in Table 1. The exposed veneer edges were sealed with an elastomeric coating to retard moisture loss. A 25 mm wide closed cell gasket was attached around the sides with caulking to create a well at the top. The gasket was also secured with staples to minimise leakage. Later versions eliminated the elastomeric as there was little evidence of leakage from the sides of the blocks (Figure 3).

Figure 3 Examples of an MPP block prior to sealing and one sealed with the water well.

The samples were weighed, water was added to a depth of approximately 10 mm in the well and the assembly was placed into a plastic bag to retard drying. The samples were incubated for 1, 4, 7,18, or 24 days. Additional water was added as needed. Each time point was replicated on a minimum of three assemblies (7 and 24 day exposures exposed 5 and 4 blocks, respectively). The assemblies were removed each time and the water was poured out of the well which was wiped with a paper towel to remove excess moisture. The assembly was weighed and the difference between initial and final mass was used to calculate total water uptake over the exposure period.

Table 1. Test Matrix

Material	**Dimensions (mm)**			**Time (Days)**	**Replicates**
	Width	**Depth**	**Thick**		
Mass Ply Panels (MPP)	153	100	75	1	3
				4	3
				7	5
				18	3
				24	4

The gasket and staples were removed, and the block was cross-cut into nine ~16 mm thick sections that were then cut into six ~10 mm slices each with ~4 veneers. The 54 samples per block were then weighed and oven-dried at 103 °C before being weighed again to determine moisture content. Final moisture contents included both the original conditioned mass as well as any moisture that moved into the wood from the wetting exposure.

The data were averaged by distance from the surface for the nine crosscuts from each block then maps were created showing moisture distribution by depth. These maps are primarily visual and intended to show the rate and degree of moisture penetration inward when subjected to overhead wetting.

3-RESULTS AND DISCUSSION

Moisture uptake in the blocks was linear with time although the moisture appeared to be concentrated in the first four veneers of the panels (Figure 4). Moisture content increased approximately 5 % in the first day of wetting and eventually increased by almost 20 % of the original level. Leakage issues led to some wetting of the underside of the test pieces, which skewed the data, but the overall trend was sharply decreased moisture levels with distance from the upper wetted surface (Figure 5). Panels exposed to wetting for 24 days also exhibited some buckling and delamination of the upper veneer. The results indicate that moisture continue to be absorbed from the exposed surface over time and illustrates the need to continually manage moisture intrusion during construction. This can be especially important when strucutres are erected during wetter periods as repeated wetting with minimal drying in between can lead to elevated moisture levels deeper in the panel.

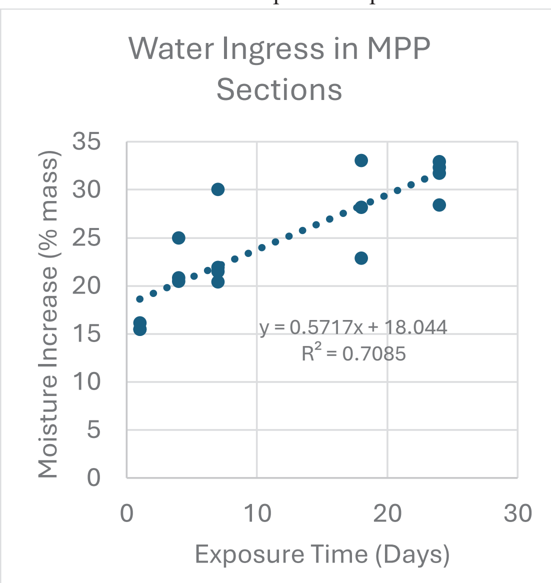

Figure 3. Moisture uptake in sections of mass ply panels exposed to wetting for 1 to 24 days.

