HEAT INDUCED DELAMINATION IN MASS TIMBER BUILDINGS

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Solid Wood ≠ Engineered Wood Products

Solid timber

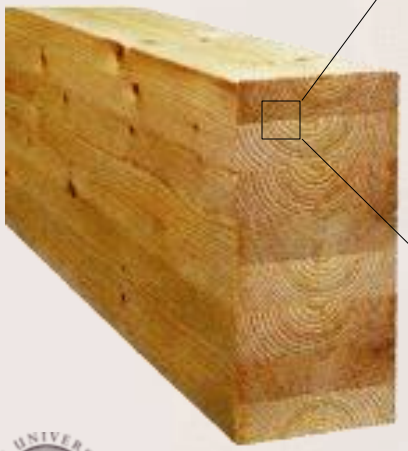
NO BOND LINE

BOND LINE

Glue laminated timber

Cross laminated timber

Laminated veneer lumber



wood

interphase

adhesive

interface

wood

BOND LINE DEFINITION

HEAT INDUCED DELAMINATION DEFINITION

BOND LINE PERFORMANCE

Heat Induced Delamination

Effects on Fire Dynamics

Addition of new fuel

Reradiation

Prolonged fire duration due to continuous burning

Effects on Structural Capacity

Loss of composite action and therefore unknown residual utilisation

Loss of virgin timber and thereby a progressive cross section loss

HEAT INDUCED DELAMINATION

NO SELF-EXTINCTION

SELF-EXTINCTION

McGregor et al. (1,5, 2013)
Browning, A. (4.3.1. PE, 4.3.1. cribs, 4.3.2. PE, 4.2.1. cribs, 2018)
Medina Hevia, A.R. (1 BW-RW, 2 LW-RW, 2014)
Bartlett, A. (α-3, β-5, β-6, 2018)
Karuse, M. (1, 2018)
Crielaard, R. (2,3, 2019)
Hadden et al. (β-2,γ-1, 2017)
Gorska, C. (LW 30, LW C 30, LW BW LW2 20, All, 2020)
Su J., Lafrance P.S. et al. (3,4,5,6, 2022)*

Mindeuia et al., (2, 2020)*
Kanellopoulos et al. (G, 2020)
Jansenss et al. (1, 2017)*
Pope et al., Wiesner et al. (2.1, 3.1, 2025)
Hopkin et al. (4a,5a,7a,8a,9a, 2024)
Johansson and Svenningsson (A1,A2, 2018)
Boe et al. (2, 2023)
Mohaine et al. (1, 2, 2023)*
Engel et al. (V2,2022)

McGregor et al. (3, 2013)
Bartlett, A. (β-4, 2018)
Crielaard, R. (1,5, 2019)
Hadden et al. (β-1, 2017)
Zelinka et al. (3, 2018)*
Gorska,C. (C 30,LW BW C, 2020)
Brandon et al. (4, 2021)
Pope et al., Wiesner et al.[29] (4.1, 2025)
Hopkin et al. (3a, 3b, 6a, 2024)
Hopkin et al. (1, 2021)*
Boe et al. (1, 2023)
Mohaine et al. (3, 2023)*
Su et al. (2,5, 2023)

Browning, A. (4.2.1. pe, 2018)
Medina Hevia, A.R (3 RW, 2014)
Bartlett, A. (α-4,β-3, 2018)
Emberley et al. (1, 2017)
Olivier et al. (BW, 2SW, SW1, SW2,C1,C2,BW+C1,BW+C2, 2019)
Zelinka et al. (2, 2018)*
Gorska, C. (LW 20, c20, LW C 20, 2020)
Su J., Leroux P. et al. (2,4, 2021)
Brandon et al. (1,2,3,5, 2021)
Jansenss et al. (2,3 2017)*
Pope et al. ,Wiesner et al.(2.2, 2025)
Johansson and Svenningsson (B1, B2, MUF1, MUF2, 2018)
Hopkin et al. (2, 2021)*
Kotovinos et al. (1, 2022)

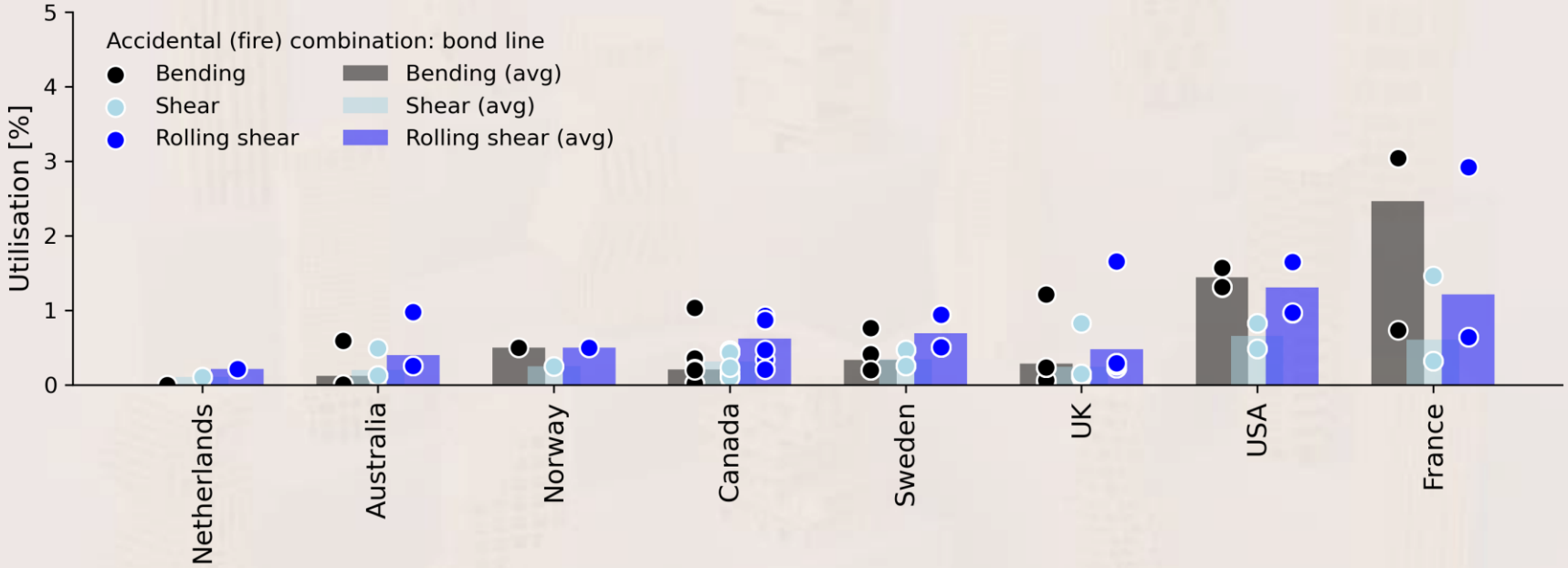
Adhesive used:
1-c-PUR | HB S | HB E | Other
1-c-PUR | HB X
MUF

