MODELLING OF ELEVATED TEMPERATURE PERFORMANCE OF ADHESIVES USED IN CROSS LAMINATED TIMBER: AN APPLICATION OF ANSYS MECHANICAL 2020 R1 STRUCTURAL ANALYSIS SOFTWARE

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TRANSFORMING LIVES SINCE 1828

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Outline

Introduction

Methodology

Results and Analysis

Conclusion

Future Research

A mass timber building in London, UK

Introduction

Cross Laminated Timber (CLT) Slab

- Increasing use of CLT from 610,000 cubic meters in 2015 to 821,270 cubic meters in 2019 in Europe for building construction
- CLT is used as wall panels, flooring panels, roofing slabs, and so on
- CLT is produced by bonding wood lamellas together with wood glue
- CLT traps approximately 1500 kilograms of carbon dioxide per ton
- CLT combustibility and flammability limits its use
- While under fire CLT undergoes charring and delamination
- 1% reduction in moisture content influences CLT's structural properties by between 2% to 6%

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Problem Statement

Difficulty in accurately modelling adhesive influence in structural performance of CLT

Lack of available knowledge on the heat performance of adhesives

Shortfalls with small scale tests or large-scale tests

Robustness of numerical tools, especially ANSYS software

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Objectives

To determine the influence of the adhesive layer on thermal behaviour of CLT

To model the thermal behaviour of solid wood

To determine the mechanical properties of wood adhesives, especially loss in the adhesive bond strength due to rise in temperature

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Methodology

Introduction and Materials

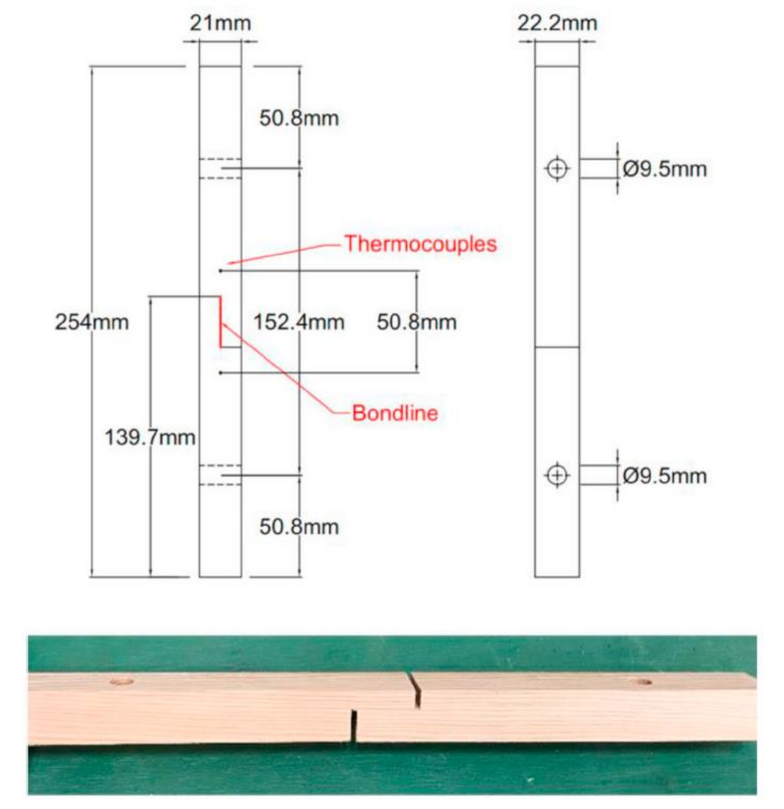


Figure 1: Geometry of the specimen used by Zelinka

Table 1: Properties of wood used in Finite Element Analysis (FEA)

