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MOISTURE INGRESS AND MOVEMENT PATTERN IN AUSTRALIAN CLT PANELS – A PILOT STUDY

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ABSTRACT: Australian Radiata Pine Cross Laminated Timber (CLT) panels were subjected to different methods aiming to increase the overall moisture content (MC). These methods were chosen to simulate scenarios of free water contact and high humidity, which are common in subtropical climates like Australia. To mimic free water exposure, CLT samples were submersed in water, while environmental chambers were used to simulate high humidity events over different duration. Specific moisture targets were set at 20% MC for high humidity and 30% MC for free water. After achieving the desired moisture levels, the distribution of moisture through CLT panels was assessed for each method. A grid system was developed to map moisture pockets within the panels and identify pathways for moisture ingress. The findings indicate that CLT panels are unlikely to reach moisture contents above 20% MC when exposed to high humidity. However, exposure to free water resulted in a rapid increase in moisture content well above 30% MC. This suggests that heavy rain and flash flooding events, and plumbing leaks pose significant concern for CLT, warranting further investigation.

KEYWORDS: CLT, moisture content, subtropical, Radiata Pine

1 – INTRODUCTION

Recent years have seen an uptake of mass timber in Australia as an alternative to steel and concrete. Mass timber is generally considered engineered wood products (EWP) such as glue-laminated timber (GLT), laminated veneer lumber (LVL) and cross-laminated timber (CLT). While CLT has been used extensively and successfully in the Northern Hemisphere, it is a reasonably new addition to the Australian market. Australian latitudes present climatic challenges to achieve a similar success.

Australia's predominately sub-tropical climate increases the likelihood of increasing moisture content in timber products due to frequent and intense rain events in the wet season and lasting high atmospheric humidity providing low drying capacity for the building elements to dry. Australian design standards [1] assume if seasoned timber (< 15%) is installed and kept dry over the design life of the building (not exceeding 15% moisture content (MC) for lengths of time more than 12 months). However, timber including CLT can get wet during and after construction therefore increasing its moisture content. Whilst it may return to its initial MC if well-ventilated and dried out, the risk exists that moisture remains trap in the product.

There is an increased likelihood of severe water exposure during construction in Australia due to climate compared to other locations, presenting a challenge to the dry-use assumptions put forward in design standard and practice. This points to a lack of information for contexts like Australia and warrants further research in this area. A pilot study has been conducted as a preliminary work to inform future research to assess self-tapping screw withdrawal performance in CLT at elevated moisture content and moisture content cycling as both situations may lead to loss of structural capacity. The aim of this pilot study was to increase the moisture content of small Radiata pine

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CLT samples to 20% and 30% MCs respectively and to evaluate the MC distribution in the samples. Another objective was to evaluate different methods to deliver the MC targets, simulating therefore MC increase due to free water contact and high humidity. Both exposures result in increasing MC in wood.

2 – BACKGROUND

Wood is a hygroscopic material that either adsorbs or desorbs water from/to its surroundings (air humidity or watering). The MC of wood expresses the mass of water in the wood relative to its oven-dry mass [2]. Equilibrium moisture content (EMC) is reached when wood is neither gaining nor losing moisture under a given set of conditions, i.e. temperature and relative humidity remain constant [3]. Wood is also an orthotropic material where the rate of water uptake differs between its orthogonal directions with longitudinal (exposed end grain) having the fastest uptake. Fibre saturation point (FSP) is reached when the cell wall is completely saturated with no water in the cell lumina. For most species FSP averages about 30% MC. Moisture content can also increase due to contact with liquid water (Absorption) and can increase above FSP [3]. EMC of wood as a function of dry bulb temperature, wet bulb depression and relative humidity has been well established and is applied to environmental chamber setting amongst other applications [4]. However, most of this work was done on solid small rectangular wood sections assuming that engineered wood products such as CLT's uptake and distribution responds same or at least similarly.

