Delay of Onset of Charring to CLT Using Different Encapsulation Materials

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ABSTRACT

The testing completed in the research evaluated the fire performance of protective linings applied to a Cross Laminated Timber (CLT) Backing. All linings tested were fixed to the CLT panel using 65 mm plasterboard screws. Modified ISO 834 ignition apparatus was used to test three different gypsum and three fibrous board linings.

Results showed the onset of char could be delayed by up to 26.5 minutes for the best performing fire rated gypsum boards. This time was achieved at a heat flux of 50 kW/m^2. As the heat flux was increased to 65 kW/m^2 the times decreased and the integrity damage to the boards increased significantly. The lowest performing lining in terms of time delay of char at the interface was the 12 mm magnesium board. The 12 mm lining allowed char at the interface in 15 minutes. Magnesium board was the only board not to be prepared in the 13 mm thicknesses.

Gypsum-based boards did not preform as well as the magnesium Board and fibrous lining when rated based on integrity. Standard gypsum performed the worst based on integrity showing large cracks at both heat fluxes. The magnesium and fibrous linings did not have any cracks at either heat flux. In total 20 tests were carried out on 6 different linings at 50 kW/m^2 and 65 kW/m^2.

1.1. Introduction

Cross-Laminated Timber (CLT) is an engineered timber product that entered the New Zealand market in 2011. XLam Ltd in Nelson manufactures CLT. Minimal testing has been carried out to determine the performance of the New Zealand product in fire scenarios.

CLT comprises of timber boards bonded together in perpendicular layers that form panels. XLam is the only manufacturer of CLT in the southern hemisphere and currently produces CLT from locally sourced Radiata Pine and Douglas Fir. Sheets of CLT are produced to various dimensions as desired by the client. The thickness varies from 60-200 mm and the panel size reaching a maximum of 15.1 × 3.3 m XLam, (2013).

CLT provides a number of advantages over traditional construction materials that gives it a competitive edge in the market. In particular, the increased speed of assembly due to prefabrication of structural elements makes it advantageous for clients looking to reduce construction time. Timber as a carbon sink also offers environmental advantages over a material like concrete, which produces large amounts of carbon dioxide during manufacture.

A gypsum cladding board consists of gypsum plaster inserted between two layers of heavy-duty paper. The raw gypsum mineral, is heated to a desired moisture content. The gypsum then has a range of additives and fibres added to form a plaster or slurry mix. Once the board is solid, approximately 3 minutes after forming, it is placed in a drying oven. In this research one standard and two fire rated gypsum boards were tested.

Magnesium Oxide Board is a versatile mineral board formed from a magnesium cement mixture and cast into thin cement panels. The product is used in residential and commercial building construction. Magnesium board is suitable for a wide range of general building uses and applications that require fire resistance mould and mildew control, as well as sound control applications and many other benefits. As an environmentally friendly building material. Magnesium board has strength and resistance properties due to very strong bonds between magnesium and oxygen atoms that form the magnesium oxide molecules, MagRoc (2011). This research tested 12 mm and 15 mm magnesium oxide boards

Magnesium boards can be used in place of traditional gypsum as wall and ceiling covering material and sheathing. It is also used in a number of other construction applications such as fascia's, soffits, shaft-linings and area separations, wall sheathing, and as tile backing (backing board) or as substrates for coatings and insulated systems, MagRoc (2011).

The fibrous board used in this testing is made from gypsum and recycled paper fibres. The gypsum and paper is hydrated to form a mixture and pressed into boards. This process involves high pressures before being dried and a water repellent applied. The boards are cut to standard sizes and distributed to site. These boards provide high stability and non-combustibility.

The fire rated gypsum board B is another gypsum based plasterboard panel designed to resist the effects of fire. Fire board B appeared to have many visual similarities to the Fire rated board A product. The product is design to provide from 30 to 240-minute fire resistance in accordance with AS/NZS 1530.4. Acoustic benefits are furthermore a property of the fire rated board B.