* Experiments with structural load applied

NO HEAT INDUCED DELAMINATION

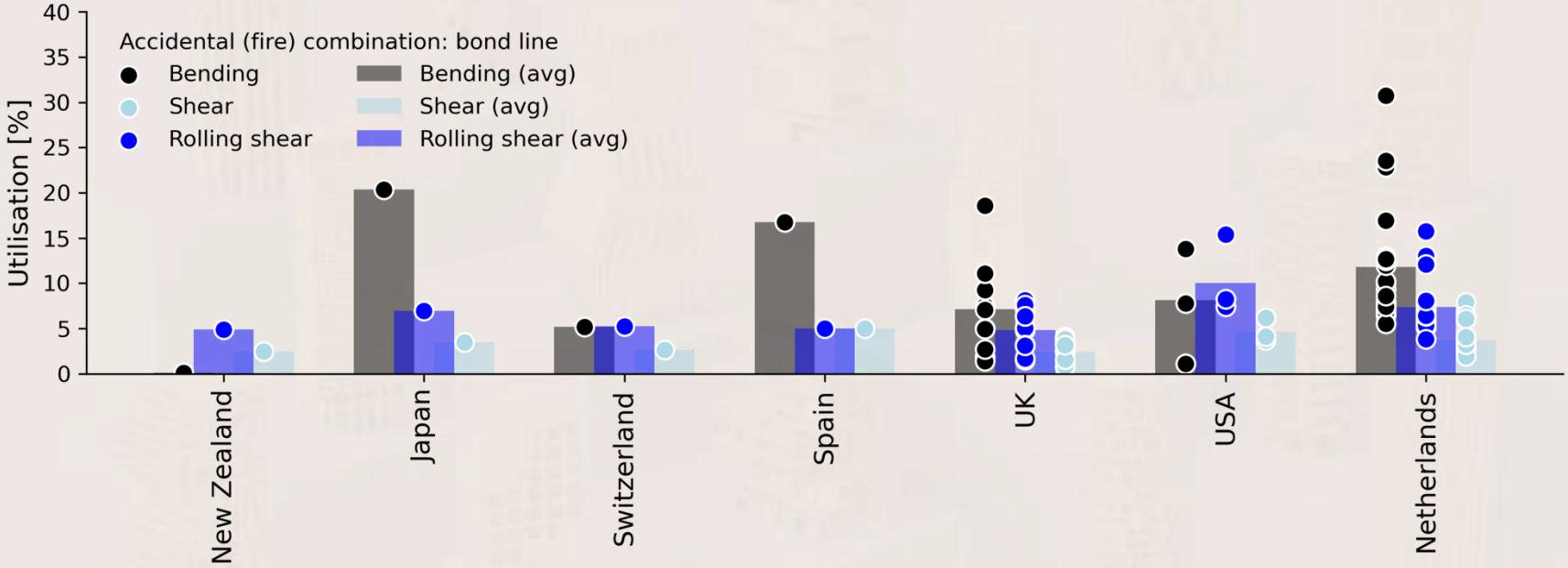
RESEARCH

SHEAR: 0-1% | ROLLING SHEAR: 0.2-2.2% | BENDING: 0.2-2.5%



PRACTICE

SHEAR: 5-10% | ROLLING SHEAR: 5-15% | BENDING: 5-30%



	Product | Structural load type	Heat source	Sequence	Thermal profile	Performance criteria
Small	Shear lap/Finger joint | Tension EWP block | Compression EWP beam | Bending	Oven	H ⇨ L_{ramp}	Uniform	Strength reduction, wood failure percentage
				Transient	Strength, strain
			L_{cons} ⇨ H	Uniform	Strain rate (creep)
				Transient	Failure time, Deformation, BLT[1]
			H ⇨ C ⇨ L_{cons}	Uniform	Residual strength
	EWP block	Flame test	H	Transient	Delamination length
Intermediate	EWP slab | No load	Furnace	H	Transient	Charring rate, MLR[2], BLT
	EWP wall| | No load	Cone calorimeter Radiant panel			Thermal penetration
	EWP wall | Compression EWP beam | Bending	Furnace	L_{cons} ⇨ H	Transient	Charring rate, deflection, thermal penetration
	EWP beam | Bending	Pool fire	H ⇨ C ⇨ L_{ramp}	Uniform	Residual strength
Large	EWP beam/slab | Bending EWP wall | Compression	Natural gas, wood cribs, furniture	H	Transient	Thermal penetration, Visual observation, BLT
			L_{cons} ⇨ H		