Parameter	Douglas Fir (DF)	Southern Yellow Pine (SYP)	Spruce Pine Fir (SPF)
E_L (MPa)	14740	13530	9790
E_T (MPa)	737	1055.34	577.61
E_R (MPa)	1002.32	1528.89	1253.12
V_{LR}	0.292	0.328	0.422
V_{LT}	0.449	0.292	0.462
V_{RT}	0.390	0.382	0.53
G_{LR} (MPa)	943.36	1109.46	1213.96
G_{LT} (MPa)	1149.72	1095.93	1174.8
G_{RT} (MPa)	103.18	175.89	97.9
Thermal Conductivity, W/(m°C)	1.01	1.12	0.90

Methodology

Introduction and Materials Cont'd

Table 2: Coefficient of Thermal Expansion of DF, SYP & SPF

Species	Radial (10^{-6} in/in/ ºF)	Tangential (10^{-6} in/in/ ºF)	Parallel (10^{-6} in/in/ ºF)
Douglas Fir - South	14	19	1.9
Southern Yellow Pine	15	20	2.0
Spruce Pine Fir	13	18	1.8

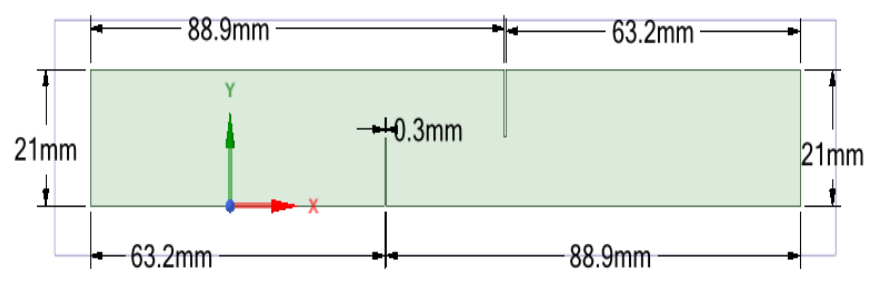


Figure 2: Geometry for solid wood used in thermal analysis

Table 3:Properties of wood adhesives

Elastic Properties	Melamine Formaldehyde (MF)	Phenol Resorcinol Formaldehyde (PRF)	Polyurethane (PUR)
Young's Modulus (MPa)	3200	3540	559
Possion's Ratio	0.33	0.443	0.351
Coefficient of thermal expansion (CTE) (/ºF,K)	60×10^{-6}	68×10^{-6}	200×10^{-6}
Thermal Conductivity (W/m.K)	0.5	0.146	0.209

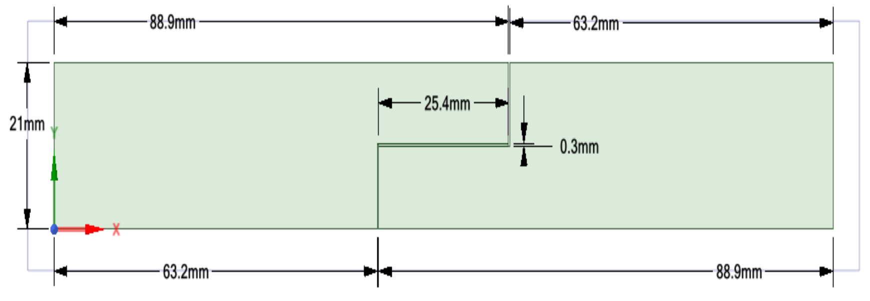


Figure 3: Geometry for wood with a glued lap joint

Methodology

Introduction and Materials Cont’d

Table 4: Temperatures and Heat Flux used in the Simulations

Temperature	**20 °C, 100 °C, 140 °C, 180 °C, 220 °C, and 260 °C**
Heat Flux	10020 W.m^{-2}
Heat	5.65 W
convective heat transfer coefficient	2.5 x 10^{-6} W/(mm^2.K)
Eurocode 5 Equation (Eq1)	$T = T_i + (T_p - T_i)\left(1 - \frac{x}{a}\right)^2$
Thermal Conductivity Equation (Eq4)	$T_{out} = T_{in} - \dot{Q}''\frac{dx}{k}$