Dissection of blocks following wetting supported the initial observation that water was rapidly absorbed by the upper veneers and then slowly moved deeper into the panel. Moisture contents of samples from the upper 15 mm of the panels increased from ~12 % at time zero to 66 % after 18 days. Levels in the 15 to 30 mm zone were similar to the starting point for the first four days, then gradually increased to ~20 % over the next 20 days (Table 2). While the moisture levels near the surface were well above those required for initiation of fungal decay, the levels further from the surface remained below that level after 24 days [16]. It is important to note that moisture will continue to diffuse inward over time, even as the upper surface is allowed to dry. This would eventually result in elevated moisture levels deeper in the wood that could support fungal growth. Parallel studies on CLT have found moisture intrusion further inward from the surface, but these increases were primarily associated with non-edge-glued joints [10].

Mass ply panels present a very different geometry for moisture intrusion. Lathe checks in individual veneers can facilitate moisture ingress, but the presence of glue lines every ~3 mm creates a discontinuous path that could inhibit further diffusion inward. However, previous studies suggest that gaps in bond lines can allow water movement, albeit at lower rates than would occur in non-bonded veneers clamped together [17] Thus, prolonged wetting will allow moisture to move deeper into the panel. This creates issues related to both panel stability and subsequent drying. Rapid drying is more likely to lead to disruption of the wood/resin interface, resulting in delaminations while prolonged wetting is likely to support fungal attack [18]. These contrasting issues make moisture exclusion an important aspect of panel installation.

Table 2. Moisture contents of sections cut from different distances inward from the surface of MPP blocks exposed to moisture for 1 to 24 days.

Distance from surface (mm)	Moisture Content (%)				
	1 Day	4 Days	7 Days	18 Days	24 Days
0 to 15	43.82 (2.66)	43.71 (6.69)	65.94 (3.91)	66.23 (4.81)	42.43 (7.67)
15-30	13.30 (0.78)	13.83 (1.04)	19.20 (2.58)	23.05 (3.98)	22.53 (1.82)
30-45	10.21 (0.51)	13.02 (1.90)	11.12 (0.65)	15.49 (1.98)	17.45 (0.81)
45-60	9.55 (0.82)	12.02 (0.54)	11.39 (1.14)	15.97 (2.62)	17.98 (0.67)
60-75	9.60 (0.81)	13.59 (0.82)	10.99 (0.45)	18.02 (4.73)	22.91 (1.60)
75- 90	9.83 (0.42)	40.50 (4.17)	10.94 (0.55)	33.43 (23.70)	57.71 (10.94)
Avg.	16.05(1.00)	22.78 (2.53)	21.60 (1.55)	28.70 (6.97)	30.18 (3.92)

[a]Values represent means of 3 or 4 blocks per exposure time while ``figures in parentheses represent one standard deviation.

It is useful to visualise moisture movement into the substrate. The panels were composed of a mixture of Douglas-fir heartwood and sapwood and there was no way to easily determine whether a particular veneer was contained either material. However, this species has a relatively thin sapwood, meaning that most of the veneers will be composed of heartwood. Sapwood is fairly permeable and easily penentrated by liquids. Douglas-fir heartwood is usually much less permeable and should resist moisture movement. The combination of heartwood and the presence of gluelines should slow moisture

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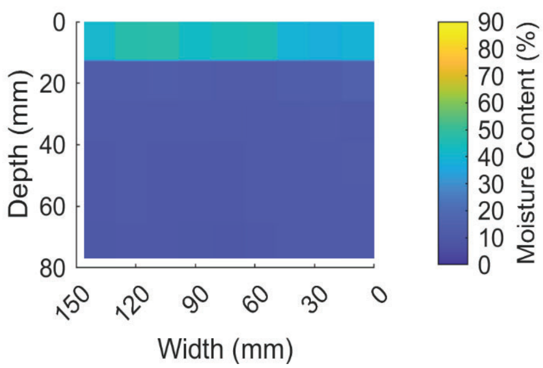
movement from the surface inward. Thus, while moisture ingress into the first four veneers was relatively rapid, further movement inward was more limited. Moisture levels were elevated in the next zone after 18 days with further increases 30 to 45 mm inward from the surface after 24 days of wetting. Increased moisture levels further inward from the surface will complicate drying after the building is completed and increase the risk of internal stressses that lead to bond failure. It is unclear what effect any internal stress will have on the panel once in service.

Figure 5. Cross cuts of an MPP panel showing moisture intrusion (darkened area above the marker) after 7 days of wetting.