Uniform heating
Ramped load

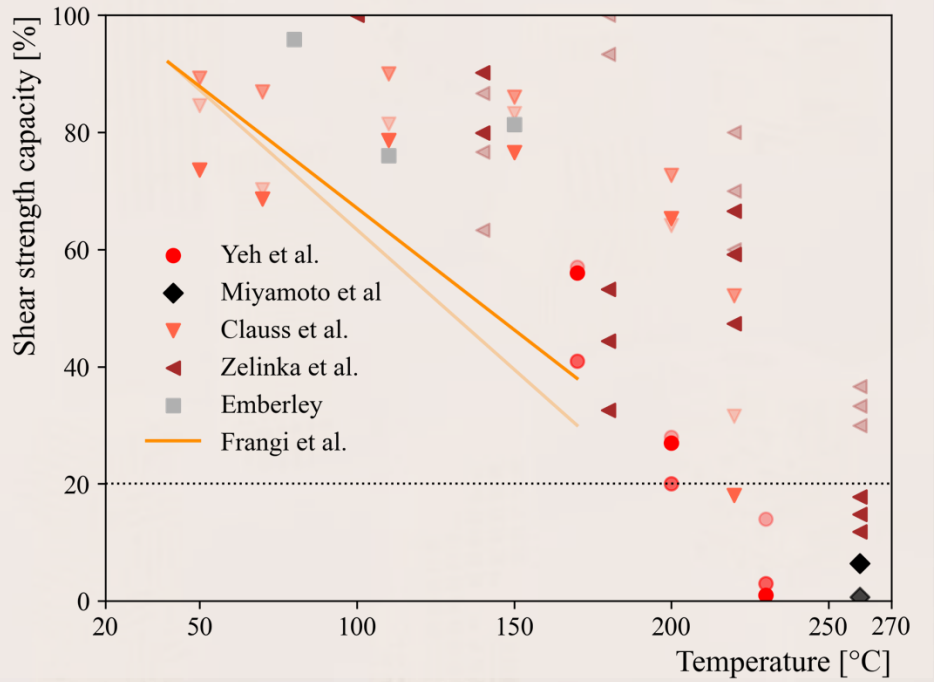
Shear strength reduction

Constant load
Transient heating

Bond line temperature
Displacement (rate)
Failure time

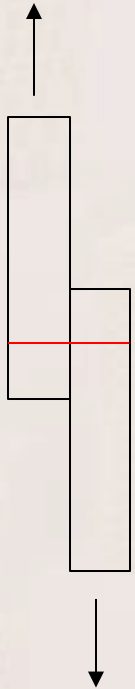
Shear strength reduction

Uniform heating ⇨ Ramped load



BOND LINE PERFORMANCE

Small scale

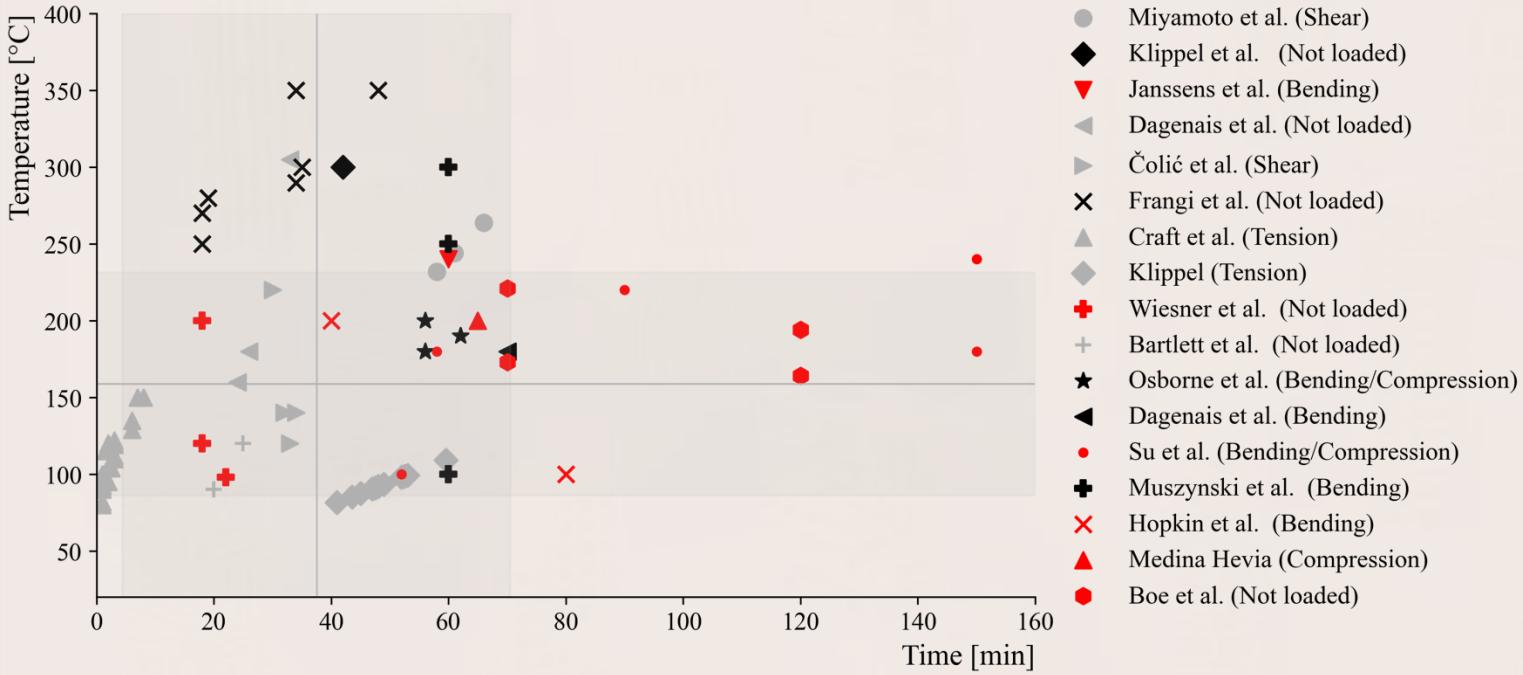


Bond line failure temperature

Constant load ⇨ Transient heating

BOND LINE PERFORMANCE

Large scale

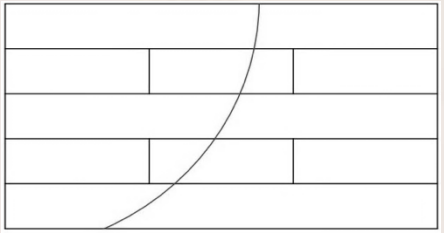


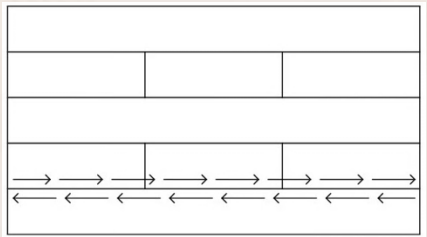
BOND LINE DEFINITION