CLT is a panel product where the boards are assembled in layers. The boards in each layer are oriented in the same direction and pushed against each other. Each adjacent layer of boards is oriented orthogonally to the next one. In between the layers of boards adhesive is applied and the layers are pressed together. In addition, depending on individual manufacturing practice adhesive is or is not applied on the edge of boards. If unglued, the adhesive applied in between the layers squeezes out between the boards providing additional adhesion between the unglued edges. There is also an allowance for gaps between boards permissible under various standards. Australia does not have a manufacturing or design standard for CLT where importers rely on "country-of-origin" or International Standard Organization (ISO) standards and local manufacturers either use European Normative (EN) or ISO standards.

Australia has currently two CLT manufacturers producing softwood CLT made from locally grown Pinus radiata (Radiata pine). Until recently Australian hardwood CLT made from Eucalyptus nitens (Shining gum) was also available. The market demand of CLT and other wood products in Australia cannot however be met by local production and requires additional overseas supplies. Imported CLT is predominately from Europe made from softwood mixes including Picea abies (Norway, Baltic, White spruce).

MC monitoring studies conducted overseas on CLT and glued laminated timber products have shown that CLT can experience MCs as high as 45% when exposed to free water, in this case snow in Oregon. However, CLT generally returns to 15% MC in ambient conditions [5]. Australian studies found MCs up to 28.2% in a residential building due to leaking cladding while MCs ranging from 20.5% to 21.7% was recorded in a CLT trial building [6]. Studies of exposure to free water in different direction (faces) of CLT section showed that moisture content reaches higher than FSP for all directions after few hours of free water pooling on surface of the panel [7, 8]. Meanwhile, monitoring the drying process of wetted panels using fan and ambient drying conditions showed moisture gradient built up within the panel depth [8]. These studies have also provided evidence that moisture pockets remain within the CLT panels when the surface has dried out. This could be due to the unglued edges and/or gaps between boards that create potential pathways for water ingress deep into the CLT panels when exposed to free water.

Wood can be subjected to MC variations using different methods. Such methods include submersion and environmental chambers. The submersion method is well suited for large cross sections and quantities as it is less restrictive than a chamber. It is also very adequate to simulate exposure to free water or achieve MCs beyond FSP and cost effective. *Sinha et al.* [9] applied submersion and bagging in durability trials conducted on CLT panels. They firstly conditioned the CLT samples in a standard room before submersing them in water for five weeks at room temperature until the samples reach 40% MC. The high moisture content had been targeted to aid fungal growth. Meanwhile, the bagging was only used to provide favourable fungal growth conditions, not to even moisture distribution in the samples.

Environmental chambers allow to set desired conditions such as relative humidity and temperature in a more controlled manner than submersion. The benefits of chambers include the high accuracy in predicting EMC, low variably in results (MCs) and even MC distributions throughout the samples. They are more suitable to simulate "tropical" climates or exposures to high humidity environments such as those encountered in Australia. Their limiting factors are however their size – inadequate to accommodate samples effectively (large cross sections) – and some fluctuations of their environment – consistent settings difficult to maintain over long periods of time (pressure drop). Furthermore, they require a long time to reach high target moisture contents (large samples require more time) and MCs above FSP are out of reach. Finally, their cost of running is also high.

3 – PROJECT DESCRIPTION

This pilot study is part of a larger project that studies the impact of higher and cyclic moisture content changes on the withdrawal performance of self-tapping screws in CLT panels. It is a small-scale trial about imposing moisture uptake on CLT panels by exposing them to high humidity environment or free water. It also addresses two key aspects: evaluating the feasibility and repeatability of exposure methods and studying moisture distributions and patterns at different moisture content levels.

Specifically, the aim of the pilot study was to simulate realistic scenarios of humidity exposures (humid/tropical environments and heavy rain) occurring in Australia and to determine their effects on the moisture content on and in CLT panels. Another objective was to establish repeatable methods that can be applied in future work of the project.