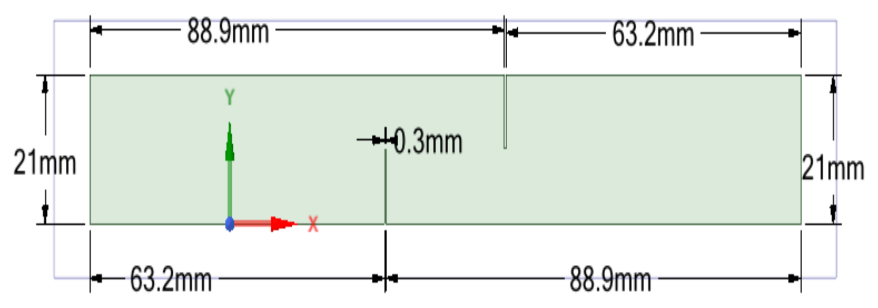


Figure 5: ANSYS set up for tensile test of wood

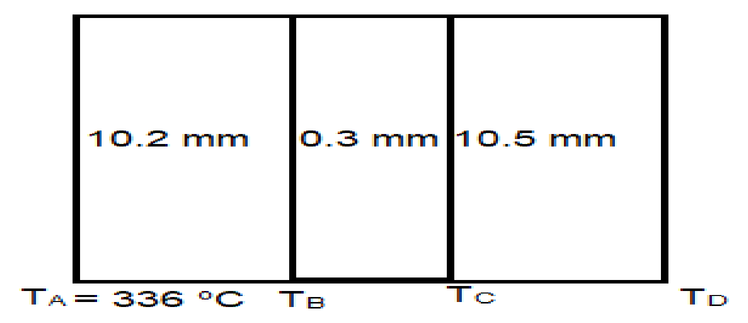


Figure 4: Specimen Dimensions for Analytical Calculations

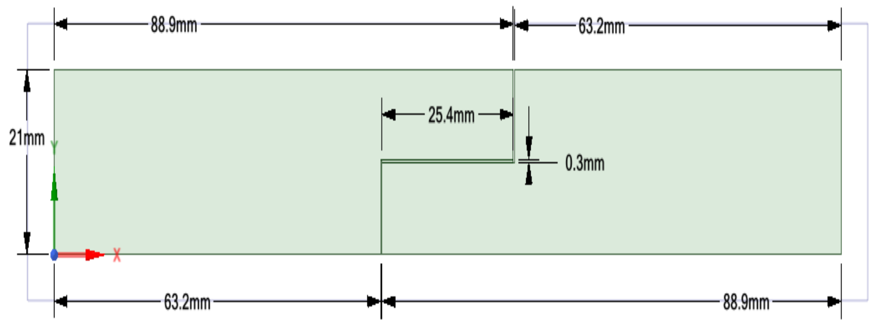
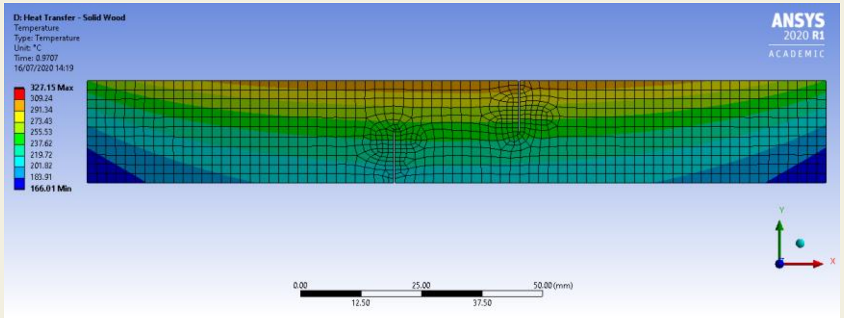