Traditionally the ISO 5657 apparatus tests is used to test samples at a constant heat flux. The heat exposure by the cone heater is done so in a horizontal plane for a traditional test. For this research, samples will be exposed in the vertical plane at a constant heat flux. A sample before testing is shown in figure 1.

Figure 1. CLT sample with a Magnesium Oxide lining pictured before commencement of testing

1.2. Objectives

There were 3 key objectives of this research. Firstly, the delay to the onset of char was desired for each of the linings. 3 gypsum board, 2 magnesium board and 1 fibrous board sample were all tested. The delay to onset was determined from experiment commencement until the CLT-lining interface reached 300°C (timber charring). The point at which timber is considered charred is 300°C according to Frangi et al. 2009.

The secondary objectives were to attain a visual inspection of each samples lining integrity at the completion of testing. The char rate between the interface and an imbedded thermocouple was additionally attained.

1.3. Literature Review

McTavish and Palmer (2013), and Aitken and Moser (2014) have carried out previous work on New Zealand CLT provided by XLam Ltd. These sets of research were carried out at the University of Canterbury.

McTavish and Palmer used the ISO 5657 ignition apparatus to determine a char rate for 100 mm × 100 mm CLT samples.

Aitken and Moser tested larger scale samples, 450 mm × 250 mm, in the University of Canterbury Electric Furnace. Both sets of research concluded with char rates of 0.83 - 0.87 mm/min for CLT. The char rates attained in each set of research are greater than the commonly accepted value of 0.65 mm/min, Standards New Zealand (1993).

Furthermore, Marc (2015) carried out research using a CLT compartment lined with 5/8'' (15.9 mm) type 'X' gypsum board. A small room compartment was submitted to a 'real' fire. Rooms were filled with expected living room fuels such as seating furniture and bookshelves and burnt to extinction. Fire loads were chosen to fall between the 50th and 95th percentiles for fuel loads based on a Canadian survey conducted by NRC Canada. Temperatures at various points throughout the compartment including the gypsum-CLT interface were determined via thermocouples. Of particular interest to this research is the temperature between the gypsum and CLT interface.

Type 'X' gypsum board is used in North America as a generic fire resistant gypsum board. The definition of type 'X' board is that it will provide a 60-minute load-bearing fire-resistance rating when one layer is fixed to each side of a stud wall. The wall can be either steel or timber. All type 'X' boards contain some fibre re-enforcing and may have other additives to improve fire performance.

Reports by FP Innovations (2013) and the IABSE SED Smith and Frangi, (2014) have been found and discuss the types of encapsulation of timber structures. These reports have been noted but are not entirely relevant for this research as they discuss encapsulation of timber in a construction aspect.

1.4. Materials and Methods

The protective linings being used in this set of testing are,

- 13 mm Standard Gypsum Board
- 13 mm Fire Rated (FR) Gypsum Board A
- 13 mm Fire Rated (FR) Gypsum Board B
- 12 and 15 mm Magnesium Oxide Board
- 13 mm Fire Rated Fibrous Board

The density for each of the chosen linings is found below in Table 1.

Table 1. Measured densities for each of the tested linings.

Lining	Density (kg/m^3)
Standard Gypsum	730
Fire Rated Gypsum A	830
Fire Rated Gypsum B	810
Magnesium Board	950
Fire Rated Fibrous Board	1150

All linings and CLT samples were cut to 250 mm × 185 mm. This was the largest size capable of fitting within the ISO 5657 apparatus. The depth of each CLT sample was 110 mm. The actual cone heater diameter and surface test area was smaller than this size.

Linings were fixed to the CLT using four 65 mm plasterboard screws. One screw set 30 mm in from each corner. This was the fixing scheme recommended by XLam for CLT panels. Each screw was to penetrate a minimum of 15 mm into the second CLT laminate.