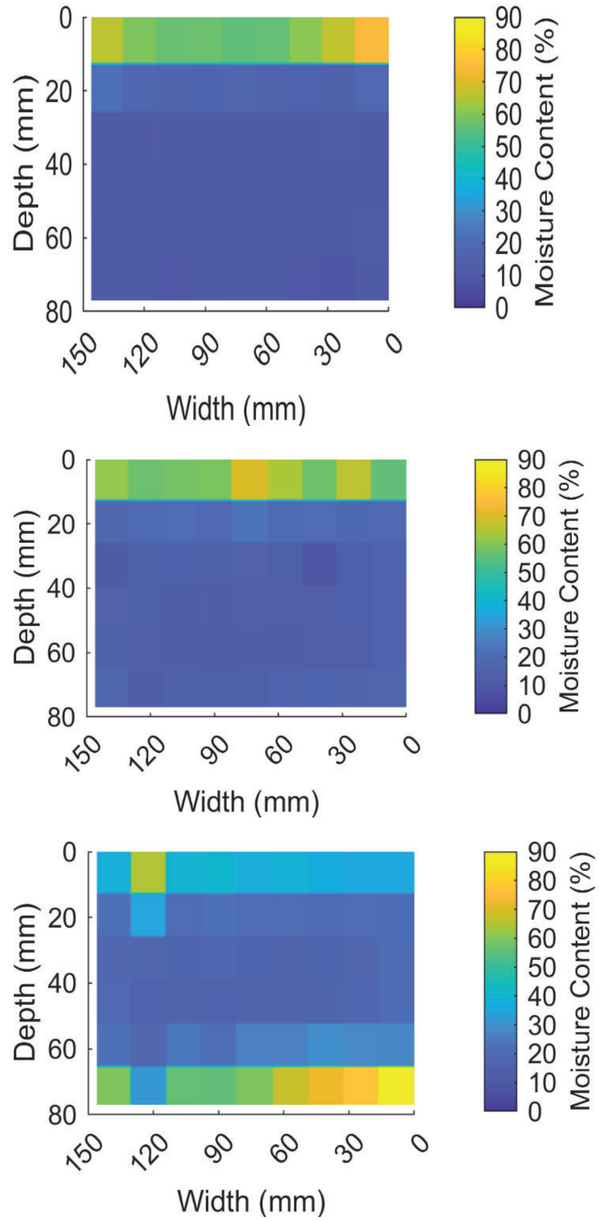


Figure 6. Examples of moisture distribution in MPP subjected to wetting for a) 1 (top), b) 7 days, c) 18 days, or d) 24 days (bottom) where increasing yellow signifies higher moisture levels.

Moisture management requires a comprehensive, integrated approach beginning at the point of manufacturing that includes close adherence to maximum moisture tolerances, protection from wetting in transport and storage on site, and finally, rapid removal of standing water during construction. Failure to remove water that accumulates from periodic rainfall events clearly results in rapid water absorption on the surface and prolonged wetting ensures that this moisture moves deeper into the wood where it will complicate drying. Taping of joints during construction and factory-applied water repellent barriers can help mitigate absorption, but will never completely limit ingress.

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A well managed program to minimise moisture ingress during erection might incorporate the following:

1. Application of a water repellent at the time of manufacturing- ideally after any cutting has been performed.
2. Wrapping in a water-resistant barrier for transport and storage on site.
3. Just-in-time delivery to minimise the risk of damage to the barriers on site.
4. Taping of any floor joints as soon as possible to minimise water ingress to the levels below.
5. Capping of any upright members to minimise downward movement of rainfall.
6. Regular sweeping of any ponded water that accumulates after a rainfall.
7. Slow introduction of air-flow to help dry members while minimising the risk of deformation.

All of these elements will help reduce moisture accumulation until the building is covered.

An equally important element in building performance will be monitoring moisture levels at selected locations over time after construciton is complete. All buildings eventually leak. Placing moisture sensors near toilets, kitchens and in the roof will allow building managers to detect and address moisture changes resulting from plumbing failures or leaks before these reach levels that lead to mould or decay. These sensors are not specific for wood as monitoring makes sense for any buidling regardless of the material employed.