Figure 6: ANSYS set up for tensile test of Adhesive

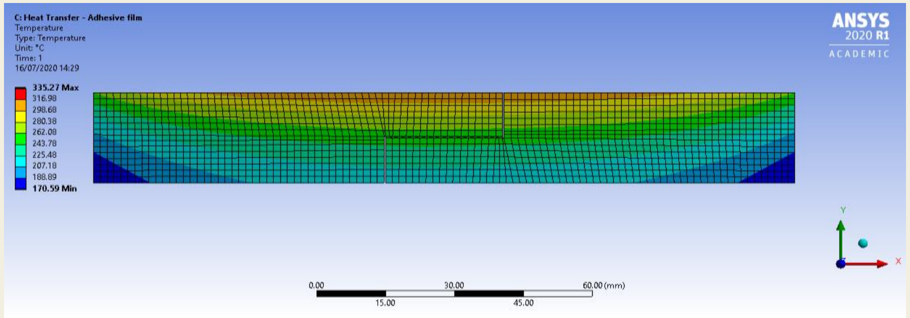
RESULTS AND ANALYSIS

Steady State Thermal Model



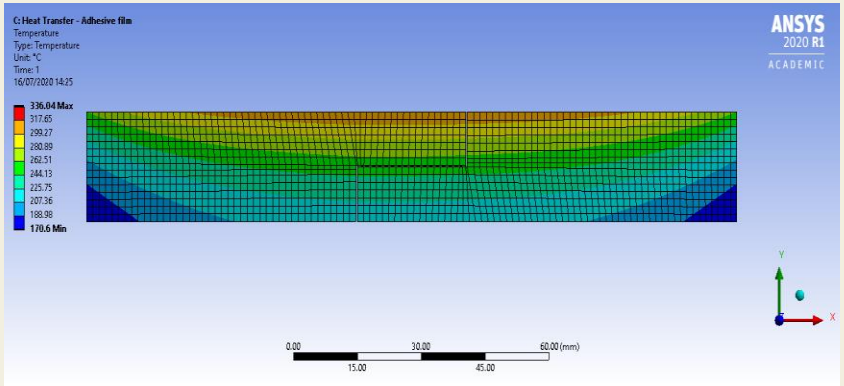
D: Heat Transfer - Solid Wood
Temperature
Type: Temperature
Unit: °C
Time: 0.9707
16/07/2020 14:19

Figure 7: Temperature distribution in solid wood (DF)



C: Heat Transfer - Adhesive film
Temperature
Type: Temperature
Unit: °C
Time: 1
16/07/2020 14:29

Figure 9: Temperature distribution in a composite of DF and MF



C: Heat Transfer - Adhesive film
Temperature
Type: Temperature
Unit: °C
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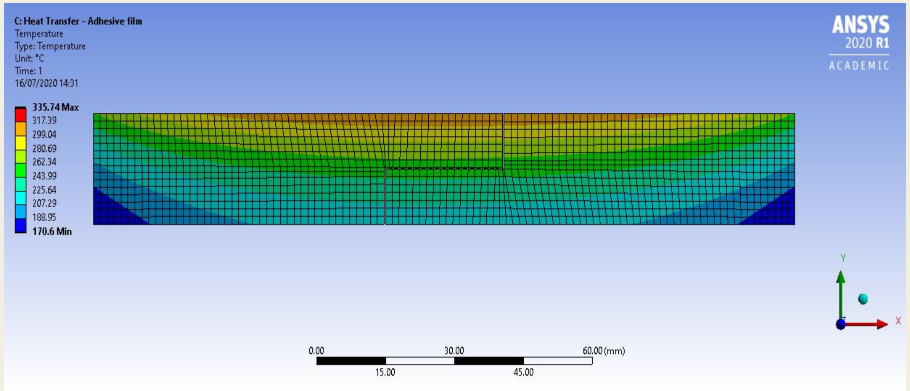
Figure 8: Temperature distribution in a composite of DF and PRF



C: Heat Transfer - Adhesive film
Temperature
Type: Temperature
Unit: °C
Time: 1
16/07/2020 14:31

