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The Development of Composite Cross Laminated Timber Panels Manufactured Using C16 Irish Sitka Spruce

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ABSTRACT: This study involved the manufacture of a variety of cross laminated timber panels using C16 Irish Sitka Spruce. A number of panels included reinforcement from glass fibre matting and steel rebar. The panels were tested in four-point bending tests to determine how panel depth affects the panel stiffness and additionally, how the presence of reinforcement affects the stiffness. Results showed that as the panel depth (and span) increases, the global stiffness of the panel increases for all types of reinforcement. Additionally, results show that adding the layer of glass fibre matting decreases global stiffness by 6.8% whereas, the addition of the steel rebar significantly increases the global stiffness of the panel by 49.4% on average.

KEYWORDS: Cross Laminated Timber; Reinforcement; Stiffness

1 – INTRODUCTION

Cross laminated timber is a versatile, man-made engineered timber product which can be used as an effective and sustainable alternative to concrete and steel within the construction industry. While European countries have embraced the use of naturally sourced materials, such as cross laminated timber, their use in the United Kingdom and Ireland is much more limited. Currently, cross laminated timber (CLT) is only manufactured in mainland Europe, with transportation to the UK and Ireland adding to costs while adding to the carbon footprint of the product. The typical grade of timber used on the continent is C24 which has higher characteristic properties than C16, the most common grade of timber grown in UK and Ireland. The UK climate generally results in fast growing trees, leading to lower density timber which is often correlated to lower strength properties. Researchers within Ireland, particularly at The University of Galway, have been leading the study of CLT and glulam over some time. CLT has been manufactured using Irish Sitka Spruce timber and the most suitable adhesive has been identified through manufacture and testing procedures [1]. Additionally, the layer thickness has also been identified as a major contributor on the mechanical performance of a CLT panel [2], and on the rolling shear strength of a panel [3].

This paper discusses the proposal of using local timber resources of Irish Sitka Spruce with a strength class of C16 for use in the manufacture of cross laminated timber. However, the use of this lower grade of timber is expected to reduce certain strength characteristics of the manufactured CLT panel.

Therefore this study determines how various reinforcing materials affect the panels performance when

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incorporated within the panel. Additionally, with the range of panels manufactured and tested, the effect of panel depth on strength characteristics has also be determined.

2 – BACKGROUND

Over the years, the use of timber within construction has been recognised as a suitable material for construction and satisfies the sustainability issues associated with traditional construction methods.

Cross laminated timber (CLT) is a type of engineered timber product that has seen an increase in focus and use throughout the world due to outstanding load-carrying capacities and adaptability. However, the availability of cross laminated timber within the UK and Ireland is limited with no production being entirely complete within the region. Therefore, any CLT panels currently used within construction within UK and Ireland are sourced from European manufacturers. In some cases, assembly and manufacture of the panels may be processed within the UK or Ireland. However, timber is typically sourced within Europe, commonly within the Nordic regions. This transportation stage adds to the carbon footprint of the product and lessens the sustainability. Therefore, a further understanding of the capabilities of homegrown timber sources is required. This would allow for an improvement in development and confidence in the product of CLT manufactured using Irish timber.

The cross-grain nature of CLT allows for a high level of dimensional stability as the panel has structural strength across two dimensions. Addionally the layer up lessens the impact of imperfectons such as knots if they are not omitted during the production processes [4]. The study of determining the strength characteristics of engineered timber products has been a part of research in recent years. The studies allow for the determination of suitbalitiy of the material for its use, particularly within construction. Studies include cross laminated timber manufactured using Japanese Larch timber [5], Canadian Hemlock [6] and Nordic Spruce [7] and in all studies, the bending stiffness of the panel is determined through guidance from the British Standard for timber structures [8]. This involves a four point bending test where the deflection is recorded during loading. Studies involving the strengthening of engineered timber products through the use of reinforcing materials have been part of research in recent years. Glulam beams were strengthened using basalt fibre reinforced polymer rods [9] and through a four- point bending test the reinforcement was evaluated with a beam stiffness increase of 16.3%. Studies have also observed that the panel dimensions also affect the panel strength characteristics with a study on cross laminated timber manufactured using Irish Sitka Spruce [10]. A decrease in mean bending and rolling shear strength with an increase in panel thickness was observed.