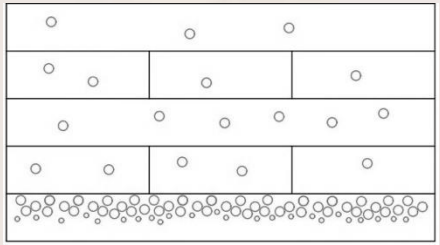
HEAT INDUCED DELAMINATION DEFINITION

BOND LINE PERFORMANCE

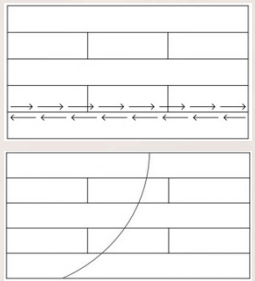
Understanding heat induced delamination



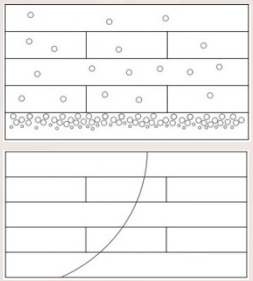




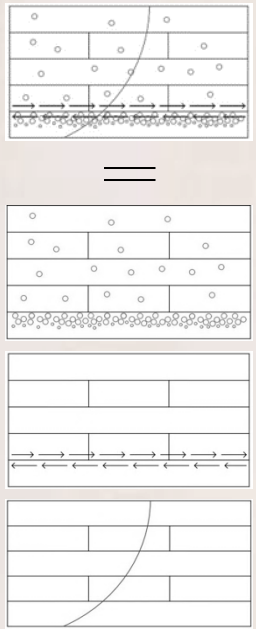
Microscale



Small scale

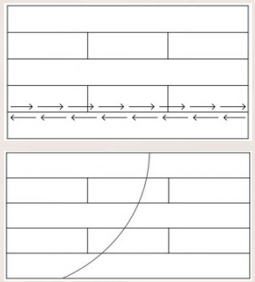


Small scale

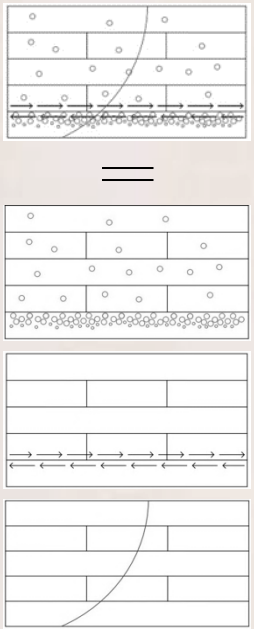


Intermediate scale

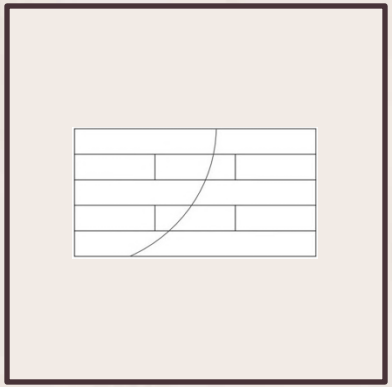
Microscale

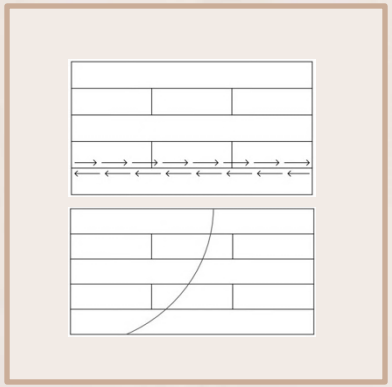


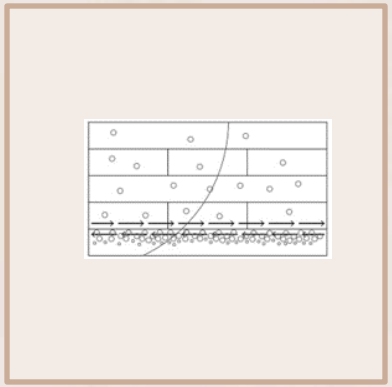
Small scale



Intermediate scale