⅛" thermocouples (3.2 mm) were installed at the lining and timber interface as well as imbedded into the CLT samples at an average depth of 10 mm. In order to install the thermocouple at 10 mm a ⅛" hole was drilled a depth of 125 mm into the sample from the outer edge. For a 250 mm × 185 mm sample the thermocouple is placed at 125 mm × 92.5 mm. The centre of each sample placement and therefore the thermocouples was positioned at the centre line of the cone heater. Figure 1 shows a sample prepared and installed in the modified ISO 5657 apparatus.

The point at which timber is considered charred is 300°C according to Frangi et al. 2009. Once prepared samples were placed in the modified ISO 5657 ignition apparatus and tested until the 10 mm thermocouple reached 300°C. For each experiment the apparatus is run for two minutes before any sample is installed. This allowed the heater to stabilise and a baseline to be attained. The baseline was later analysed to ensure all instruments were displaying the correct readout therefore validating the experiment. All data was recorded using a one second time step.

Tests were run at heat fluxes of 50 and 65 kW/m^2. These heat fluxes were chosen in order to be comparable with the work of McTavish and Palmer (2013). Due to sample availability, 2 sets of each lining were tested at each heat flux. The ISO ignition apparatus was calibrated at the beginning of each testing day to ensure correct heat fluxes were output.

At the completion of each test, the lining was removed as soon as practicable and the CLT sample was cooled with water to below 300°C. This prevented any further char of the sample.

The total change in thickness of the CLT sample at the centreline was also measured at experiment completion. This was done to verify the depths of the 10 mm thermocouple and attain a char depth of the CLT.

All errors used in this research are attained using the half range method. This was selected in order to be comparable with the work of McTavish and Palmer (2013), and Aitken and Moser (2014).

1.5. Results and Analysis

Prior to testing the moisture content and density parameters of each CLT sample was recorded. Moisture contents for samples were 9% ±1%. The density of CLT averaged 460 kg/m^3 ±13 kg/m^3.

A typical set of results is shown below in Figures 2 and 3. The data shows the thermal profile at the interface and at an imbedded depth into the CLT sample. Figure 2 displays the temperature with time for 13 mm Fire Rated Gypsum A and B samples, whilst Figure 3 is of the 12 mm and 15 mm Magnesium samples. The profiles are for a heat flux of 65 kW/m^2.

The data set shown highlights key features such as the temperature plateau at 100°C where the moisture in the sample is being driven back into the sample.

Approximate linear gradients were found between 100°C - 400°C of the interface thermocouple. This is expected, as the make-up of the linings is relatively uniform.

Beyond the latent heat of gasification plateau, the heating gradients varied between tests as the total char depth differed among samples. Samples with a greater char depth took longer for the imbedded thermocouple to reach 300 °C and therefore had a lesser gradient than samples with smaller char depths.

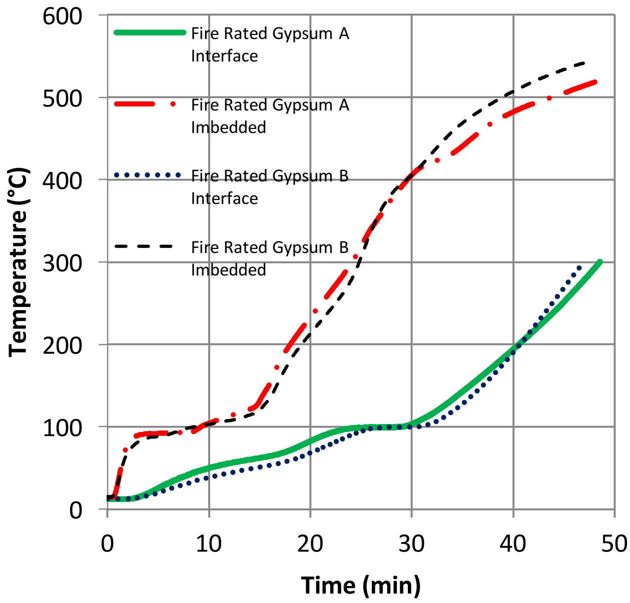

Figure 2. Thermal profiles for 13mm Fire Rated Gypsum A and B samples heated at 65 kW/m^2.