3 – PROJECT DESCRIPTION

This study involved the manufacture and testing of a variety of cross laminated timber panels. This included a range of panel depths (and corresponding spans). For each panel depth there were three types of panel composition; unreinforced, glass fibre mat reinforced and steel rebar reinforced. The panels were tested using a four-point bending test under guidance from the relevant British Standard [8] and for each panel, the bending stiffness was determined through calculations as shown in (1)

$$EI_{global} = \frac{L^3}{12} \cdot \left[\frac{F_2 - F_1}{w_2 - w_1}\right]\left[\frac{3a}{4L} - \left(\frac{a^3}{L}\right)\right] \quad (1)$$

where:

L – effective span, mm

a – distance from support point to load position, mm

F_2-F_1 – Forces, N

w_2-w_1 – Global deformations forresponding to loads (F), mm

3.1 MATERIALS

A range cross laminated timber panels were manufactured using locally sourced Irish Sitka Spruce of strength class C16. A one-component polyurethane wood glue was used throughout the manufacture of the panels to allow for face bonding and for the adhesion of the glass fibre mat layer.

3.2 PANEL CONFIGURATION

The panels had the following, varying layer-up configurations; 3 layers of 30mm (90mm), 3 layers of 40mm (120mm), 5 layers of 30mm (150mm) and 5 layers

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of 40mm (200mm). For each panel with varying thicknesses, the panel span was determined following guidance from British Standards [8] as detailerd in (2) and giving a range of corresponding spans of; 2250mm, 3000mm, 3750mm and 4700mm. The width of each panel remained constant at 500mm.

$$\text{Panel Span} = 25h – 31h \quad (2)$$

where;

h – Panel depth, mm

3.3 MANUFACTURING PROCESS

The timber was dried and conditioned in a conditioning chamber at 20ºC and 55% RH until the equilibrium moisture content of 12% was achieved. Moisture content was determined using a handheld pin-less moisture meter and confirmed through mass measurement before and after oven drying, from guidance in the British Standard [11] and using (3).

The oven drying method is the most accurate form of testing the moisture content of a piece of raw timber as it directly measures the mass of moisture in the sample. The accuracy of other methods of determining moisture content can be verified using the oven drying method [12]. The method is described in a BS EN 13183-3 for the moisture content of timber and involved taking samples of a length of timber, each being 20mm in thickness [13]. The first sample was taken 300mm from the end of the sample and this piece should be discarded. In this case, a selection of 10 samples were cut. Immediately after being cut, these samples were weighed and recorded and then placed in an oven at 103ºC (±2ºC) and left for two hours, as shown in Figure 1. The samples were weighed every two hours until the difference between two successive weighing's was less than 0.1%.

Figure 1. Samples of C16 timber in oven for the determination of moisture content

The moisture content of the timber was calculated using (3)

$$\omega = \frac{m_1 - m_0}{m_0} \,.\, 100 \quad (3)$$

where;

ω - the moisture content as a percentage

m_1 – mass of the test slice before drying, grams

m_0 – mass of the test slice after oven drying, grams

The timber was then planed and cut to size ready for panel manufacture in accordance with the British Standard [8]. The process of planing gave the timber a smoother surface for the adhesive to be applied and allowed a more established join between the layers of CLT. The surfaces of each lamination were planed on all four sides and this planing process was carried out less than 24 hours before bonding, in accordance with the British Standard on the manufacturing of CLT [8]. For all panels made up of 30mm layers, boards of 35mm thicknesses were planed down to 30mm. For panels made up of 40mm layers, boards of 45mm thicknesses were planed down to the 40mm. This complied with the guidance from BS EN 14081 on the grading of timber which stated that for a grade of timber to still hold relevance after planing, planing should not cause a reduction over 5mm for dimensions of tiber between 22mm and 100mm [14]

The panel was manufactured within a frame and layers were face-bonded using a suitable adhesive (one-component polyurethane) at a rate of 160g/m^2 per layer.

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To eliminate the presence of gaps between the timbers, lateral and vertical pressure was applied using hydraulic rams and presses. Figure 2 shows the full five layers of the panel assembled and the lateral loads from the hydraulic rams applied. The lateral loading pushes the boards together in each layer before the vertical load is applied. It is important that this lateral load is applied slowly while observing the movement of the layers to ensure it does not cause any upward movement. In some cases, some of the loading equipment was applied to create a load to prevent this upward movement from occurring.

Figure 2. Manufacutre of CLT panel involving the lateral pressure application

The unreinforced panels were manufactured first, followed by the glass fibre mat reinforced panels and finally the unreinforced panels were reinforced with the steel rebar.