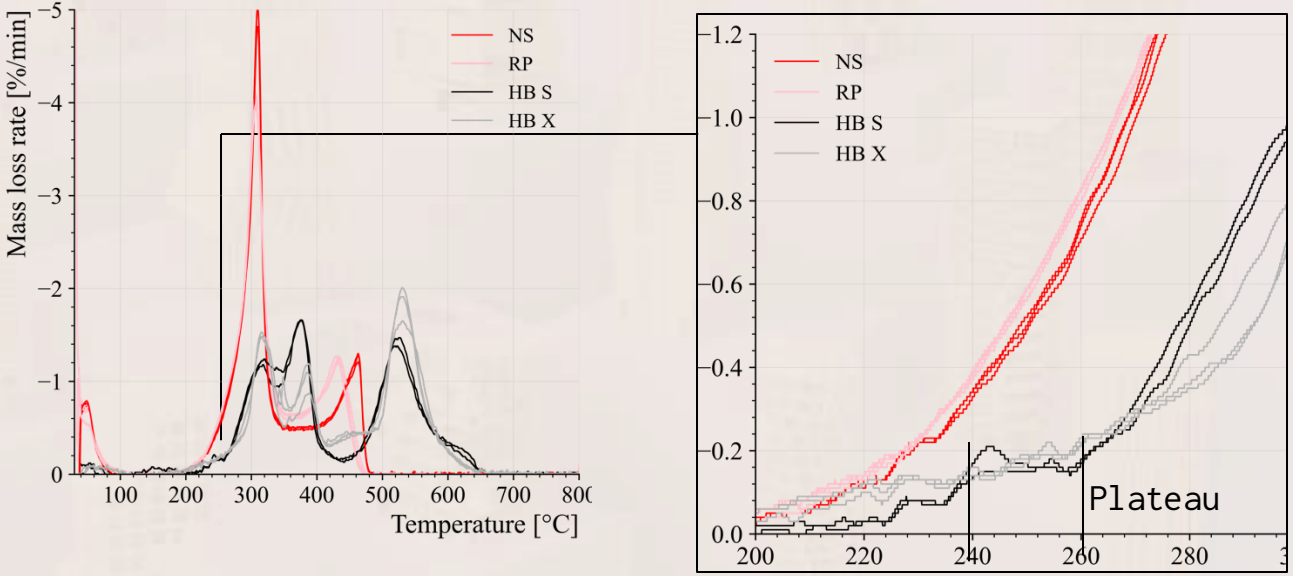




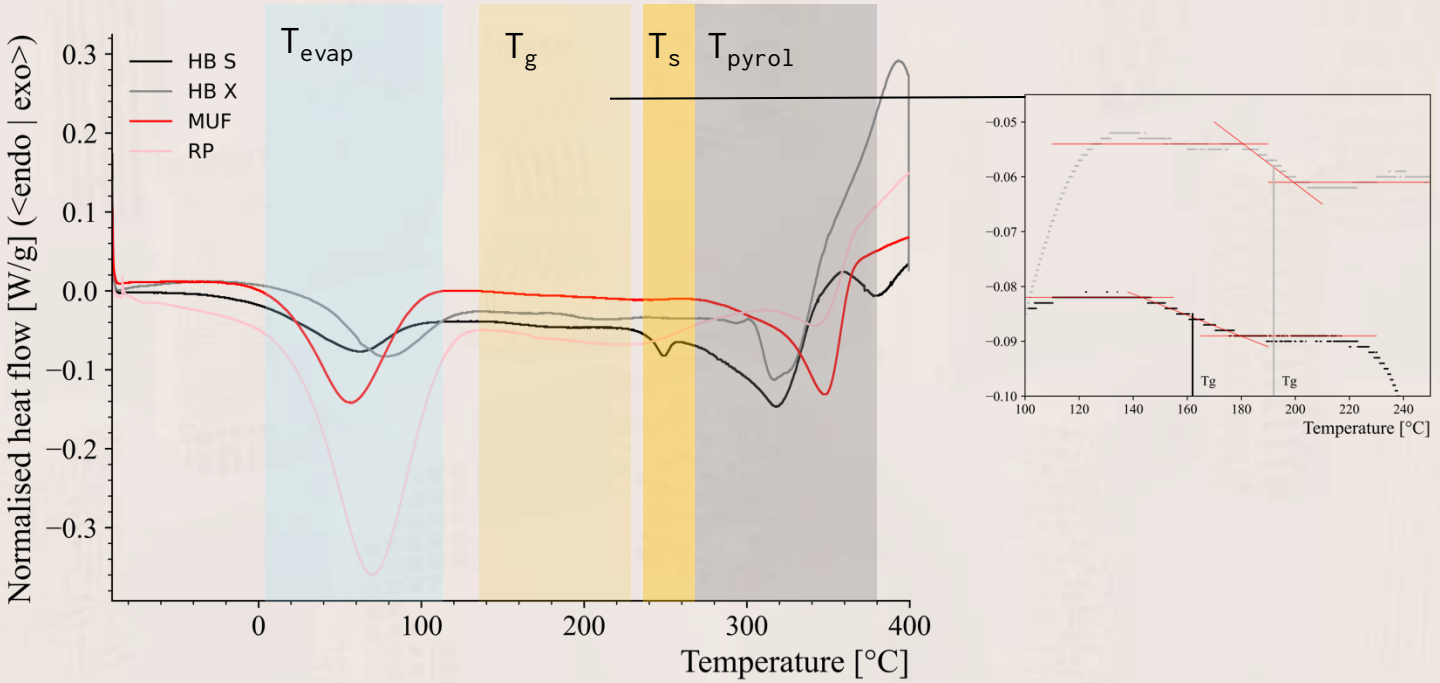
Thermogravimetric analysis Air

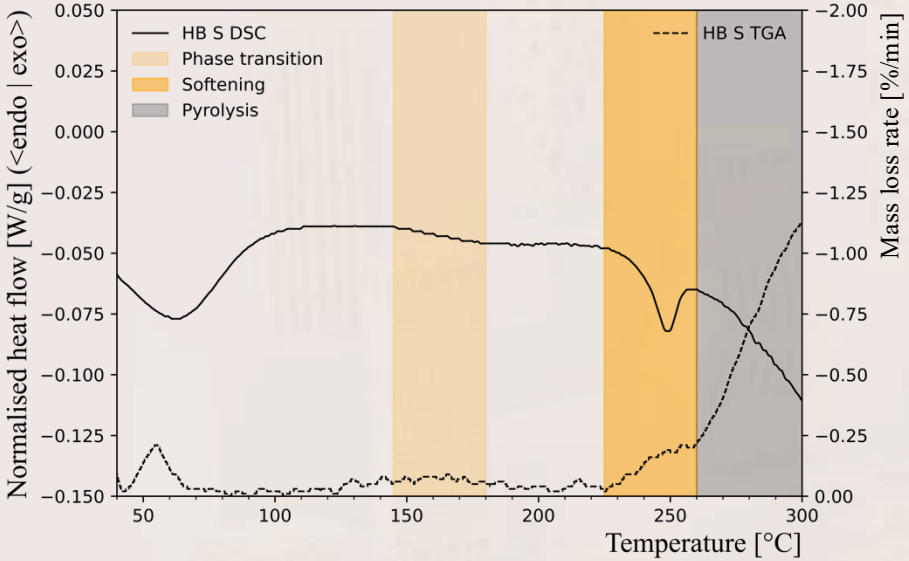
Adhesive film

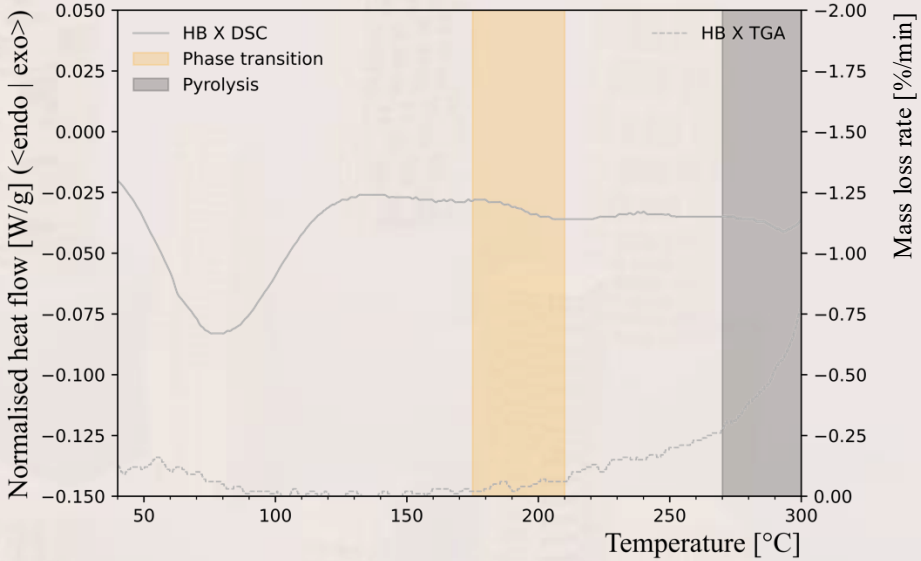
Timber veneers



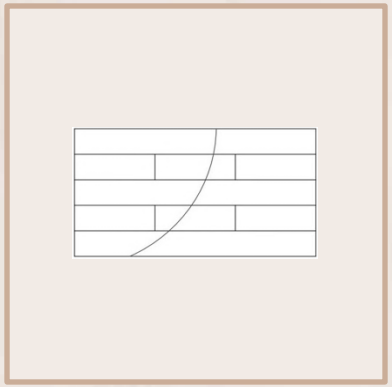
Differential scanning calorimetry

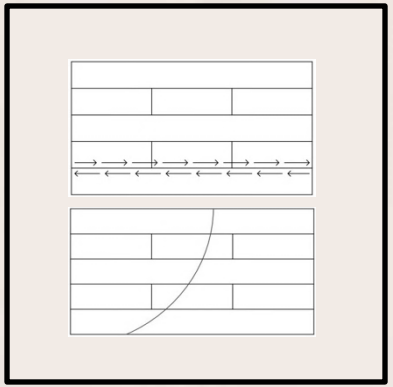


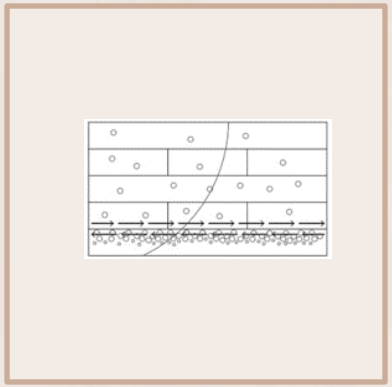


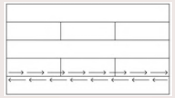


Tg – Glass transition: HB S 145-180 °C | HB X 180-210 °C
Ts – Softening: HB S 225-260 °C
Tp – Pyrolysis: HB S >260 °C | HB X >270 °C