Figure 10: Temperature distribution in a composite of DF and PUR

RESULTS AND ANALYSIS
Analytical Model

Table 5: Summary of Analytical Results

Material	**Heat Flux (W/m^2)**	**Thermal conductivity ($Wm^{-1}K^{-1}$)**	**T_B (ºC)**	**T_C (ºC)**
Eurocode 5 Equation (Eq1)				
Solid Wood - DF			175	172
Thermal Conductivity Equation (Eq4)				
Solid Wood - DF	10020	1.01	235	232
Adhesive layer - PRF	10020	0.146	235	214
Adhesive layer - MF	10020	0.5	235	229
Adhesive layer - PUR	10020	0.209	235	220

RESULTS AND ANALYSIS

Thermal - Structural Behaviour of Wood

Table 6: Douglas Fir (DF)

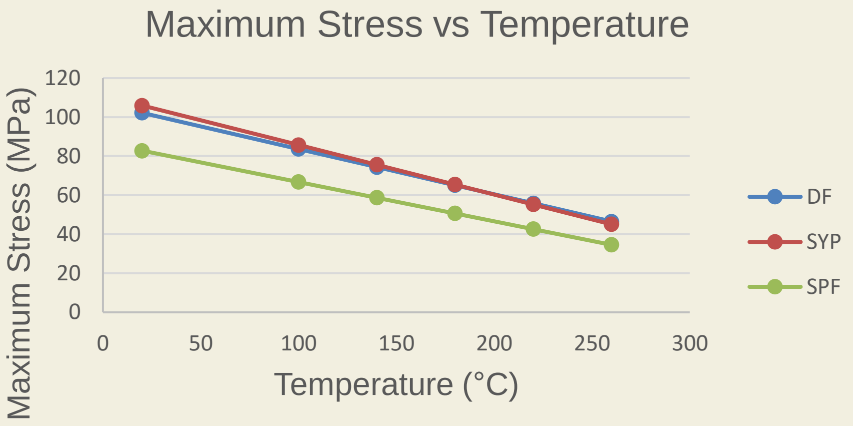
Temperature (°C)	Stress (MPa)	Strain (mm/mm)
20	102	0.0278
100	83.7	0.0198
140	74.4	0.0159
180	65.1	0.0120
220	55.8	0.00805
260	46.5	0.00724

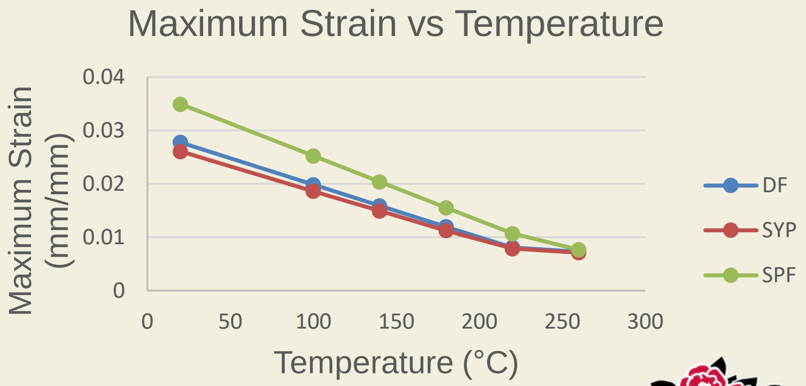
Table 7: Southern Yellow Pine (SYP)

Temperature (°C)	Stress (MPa)	Strain (mm/mm)
20	106	0.0261
100	85.7	0.0186
140	75.6	0.0149
180	65.4	0.0112
220	55.3	0.00783
260	45.1	0.00709

Table 8: Spruce Pine Fir (SPF)

Temperature (°C)	Stress (MPa)	Strain (mm/mm)
20	82.7	0.0349
100	66.7	0.0252
140	58.7	0.0204
180	50.6	0.0155
220	42.6	0.0107
260	34.5	0.00764