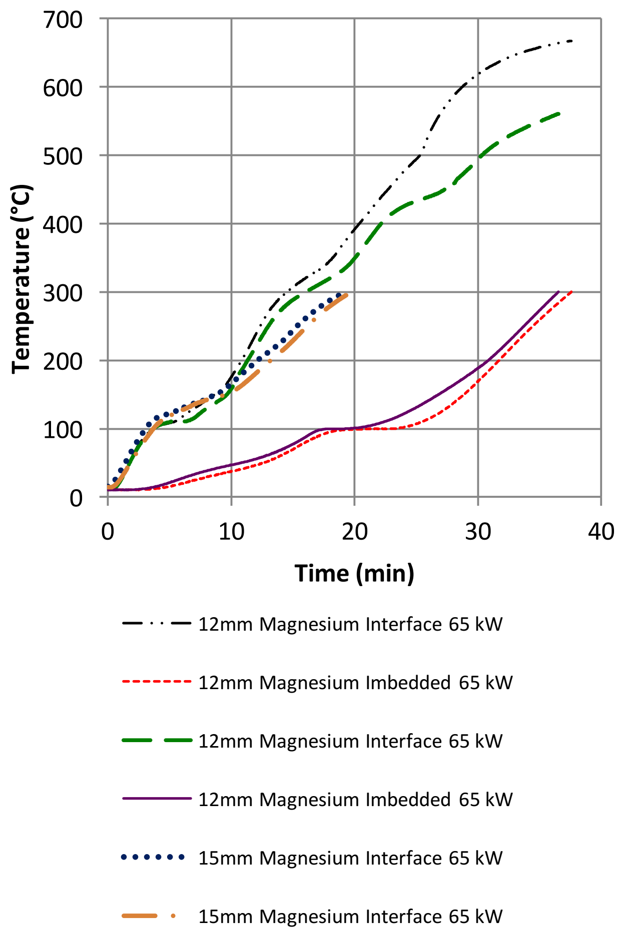

Figure 3. Thermal profiles for 12mm and 15mm Magnesium board tested at 65 kW/m^2.

Figure 4 shows the time for the interface to char under the protection of the protective linings.

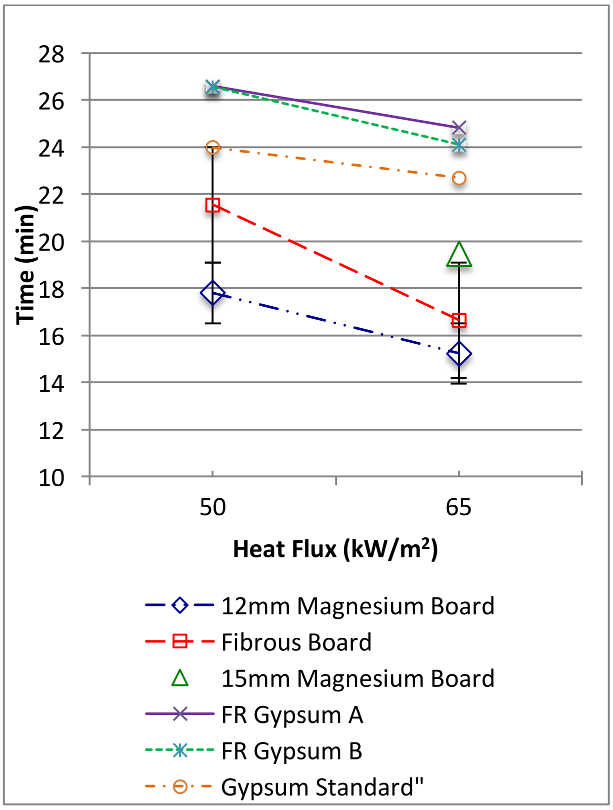

Figure 4 time to interface char when protected by respective linings.