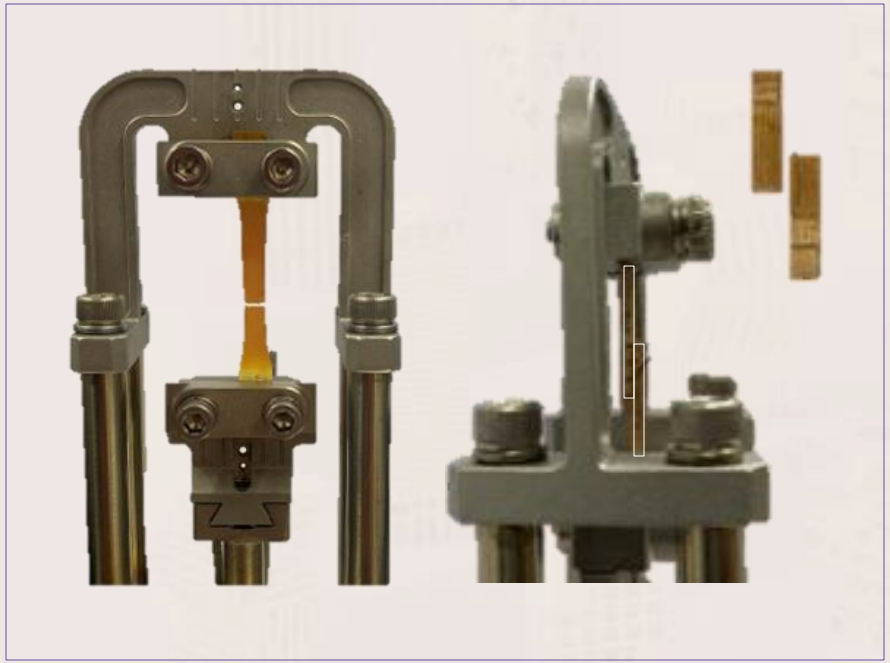




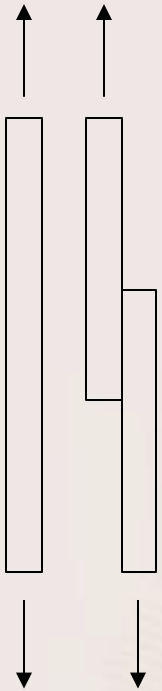


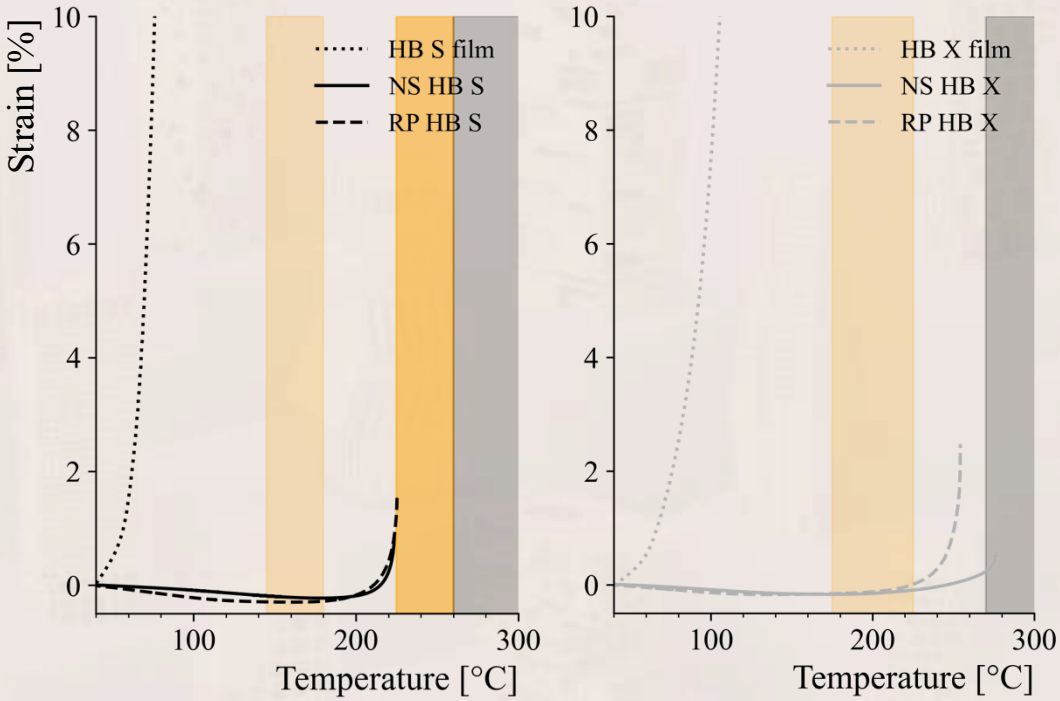


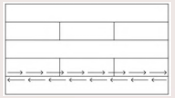
HB S

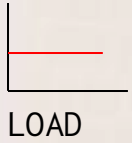


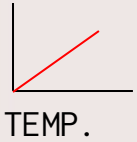
HB X

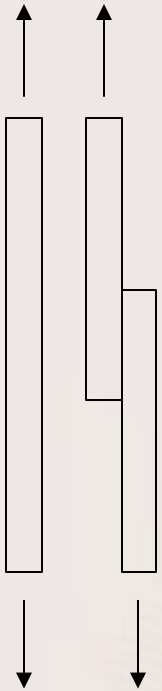


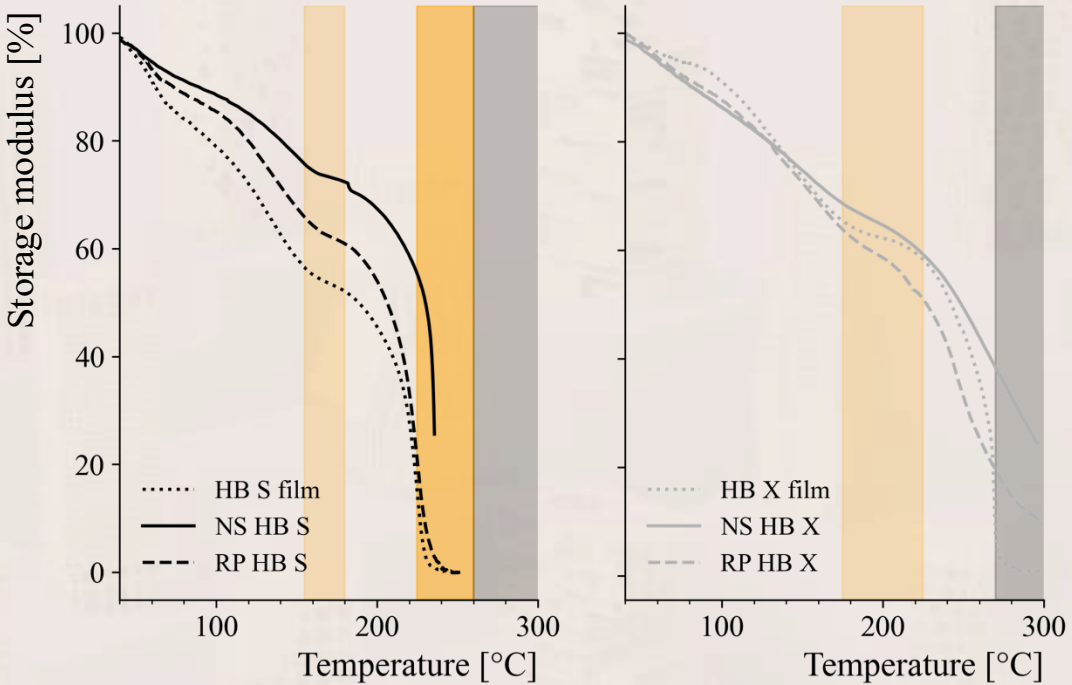

Strain [%]
10
8
6
4
2
0
100
200
300
Temperature [°C]
HB S film
NS HB S
RP HB S
HB X film
NS HB X
RP HB X

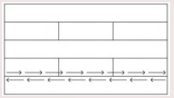


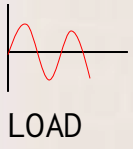

LOAD


TEMP.




Storage modulus [%]
100
80
60
40
20
0
HB S film
NS HB S
RP HB S
100
200
300
Temperature [°C]
HB X film
NS HB X
RP HB X
100
200
300
Temperature [°C]

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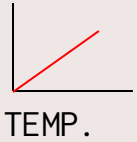
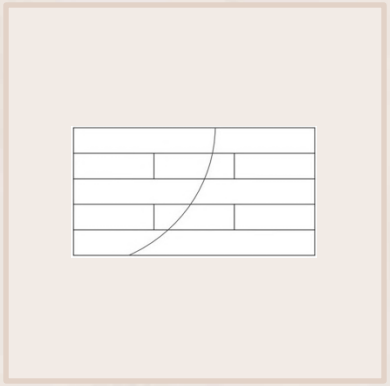
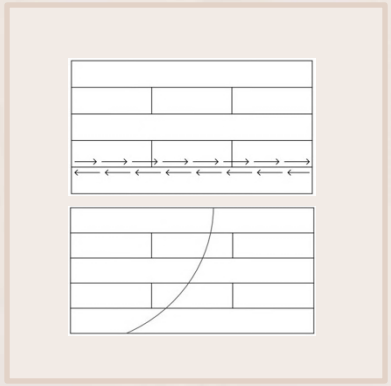
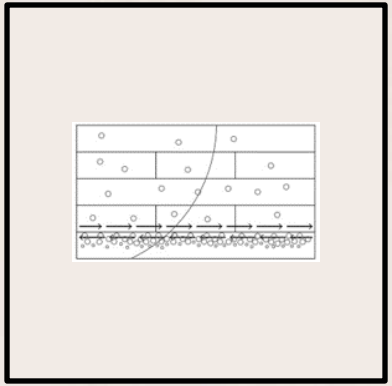

TEMP.