4 – EXPERIMENTAL SETUP

4.1 SAMPLES

The samples were cut from commercial grade Australian Radiata Pine 5-layer CLT as supplied by the manufacturer, i.e. total of 8 samples with approximate dimensions of 480 mm long, 120 mm wide and 140 mm thick were cut. The average MC of the CLT at cutting was 10%.

The samples were separated into four series with two pairs each, labelled (a) and (b) due to variations in the exposure protocol. After wetting or conditioning, the samples were cut into smaller sections to a determined pattern (see Fig. 1) to assess the MC and MC distribution, i.e. identification of potential variations throughout the samples. This assessment of the samples and MC investigation was conducted by the oven dry method [2].

4.2 EXPOSURE PROTOCOLS

Two methods were considered to increase MC of the samples (1) by free water uptake (submersion) – Series 1 to 3 – and (2) by high humidity conditions (environmental chamber) – Series 4. MC targets of 20% and 30% were identified to meet the study requirements. However, a MC of 45% was also targeted as this measurement had been reported in CLT panels experiencing free water exposure [5]. Anticipating rapid and "uncontrollable" moisture uptakes with the submersion method and the challenge to timely remove the CLT samples, a tolerance of ± 3% of the MC target was established. Furthermore, achieving high MCs of 30% or more were regarded as difficult to reach with the chamber, also considering the size of the CLT samples.

The initial weight for all samples was recorded at average ambient temperature (25°C) and relative humidity (75%) condition after cutting. The weights of the samples were recorded while undergoing and at the end of exposure. The timing of these measurements allowed to verify how accurate weight relates to the MC of the samples. The purpose of this experimental organisation was to develop simple, practical and fast estimates to identify the required exposure time, i.e. to effectively time the removal of the samples from high moisture or water exposure.

For the free water exposure paired samples were placed under water at ambient temperature in a lab environment. The duration varied from one week (Series 1), two weeks (Series 2) and four weeks (Series 3). When the specified time was reached both samples were removed from the tub of water, excess surface water was wiped off with a cloth. Both samples were weighted, and Sample (a) was cut into smaller sections in agreement with the pre-determined pattern, as follows and shown in Figure 1:

1. The sample was sliced vertically in 40-mm increments first (11 slices)

2. Each slice was cut horizontally along the gluelines into five smaller sections (first, third and fifth section 30 mm thickness, second and forth 20 mm thickness).

This cutting pattern produced 55 small sections of 40 x 120 x 20/30 mm from each sample.

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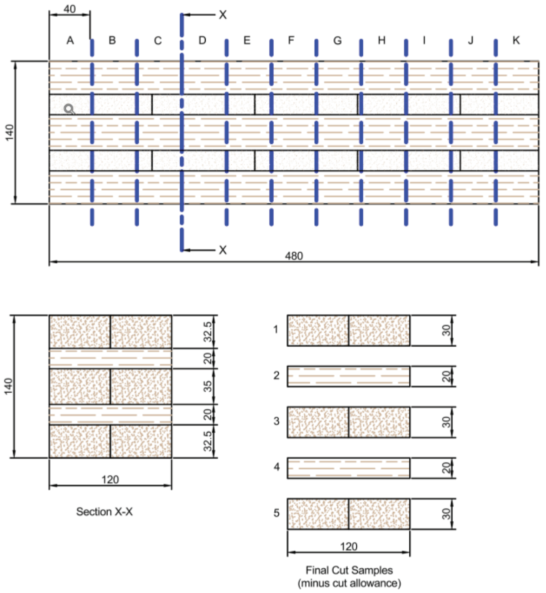

Figure 1. Schematics of CLT sample full length, cut vertically into 40 mm increments, and cut horizontally into five smaller sections.