Standard gypsum performed well lasting 24 and 23 minutes at 50 kW/m^2 and 65 kW/m^2 respectively. The biggest downfall of the standard gypsum was the integrity failure. Standard gypsum was the only product to show cracking that lead to the sample falling apart upon lining removal at completion.

The 12 mm Magnesium Board stopped temperatures above 300°C reaching the CLT sample by 18 and 15 minutes at 50 kW/m^2 and 65 kW/m^2 respectively. Using the gradient of the 12 mm Magnesium sample and the data point of the 15 mm board, it can be predicted that the 15 mm Magnesium sample would last approximately 22 minutes at 50 kW/m^2.

The Fibrous lining took slightly longer than the 12 mm Magnesium board to reach 300°C at the interface, this is expected as the Fibrous board is a slightly thicker sample. The Fibrous board showed no signs of integrity failure.

Furthermore, Figure 4 can be used to predict the insulation time for heat fluxes between 50 and 65 kW/m^2. Interpolating outside the range of heat fluxes tested can be done but in doing so caution is advised.

Due to the technical difficulties of drilling to a depth of 105 mm, the actual location of the thermocouple at the sample centre varied between samples. Table 2 shows the wide range of depths thermocouples were located and the respective char rates. These measurements where taken at the completion of testing with the char layer removed using a drop down measurement from the initial surface height. The largest results of this error were the varying wood density throughout the sample and deep drilling using a small diameter drill piece.

Using the time at which the interface begins to char and the time the imbedded thermocouple reaches 300°C; the charred depths of each sample can be used to attain a char rate. These char rates for each sample are likewise shown in Table 2.

Table 2 depths of thermocouple measure at completion of test once the char has been removed

Heat Flux (kW/m^2)	Sample	Imbedded Thermocouple Depth (mm)	Char Rate (mm/min)
50	Magnesium 12	11	0.46
50	Magnesium 12	10	0.50
50	Gypsum Std.	20.5	0.63
50	Gypsum Std.	3.5	0.63
50	Gypsum Std.	8.5	0.56
50	FR Gypsum B	11	0.41
50	FR Gypsum B	16	0.51
50	FR Gypsum A	11	0.53
50	FR Gypsum A	12.5	0.46
50	Fibrous Board	9	0.36
50	Fibrous Board	9	0.49
65	Magnesium 12	14.5	0.65
65	Magnesium 12	10	0.46
65	Gypsum Std.	9	0.40
65	FR Gypsum B	12	0.49
65	FR Gypsum A	13.5	0.61
65	Fibrous Board	11	0.54
65	Fibrous Board	12	0.48
65	Magnesium 15	-	-
65	Magnesium 15	-	-

No char rate was attained at 65 kW/m^2 for the 15 mm Magnesium Board samples. This was due to tests on these samples being terminated upon charring of the lining-CLT interface. The decision to terminate the test early on these samples was because of variations and imperfections in the CLT. These imperfections where determined to produced misleading results if tested. The imperfections in these CLT samples were not found in any of the other samples therefore char rates were attainable in them.

Char rates from table 2 can be compared with the rates attained by Aitken and Moser (2014) for the first 10 mm. The average char rate at 50 kW/m^2 and 65 kW/m^2 was 0.50 and 0.52 mm/min respectively in this research. Aitken and Moser attained a char rate over the first 10 mm of 0.74 ± 0.10 mm/min. This is higher than all values attained in this New Zealand CLT research. This shows that applying a lining to CLT will reduce the char rate over the early stages of a fire. There are a few significant changes between the methods used in each set of research that should be noted. The previous research followed the ISO 834 temperature profile and the CLT was directly exposed to the heating surface compared with ISO 5657 heating and a surface lining applied.