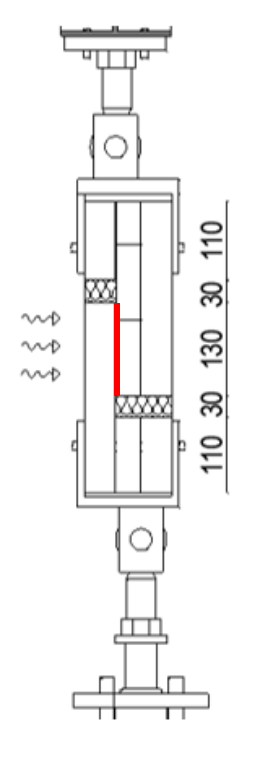


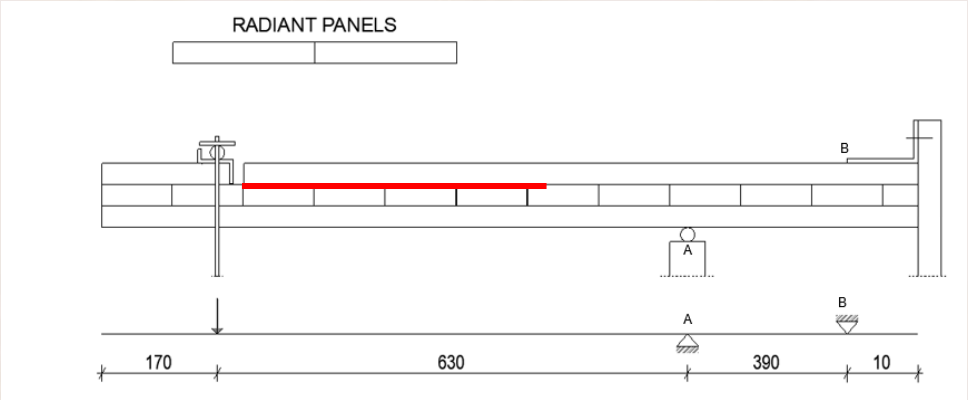
Uniform heating Ramped load	Shear strength reduction
Constant load Transient heating	Bond line temperature Displacement (rate) Failure time