Each section was labelled, weighted and placed in the oven at 103°C, thus following the method put forward in AS/NZS 1080.1 [2] to determine the MC of each section. Fig 2 shows a full samples and slice cut from the sample.

Meanwhile, Sample (b) was placed in a sealed heavy-duty plastic bag and placed in a chamber at 4°C. The CLT was required to be kept at a low temperature to avoid mould growth while the bag was anticipated to produce a sealed environment and aid even moisture distribution in the samples and reduce drying of the outer surfaces. After four weeks of this conditioning, Sample (b) was removed and processed similarly to Sample (a), i.e. cut, labelled, weighted and MC tested. This process was undertaken for Series 1, 2 and 3.

Both samples of Series 4 were placed in an environmental chamber, whose settings were 35°C and 90% relative humidity (RH). Sample (a) was removed after 21 days while Sample (b) stayed in the chamber for 55 days at the same settings and another three days where the temperature remained at 35°C but the relative humidity was increased to 93%. The moisture uptake of the samples was monitored through ongoing weight measurements. These records were also used to approximate the MC of the samples estimates.

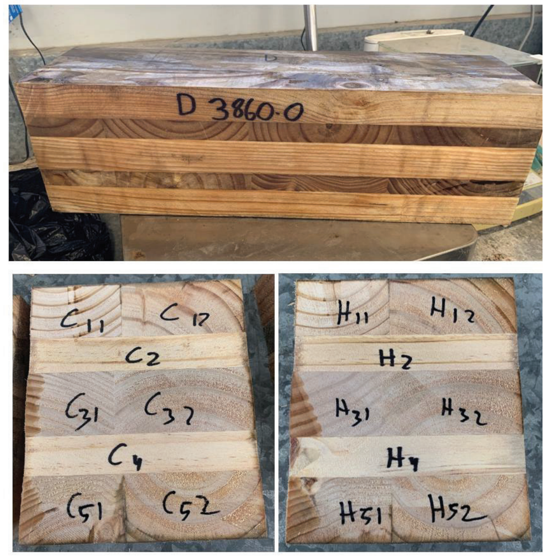

Figure 2. Full section CLT after submersion trials (with two smaller sections to be cut into five).

5 – RESULTS

Series one was removed from free water exposure after one week and processed as outlined in Section 4.2. Sample 1(a) showed an average of 38% MC, where four of the small sections were between 19 to 20% in the centre of the panel. The sections cut at both outer vertical edges were 59% and 58% respectively, the highest in the record of Sample 1(a). Furthermore the top layer was 36% and the bottom layer of the CLT was 48% on average.

Sample 1(b) exhibited an average MC of 40%, no sections showed MC below 20%. The sections cut from the outer vertical edges also had much higher MCs, ie. 47% and 49%. The top layer was 38%, while that of the bottom was 58%.

Fig. 3 depicts the MCs of each small CLT section and the MC distribution across Series 1 samples. The peaks of MC occurring at the end of the samples can be clearly identified. Fig 3. also suggests the centre of the sample experienced no to very little moisture intake.

The CLT sections cut from Sample 2(a) (two weeks submersion, not bagged) averaged 59% MC, with many sections within the lowest MC range of 31% located in the centre of the sample. Sections from both outer vertical edges exhibited 78% and 79% MCs respectively, the highest in the set. The top layer was 72% MC, and the bottom layer was 67% MC on average.