1.6. Discussion

A small number of data sets showed small variations in the interface temperature once charring (300°C) had occurred. This was due to movement of the interface thermocouple once a cavity opened. As the sample began to char, space between the lining and CLT increased. Small amounts of loose char were observed when the lining was removed from the CLT at test completion. It is expected the thermocouple fixing failed and allowed movement or a small amount of char covered the end of the thermocouple causing a shielding effect. Variations were only ever small deviations from the heating gradient and usually returned to normal within a minute. These variations had no effect prior to interface charring or the imbedded thermocouple reaching 300°C.

No 15 mm magnesium board samples were tested at 50 kW/m^2. This was due to a limitation in the number of CLT backing samples. 65 kW/m^2 was the more demanding of the heat fluxes and it was therefore decided to test two 15 mm magnesium board samples at this heat flux. Figure 5 shows a magnesium sample immediately after completion of a 65 kW/m^2 test. No integrity damage to the sample can be seen.

Integrally the magnesium and fibrous board performed the best of all the samples tested at both heat fluxes. No cracking was observed during testing and the board remaining rigid during removal.

This integrity failure and lesser performance of standard gypsum compared to the two fire rated counterparts is expected. Fire performance is not a primary function for Standard gypsum unlike fire rated boards. The integrity failure is shown in figure 7, it must be noted the central triangle missing was removed manually although this required minimal effort.

Figure 1 sample of CLT with 12 mm Magnesium Board lining pictured at completion of 65 kW/m^2 test

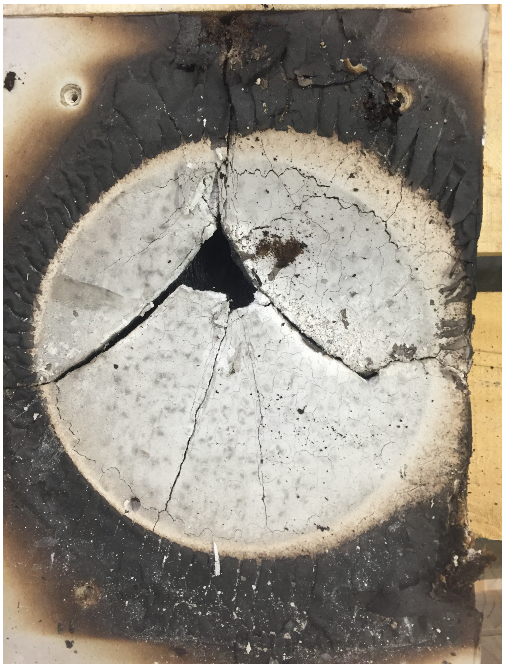

Figure 2 integrity failures of 13mm Standard Gypsum board at 50 kw/m^2

The two fire rated gypsum samples showed small signs of cracking at the 65 kW/m^2 heat flux but did not break, or fall apart until they were removed post experiment. The cracks in the fire rated gypsum boards were only on the exposed surface and did not penetrate the full 13 mm through the samples. At 50 kW/m^2 neither fire rated gypsum board cracked or showed signs of integrity failure.

Figure 8 shows the two samples of CLT tested with the 15 mm magnesium board lining. The photos are taken at the immediate completion of testing. It is clearly visible that only a section of CLT smaller than the heater diameter has begun to char. There was no change in thickness of the sample from its original depth. From these results it can be confidentially assumed that using the 300°C isotherm is appropriate to determine the point at which New Zealand CLT has charred. Further observations from Figure 8 shows that no integral damage was undertaken by the 15 mm Magnesium board