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RESULTS AND ANALYSIS

Thermal - Structural Behaviour of Adhesives

Table 9: PRF Adhesive

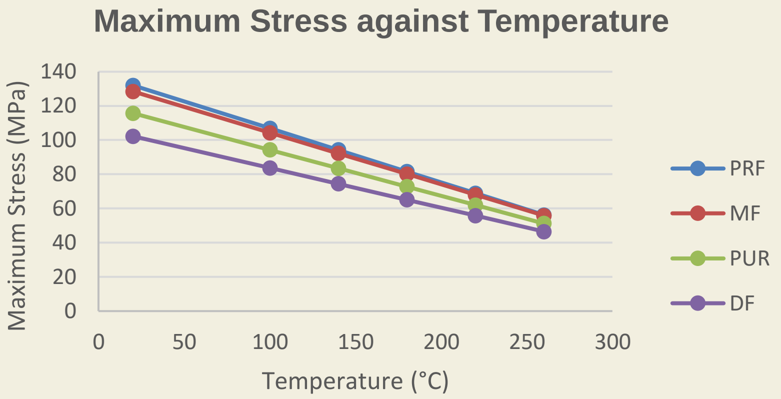
Temperature (°C)	Stress (MPa)	Strain (mm/mm)
20	132	0.0696
100	107	0.0524
140	94.2	0.0439
180	81.6	0.0354
220	68.9	0.0270
260	56.1	0.0186

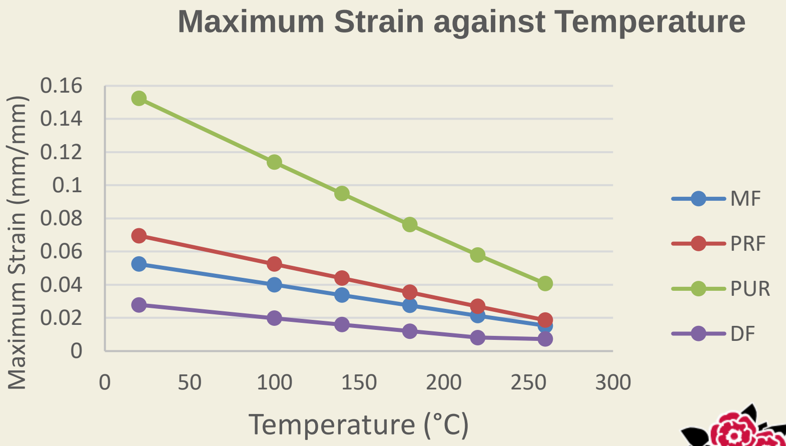
Table 10: MF Adhesive

Temperature (°C)	Stress (MPa)	Strain (mm/mm)
20	128	0.0525
100	104	0.0400
140	92.2	0.0337
180	80.1	0.0275
220	68.0	0.0214
260	55.8	0.0153

Table 11: PUR Adhesive

Temperature (°C)	Stress (MPa)	Strain (mm/mm)
20	116	0.152
100	94.3	0.114
140	83.5	0.0949
180	72.8	0.0762
220	62.0	0.0580
260	51.2	0.0407