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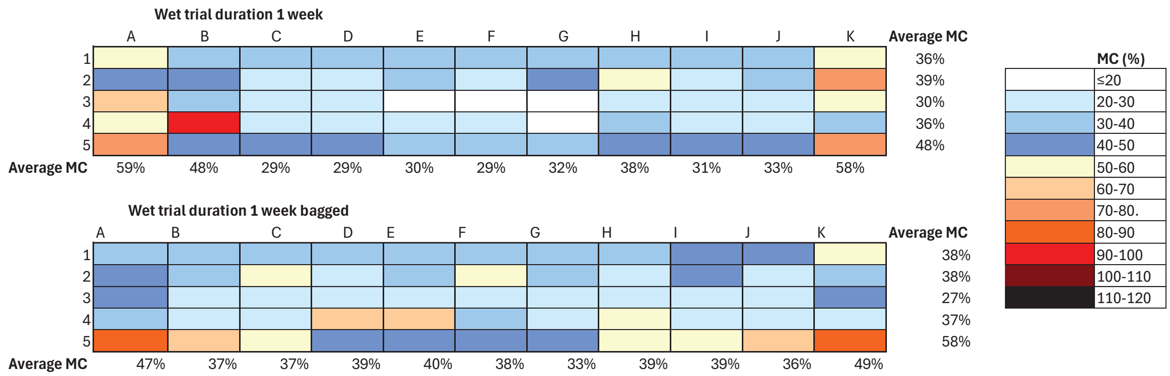

Figure 3. Moisture content profile – Side view CLT- Submersion duration one week.

Sample 2(b) was bagged for four weeks after two weeks of submersion. It showed an average of 49% MC. A drop of 10% MC compared to 2(a) with the same submersion time, noting MC of 2(a) was measured immediately after submersion. Sample 2(b) had a total of six smaller sections within ±3% of 30% in the core of the CLT, however the entire core section remained lower in MC than its paired Sample 2(a). The sections extracted from the outer vertical edges had much higher MCs of 60% and 68%. Top layer was 60% MC and bottom 46% MC.

Fig. 4 shows the locations of the sections of Samples 2(a) and 2(b) and their average MCs. It also depicts the average MC distribution in the samples and its layers.

The longest free water submersed Samples 3(a) and 3(b) (four weeks), Sample 3(a) exhibited an average MC of 60%, while an average 42% MC was measured in the centre layers. The outer top layer showed an MC of 62% and the bottom layer 70% MC. The samples cut from the vertical outer surface had MCs of 87% and 86%.

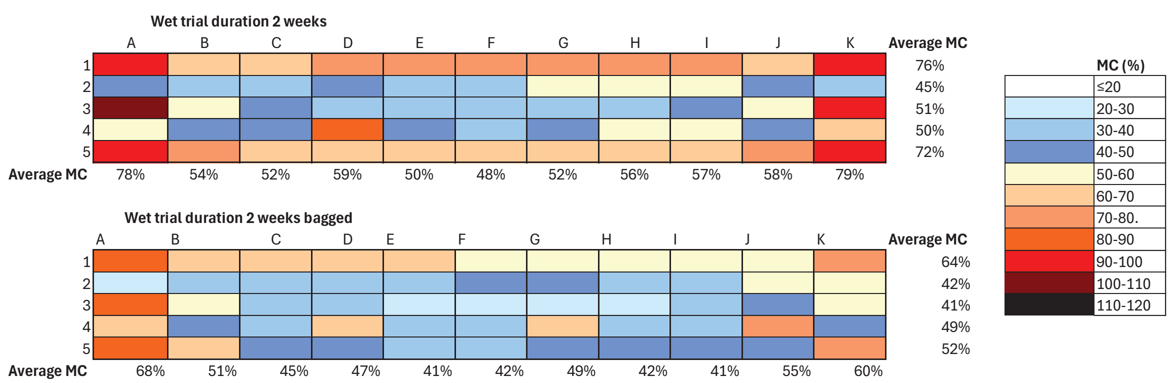

Figure 4. Moisture content profile – Side view CLT- Submersion duration two weeks.