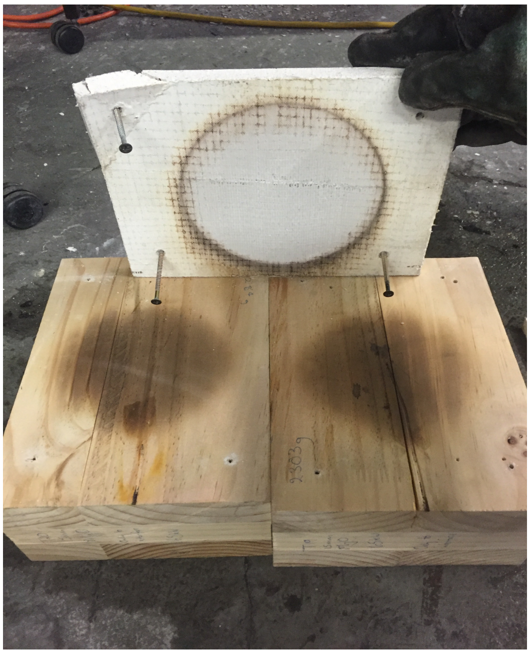

Figure 3 15 mm Mag Board samples tested only to interface

1.7. Conclusions and Recommendations

A total of 20 experiments were performed using a modified ISO 5657 ignition apparatus. Tests were carried out in order to determine a delay until the charring of a CLT sample occurred. The heat fluxes used were 50 and 65 kW/m^2. Each test was terminated when an imbedded thermocouple in the CLT reached 300°C.

Results showed the onset of char could be delayed by up to 26.5 minutes when analysing the best performing lining in terms of heat transfer. This was achieved by the A and B Fire Rated Gypsum boards at a heat flux of 50 kW/m^2. As the heat flux was increased to 65 kW/m^2 the times decreased. The lowest performing lining in terms of thermal transfer was the 12 mm magnesium board which allowed char onset in little over 15 minutes. The magnesium boards were the only two samples not to be prepared in 13 mm thicknesses.

It was noted that the gypsum-based boards did not preform as well as the magnesium and fibre linings when rated based on integrity. Standard Gypsum performed the worst based on integrity showing large cracks at both heat fluxes. Magnesium and fibrous boards did not have any cracks at either heat flux.

The char rates attained over the initial stages of the CLT burning were much lower than those achieved by Aitken and Moser (2014). The average char rate at 50 kW/m^2 and 65 kW/m^2 were 0.50 and 0.52 mm/min respectively.

Given the setup used, it was difficult for any linings to fall off the CLT sample during testing. It would be expected that standard gypsum would fall off when not pushed onto the substrate as in the ISO 5657 ignition apparatus. Testing a more realistic fixing system with batons should be undertaken.

Battening would allow the interface heat to circulate rather than the lining backing immediately heating the CLT sample. Furthermore, battening is more realistic to the real world conditions where battens are used to attain a level surface finish.

Larger scale testing is not overly necessary, as work on a large compartment has been carried out by Marc Janssen. Marc's research did not involve battening the type X gypsum lining to the CLT.

Testing across and including a join in the lining would be highly recommended as this is predicted to cause an earlier time to failure. No samples tested involved heating near the edge of the sample or the screw fixing. With the conditions tested in this research the fixings performed well but it would be expected that results differ around the fixing area. As fixings are often metal the properties when heated would differ significantly from those of the lining or CLT backing. This could cause deflections or warping in the lining leading to an earlier failure.

It would be recommended that some common surface finishes on the linings be considered for testing. Surface finishes are likely to increase flame spread or in some case provide extra insulation. Surface finishes are also going to be used in construction so their performance to this type of system would be desired.

1.8. Acknowledgments

Throughout this experimental project I have had a large amount of input and advice from laboratory technician, Grant Dunlop. I would like to thank Grant for his time assisting with sample preparation and equipment operation.

MagRoc Christchurch kindly donated resources and expertise for this research project. Further more the office staff Steve, Joel and others took time to explain the product and it performance confines.

Sam Leslie, of XLam NZ Ltd has likewise been invaluable providing CLT samples and Fibrous linings. Sam along with other staff of XLam have also donated significant amounts of time to provide comments on the experimental procedure. A thank you would like to be extended to XLam Australia for the supply of the fire rated gypsum B linings.

Finally, I would like to acknowledge my supervisor, Dr Michael Spearpoint for his guidance throughout the project. His knowledge in the area of fire research and experiments has made this project possible and I am grateful for his guidance during the time of my study.

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