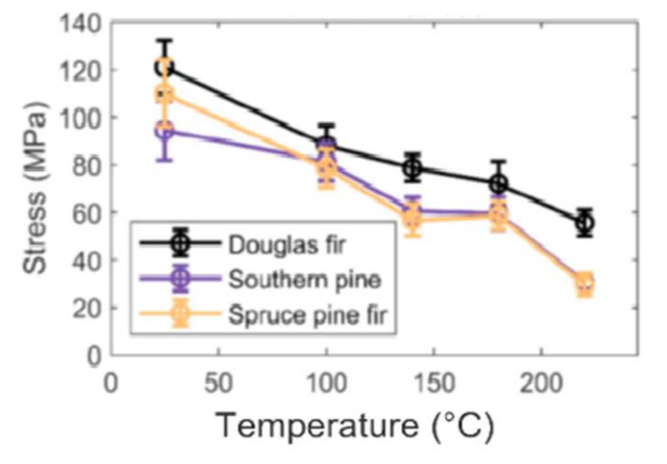




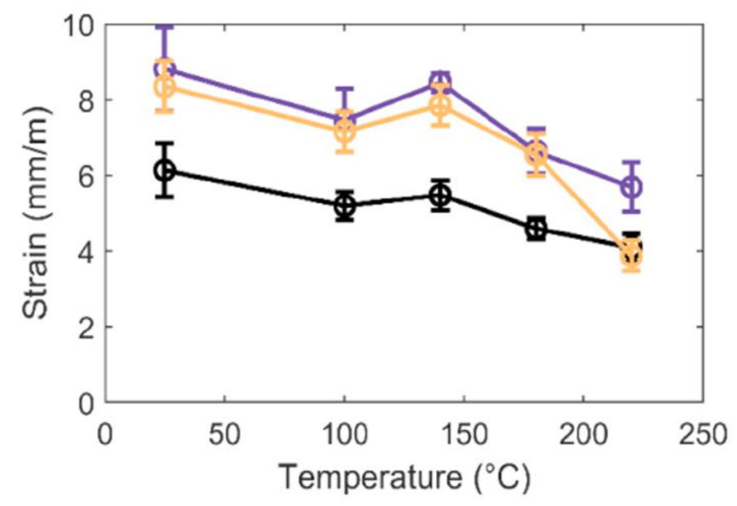
RESULTS AND ANALYSIS

Results from Zelinka's Experiment

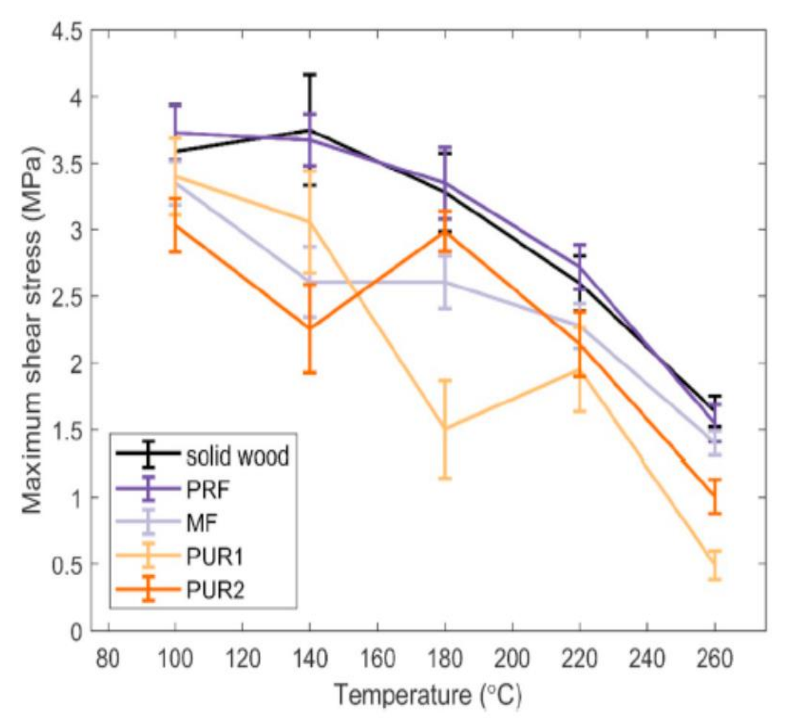
STRESS VS TEMPERATURE FOR SOLID WOOD



STRAIN VS TEMPERATURE FOR SOLID WOOD



ERROR GRAPH OF STRESS VS TEMPERATURE FOR ADHESIVES



Conclusion

The thermal properties of glued timber are the same as for solid timber

Wood adhesives have a significant influence on the structural properties of CLT

The stresses and strains of wood species decreased with increase in temperature

The stresses and strains of wood adhesives reduced with increase in temperature

PRF and MF are better structural adhesives than PUR

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Future Research

There needs to be a study of assemblies rather than rectangular slabs and for higher temperatures and perhaps defects such as ducting also need more study

There needs to be an extensive study on CLT with more than two glue layers

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