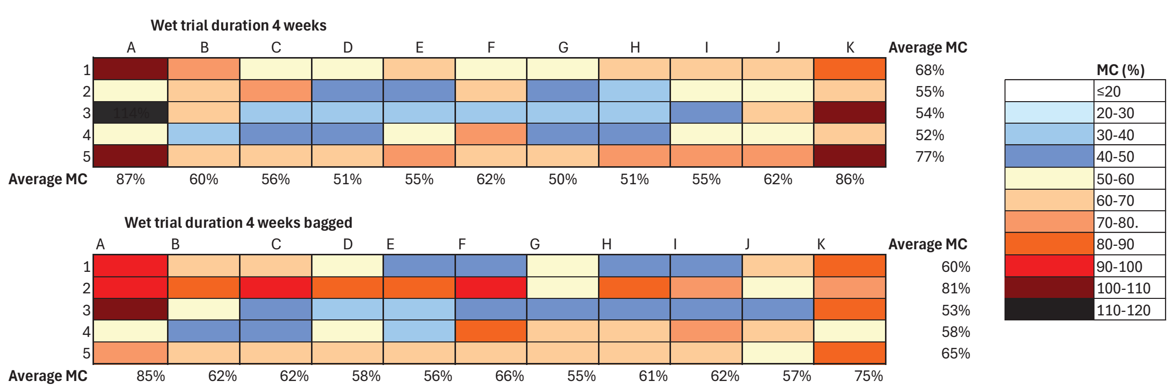

Figure 5. Moisture content profile – Side view CLT- Submersion duration four weeks.

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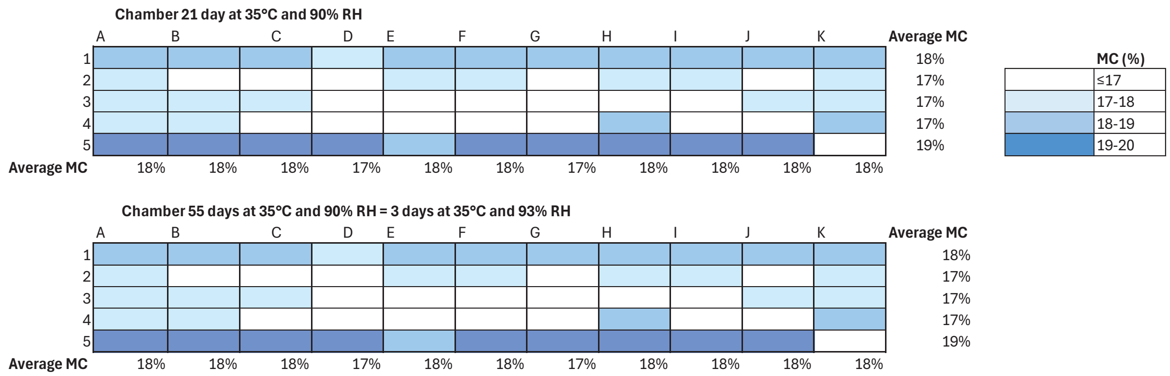

Figure 6. Moisture content profile – Side view CLT- Environmental Chamber.

Sample 3(b) had an slightly higher average MC of 40% compared to 3(a), and its centre layer showed an average MC of 44%. The top layer and bottom layers of 3(b) had average MCs of 53% and 61% respectively. As previously obersved, the sections extracted from the vertical outer surface exhibited the highest average MCs of 85% and 75%. Fig 5 illustrates the section location, their average MCs and magnitude of moisture content.

Samples 4(a) and 4(b) were conditioned in high relative humidity environments using environmental chambers. Sample 4(a), removed after 21 days of exposure, showed an average MC of 18%. An average MC of 17% was recorded in the inner three layers of the sample, while average MCs of 18% and 19% were measured in the top and bottom layers respectively.

Sample 4(b) was exposed for an additional 58 days with an increased relative humidity (+3%) for the last three days. An average MC of 18% was measured for Sample 4(b), i.e. similar to Sample 4(a) that was subjected to a shorter exposure. Sample 4(b) exhibited average MCs of 18% in its outer top layer, 19% outer bottom layer, and 18% at both edges (vertical outer surfaces).

Fig. 6 depicts the average MC distribution in Samples 4(a) and 4(b), showing the locations of the sections and their their average MCs.