4- CONCLUSIONS

- Moisture intrusion into MPP occurred within 24 hours but was concentrated in the upper 4 layers. Moisture levels were above 20 % in the upper layers.
- Prolonged exposure resulted in a gradual moisture increase deeper in the panel.
- The rapid ingress of moisture emphasizes the importance of minimising exposure and removing any accumulations that occur to minimise the need for post-construction drying.

5- REFERENCES

[1] Karacabeyli, E. and B. Douglas (Eds.). 2013. CLT Handbook: cross laminated timber. Special Publication SP-529E. Bi-national Softwood Lumber Council. USDA Forest Service, Forest Products Laboratory, Madison, WI.

[2] American Wood Council (AWC). 3034. 2024 National Design Specification (NDS) for wood construction. AWC, 50 Catoctin Circle NE, Suite 201, Leesburg, VA 20176

[3] Singh, T., D. Page and I. Simpson. 2019. Manufactured structural timber building materials and their durability. Construction and Building Materials, 217, 84-92.

[4] Kirker, S. Lebow, M. Mankowski; H.M. Barnes, and J.J. Morrell. 2018. Durability of mass timber structures: The biological side. Wood and Fiber Science 50:110-127.

[5] Udele, K. E., J.J. Morrell, and A. Sinha. 2021. Biological durability of cross-laminated timber—The state of things. Forest Products Journal, 71(2), 124-132.

[6] Udele, K.E, A. Sinha, and J.J. Morrell. 2023. Effects of re-drying on properties of cross-laminated timber (CLT). J of Building Engineering https://doi.org/10.106/j.jobe.2023.107298.

[7] Cappellazzi, J., M.J. Konkler, A. Sinha, and J.J. Morrell. 2020. Potential for decay in mass timber elements: A review of the risks and identifying possible solutions. Wood Material Science and Engineering 15:351-360. DOI 10.180/18480272.2020.1720804

[8] Austigard, M. S. and J. Mattsson. 2020. Fungal damages in Norwegian massive timber elements–a case study. Wood Material Science & Engineering, 15(6), 326-334.

[9] Lima, D. F., S. Duarte, J.M. Branco, and L. Nunes. 2024. Mass Timber Buildings: The associated risks of rainwater exposure during construction in the Portuguese climate. Journal of Building Engineering, 98, 111110.

[10] Morrell, J.J., I.N. Morrell, D. Trebelhorn, and A. Sinha. 2018. Moisture intrusion in cross laminated timber and the potential for fungal attack. World Conference on Timber Engineering, August 20-24, Seoul Korea.

[11] Olsson, L.2021. CLT construction without weather protection requires extensive moisture control. Journal of Building Physics, 45(1), 5-35.

[12] Riggio, M., E. Schmidt, and G. Mustapha. 2019. Moisture monitoring data of mass timber elements during prolonged construction exposure: The case of the Forest Science complex (Peavy Hall) at Oregon State University. Frontiers in Built Environment, 5, 98.

https://doi.org/10.52202/080513-0319

[13] Schmidt, E., and M. Riggio. 2019. Monitoring moisture performance of cross-laminated timber building elements during construction. Buildings, 9(6), 144.

[14] Shirmohammadi, M., W. Leggate, and A. Redman. 2021. Effects of moisture ingress and egress on the performance and service life of mass timber products in buildings: a review. Construction and Building Materials, 290, 123176.

[15] Wang, J.Y. and T. Thomas. 2016. Assessment of construction moisture risk for mass timber components in Brock Commons Phase I Project. Report to Natural Resources Canada, FPInnovations, Vancouver, BC.

[16] Zabel, R.A. and J.J. Morrell. 2020. Wood microbiology, Academic Press, San Diego, CA.

[17] Bolton, A.J. and P.E. Humphrey. 1994. The permeability of wood-based composite materials. Holzforschung 48:95–100

[18] Siau, J.F. (1995) Wood: Influence of moisture on physical properties. Department of Wood Science and Forest Products, Virginia Polytechnic Institute and University, Blacksburg, VA.