The manufacturing of the glass fibre mat (GFM) reinforced panels was similar to that of the timber only unreinforced control panels. The glass fibre mat was cut to the required panel dimensions using a knife. The manufacturing begun as with the unreinforced control panel with the five longitudinal boards being placed into the manufacturing frame followed by the measured quantity of adhesive, spread evenly using the rubber hand roller. The piece of mattung was laid on top of the first layer of longitudinal timbers and the adhesive was applied to the mat until fully saturated, as shown in Figure 3. The next (transverse) layer was then added, and further layers were added as before.

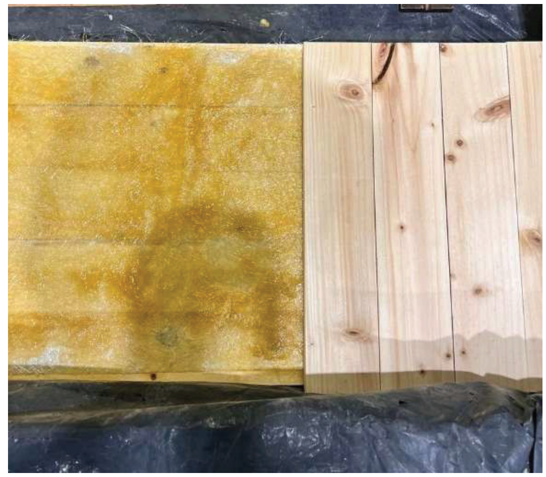

Figure 3. Glass fibre matting applied between the layers of timber, bonded using one component adhesive

A two-part engineering adhesive was then used as a bonding agent to fix the steel rebars in place. This chosen adhesive was selected due to its ability to be a gap-filler as well as having the capability to create a good bond between the steel and the timber. This type of engineering adhesive had been successfully used in past research to bond lengths of basalt fibre polymer rods in place within gaps in timber [9]. The panels with the rebar bonded in place is as shown in Figure 4.

Figure 4. CLT panel with additional rebar reinforcement

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4 – EXPERIMENTAL SETUP

To assess how depth affects a CLT panel stiffness and additionally how the presence of glass fibre mat and steel rebar reinforcement affects stiffness, the panels were tested with a four-point bending test and deflections were recorded. The test set up was in accordance with the British Standard [15] and as illustrated in Figure 5.

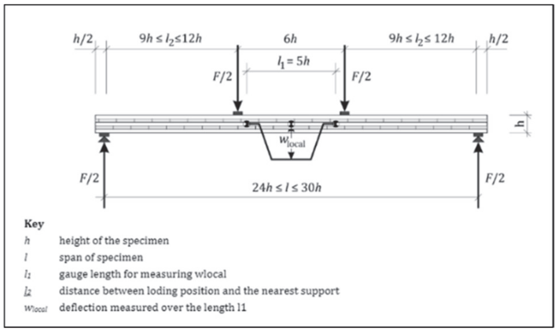

Figure 5. Experimental set up for the determination of panel stiffness

The tests involved taking the panels to a deflection of 15mm and recording the load required to achieve this deflection. Deflections were recorded using linear variable differential transformers (LVDT) on both sides of the panel. Testing results provided load and deflection values and these were used to calculate the panel stiffness using guidance from [9].

5 – EXPERIMENTAL RESULTS

5.1 INCREASING DEPTH

Figure 6 shows that in all reinforcement types, as the panel depth increased, the panel global stiffness also increased. This is to be expected as an increase in depth increases the second moment of inertia of the panel cross section with directly correlates to the stiffness of the panel (EI).

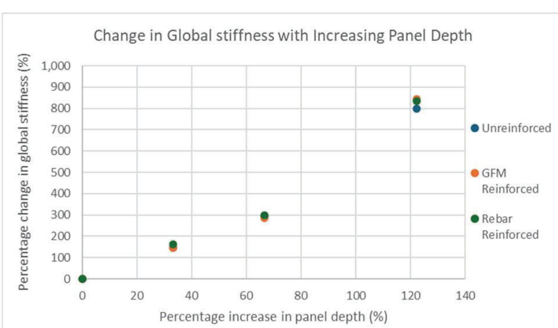

Figure 6. Change in global stiffness with increasing panel depth

Another useful method of determining the effect of panel dimension on panel performance is to calculate the stiffness to depth ratio for each panel. From this, the panel with the highest ratio would be regarded as the optimum size for each reinforcement type. The ratios for the panels are shown in Figure 7.