6 – DISCUSSION

The submersion – free water – and enviromental chamber – high relative humidity – successfully achieve to increase the MC of CLT panels. The submersion method encouraged rapid and extreme water intakes, while the environmental chamber method imposed slow and mild MC increase to the samples.

The weighting of the samples – precutting shape – did not show a good correlation with the measured overall average MC of the samples. These measurements were also unhelpful to estimate the moisture intakes of the samples with the submersion method. On the other hand, the ongoing weight measurement of the climate-chmaber conditioned samples showed a good correlation with 0.5% of the actual or final average MC of 18% of the samples.

The one-week water submersion proved too long to target 30% MC. For future work, the exposure will be reduce and further refined. A length of exposure between one to two weeks appears suitable to achieve an MC of 45% that is another MC target for future work.

No distinct pattern of moisture uptake could be identified with the submersion method, ie. no moisture pockets were observed. This may indicate the glulines form waterproof membranes and some measure of edge gluing.

The one-week bagging seems to have no effects on evening the average MC distribution in the samples. It did however prevent the ends from drying out but it appears to encourage water or moisture migration to the bottom of the sample.

The environmental chamber produces, as expected, more evenly distributed MC throughout the samples than submersion. However, the duration to achieved substantial MC increases is very detrimental to the environmental chamber method. Environmental chamber conditioned samples also exhibited effective average MCs of about 18%. Eighteen percent MC seems to correspond to the limits of this method. The environmental chamber therefore appears inadequate for future work where MCs above 18% are required.

Samples that experienced submersion exhibited more heterogenous MC distributions than environmental - chamber conditioned samples. Submerged samples showed peak of MC in their extremities, i.e. outer layers and ends. They also tend to uptake more moisture in the bottom layers. Observations of the samples conditioned in the environmental chamber allow to better visualise and confirm the migration of moisture through the layers of the CLT panel.

Both methods will eventually be used for future works of this research. The environmental chamber can produce 18% MC in CLT samples of this size which is with 20±3%MC. The submersion method requires additional work to adjust the submersion time to achieve ±3% of 30% as the main target MC. It is anticipated the reduced and optimise exposure time will also improve the MC distribution in the samples – samples experiencing one-week submersion did exhibit more even MC distribution than samples with longer durations. Further consideration and refinment of the conditioning method (post submersion) to achieve a better MC distribution may also be required.

As the highest moisture content was measured on the edges while the centre of the panel was averaging 30% MC with a reasonable even distribution. Submersion of less than a week is expected to reduce the high uptake in the outer layers which should generate less variability and close to the average target of 30% MC overall. A conventional pin moisture meter in conjunction with weight measurements will be used to aid a more accurate prediction as to when the target MC is reached.

7 – CONCLUSION

Two methods, submersion and environmental chamber, to impose water intakes of CLT panels have been investigated with the aim to expose these panels to Australian climatic conditions. These methods simulate the effects of free water caused by heavy rain during construction and leaks when the building is in service and high humidity.

The performance of both methods have been evaluated. Submersion – exposure to free water – achieves rapid increase of MC in the samples and very heterogenous MC distribution throughout the samples, with the outer layers and ends of the samples exhibiting higher MCs (36-70%) while MCs of the centre sections ranging 31-42%. Meanwhile samples exposed to high moisture environment (environmental chamber) required long exposure to reach the 20% MC target. The MC distribution of these sample was homogenous with less differences observed between their centre and outer sections.

This investigation informs the practice adopted for future works of this research where high MCs and MC variations are required to condition samples. The submersion approach is preferred to prepare the samples. However, it will first be refined and optimised to achieve the desired MC targets, while the enviromental chamber will be used for specific cases of humidity conditions. This limited use of the environmental chamber is guided by the extended duration of exposure to reach the MC target.

8 – ACKNOWLEDGEMENT

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