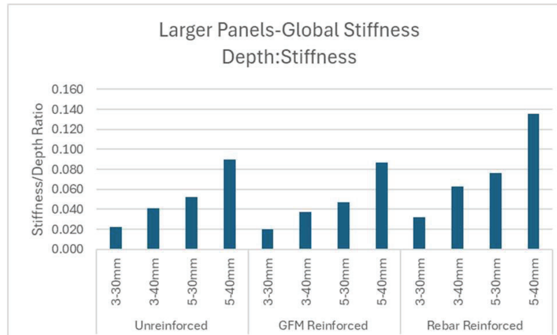

Figure 7. Depth: Stiffness for larger span panels

A higher value for the ratio shows a panel with greater performance. The optimal panel size is the panel with the greatest depth (5-40mm). There is a greater difference in the ratio between the two larger panels than all other, indicating the 5-40mm panels are significantly dominant when stiffness is considered. This is the trend observed in all reinforcement types.

5.2 ADDITION OF REINFORCEMENT

The global stiffnesses of the panels are presented in Figure 8. Results presented show the effect of the presence of the GFM reinforcement and the rebar reinforcement in the CLT panels.

The effect of the GFM reinforcement on the global stiffness values involved an average reduction in global stiffness of 6.8%, with the greatest reduction in stiffness of 9.10% again coming from the panel with configuration B-5-30. The results observed in the testing of the larger bending panels concluded by suggesting that the effect of GFM reinforcement on panel performance is insignificant and therefore GFM is not regarded as a suitable method of reinforcement of a CLT panel manufactured using C16 Irish Sitka Spruce.

The effect of the rebar reinforcement is however much more significant with an increase in global stiffness for all panel dimensions. The results for global stiffness show the rebar reinforcement having the greatest increase in stiffness for the panel with dimensions B-3-40, with a global stiffness increase of 53.9%. The increase in global stiffness for all panels was similar with an average increase of 49.4%. This is as expected as the timber being removed has a modulus of elasticity of 8160N/mm^2 and is being replaced by steel rebar which has a modulus of elasticity of 210000N/mm^2.

The use of ten lengths of 12mm diameter steel rebar result in an increase in panel stiffness of 49.4% as an average of local and global stiffnesses. This increase in stiffness is greatly advantageous for the production of CLT panels manufactured using C16 Irish Sitka Spruce.

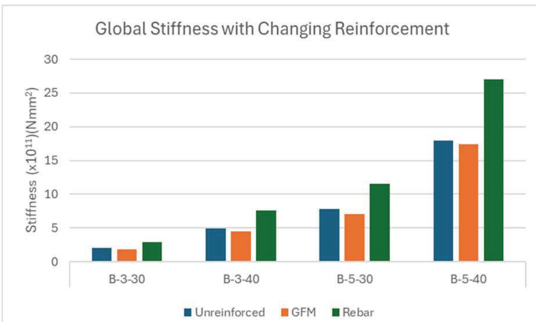

Figure 8. The global stiffness of CLT panels with changing reinforcement types

6 – CONCLUSIONS

Cross laminated timber panels were manufactured using C16 Irish Sitka Spruce timber. These panels were tested in a four-point bending test until a full panel deflection of 15mm was experienced and their associated stiffness values were calculated. A variety of reinforcement types were used including glass fibre matting and steel rebar. From the results, the panel stiffness increased for each panel with the addition of the steel rebar and the average stiffness increase over the four panel spans was 49.4% however the addition of the glass fibre matting negatively impacted the stiffness of the panels of all dimensions with an average decrease in stiffness of 6.8%. The results also indicated an increase in stiffness with increasing panel depth and panel span for all panel reinforcement types.

The span of the panels varied depending on the desired test outcome (bending or shear). The plan involved a total of four panel dimensions and three reinforcement types (unreinforced, GFM reinforced, and rebar reinforced). This full manufacturing plan allowed for the successful determination of how panel dimensions and reinforcement presence affect the stiffness of a CLT panel.

The study is concluded by confirming that the stiffness of a CLT panel is directly increased by an increase in the panel depth. The study also concluded that the effect of one layer of glass fibre mat is unsuccessful in reinforcing a CLT panel. However, the use of ten lengths of 12mm diameter steel rebar successfully can reinforce an Irish CLT panel

7 – FUTURE RECOMMENDATIONS

Additional future work has been identified and further research questions have been established and are as follows:

- Determination of degree of movement between two layers of timber where GFM reinforcement has been added and the impact of increasing the cross section of GFM
- Could post tensioning or precamber be used to increase the capacity of composite CLT panels by reducing the net deflection under service and with lesser material?
- Consideration of panels manufactured using timber >C16 Irish Sitka Spruce which exists within the stock produced but is not graded greater than C16 currently.
- Determine maximum permissible span or optimization of design to reduce material use.

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