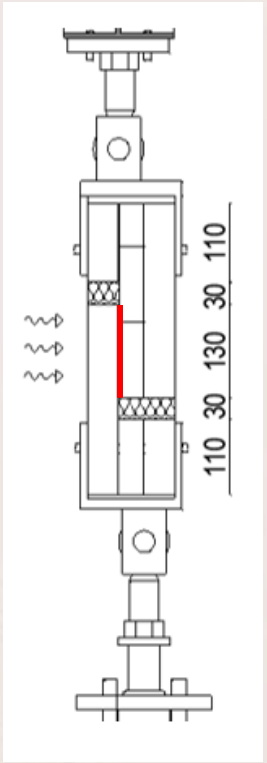
METHOD

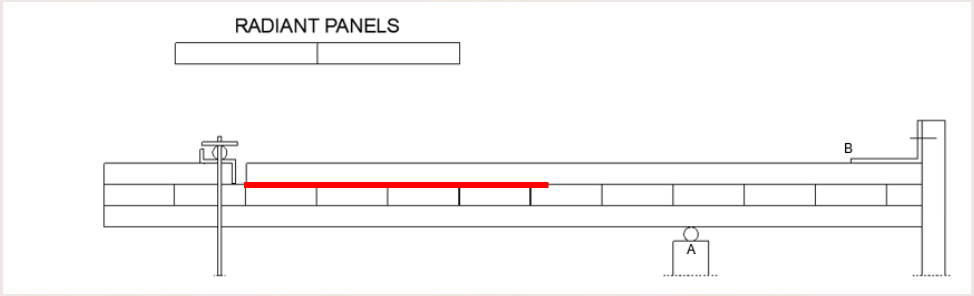
RESULTS

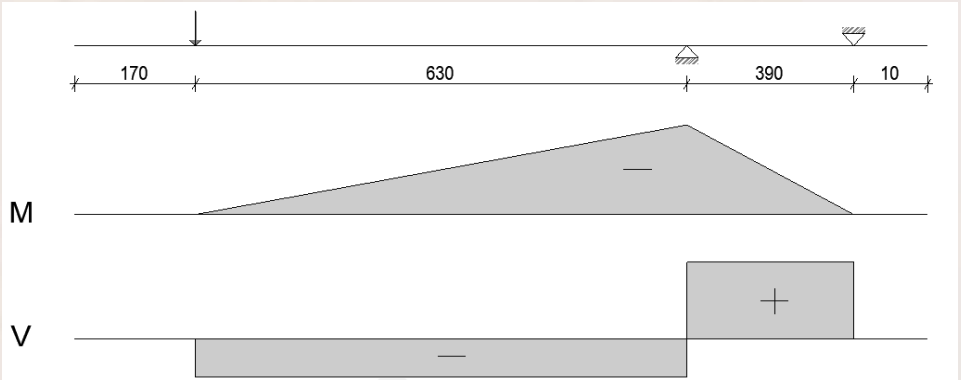
CONCLUSION

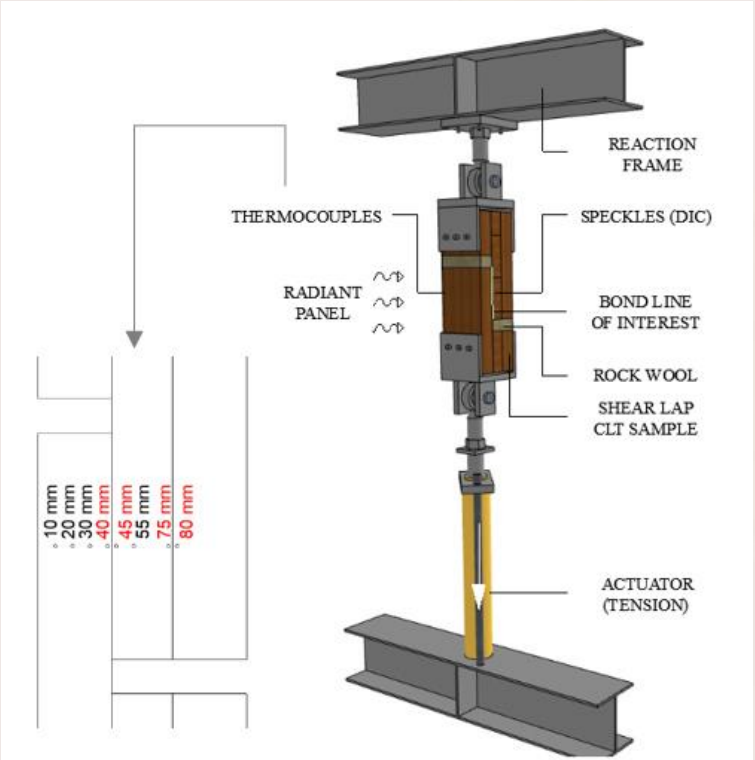

110
30
130
30
110

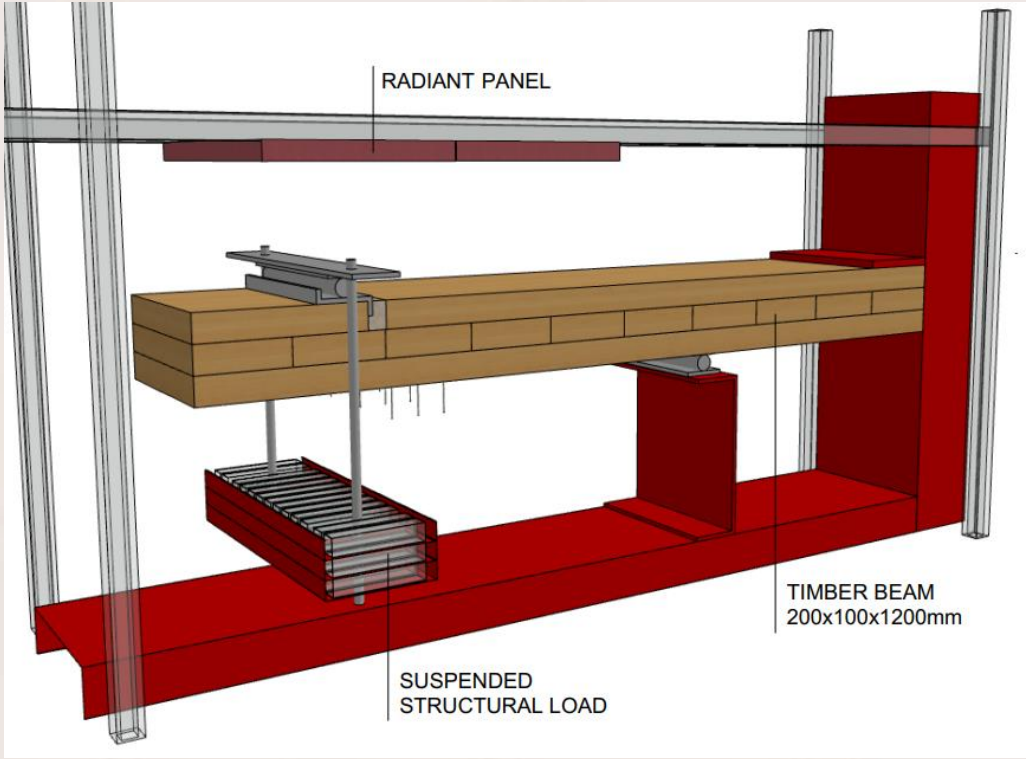

RADIANT PANELS
B
A
A
B
170
630
390
10


110
30
130
30
110


RADIANT PANELS
B
A


170
630
390
10
M
V


REACTION FRAME
THERMOCOUPLES
SPECKLES (DIC)
RADIANT PANEL
BOND LINE OF INTEREST
ROCK WOOL
SHEAR LAP CLT SAMPLE
10 mm
20 mm
30 mm
40 mm
45 mm
55 mm
75 mm
80 mm
ACTUATOR (TENSION)


RADIANT PANEL
TIMBER BEAM
200x100x1200mm
SUSPENDED
STRUCTURAL LOAD

Experimental Matrix: Shear Laps

Adhesive Types

Two 1-C-PUR adhesives:

- standard (Loctite **HB S**)
- improved performance at elevated temperatures (Loctite **HB X**)

Heat Flux Severity

ambient conditions

25 kW/m^2

50 kW/m^2

Loading conditions

20% ambient shear capacity

Moisture Conditions

21°C + (RH 65% or 80%)

Initial moisture contents:

9% and 14%

Experimental Matrix: Beams

Adhesive Types

Two 1-C-PUR adhesives:

- standard (Loctite **HB S**)
- improved performance at elevated temperatures (Loctite **HB X**)

Heat Flux Severity

ambient conditions

25 kW/m^2

50 kW/m^2

Loading conditions

6% ambient shear capacity

12% ambient shear capacity

Moisture Conditions

20°C + (RH 65%)

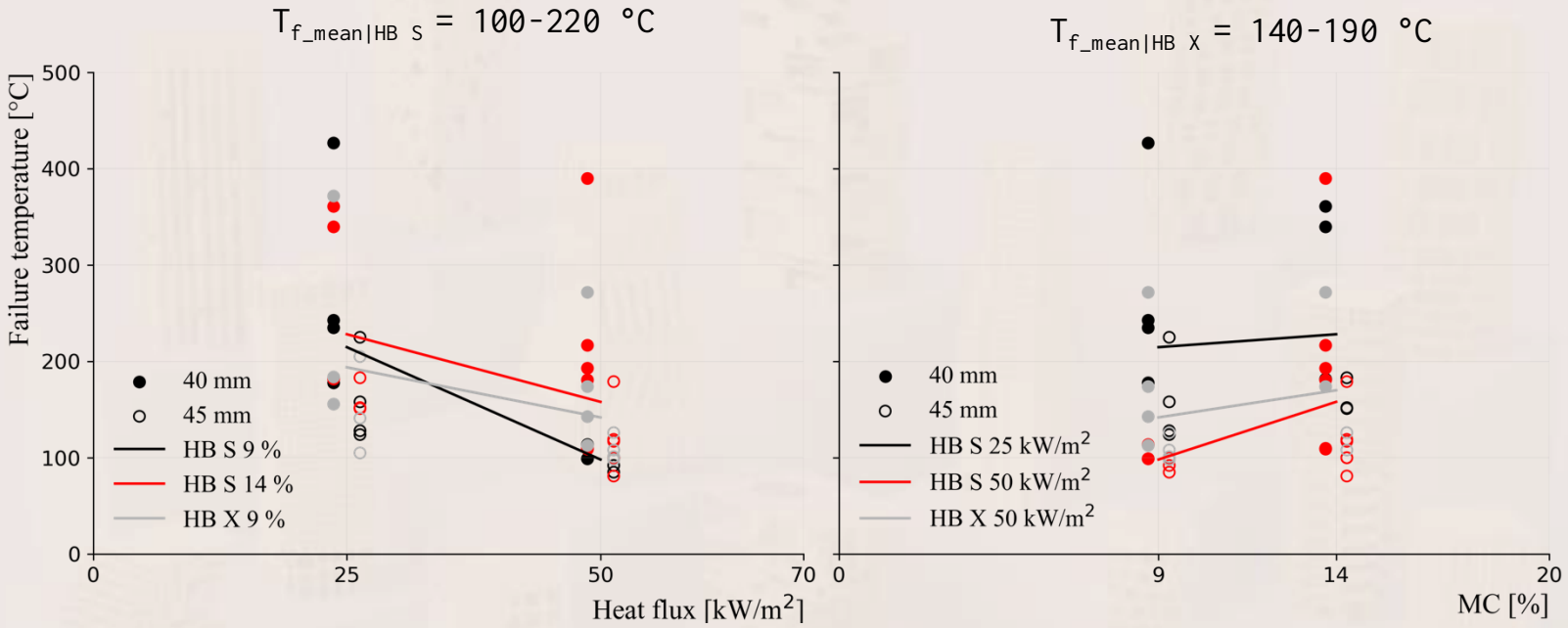
10.9 ± 0.07 % (n=8)

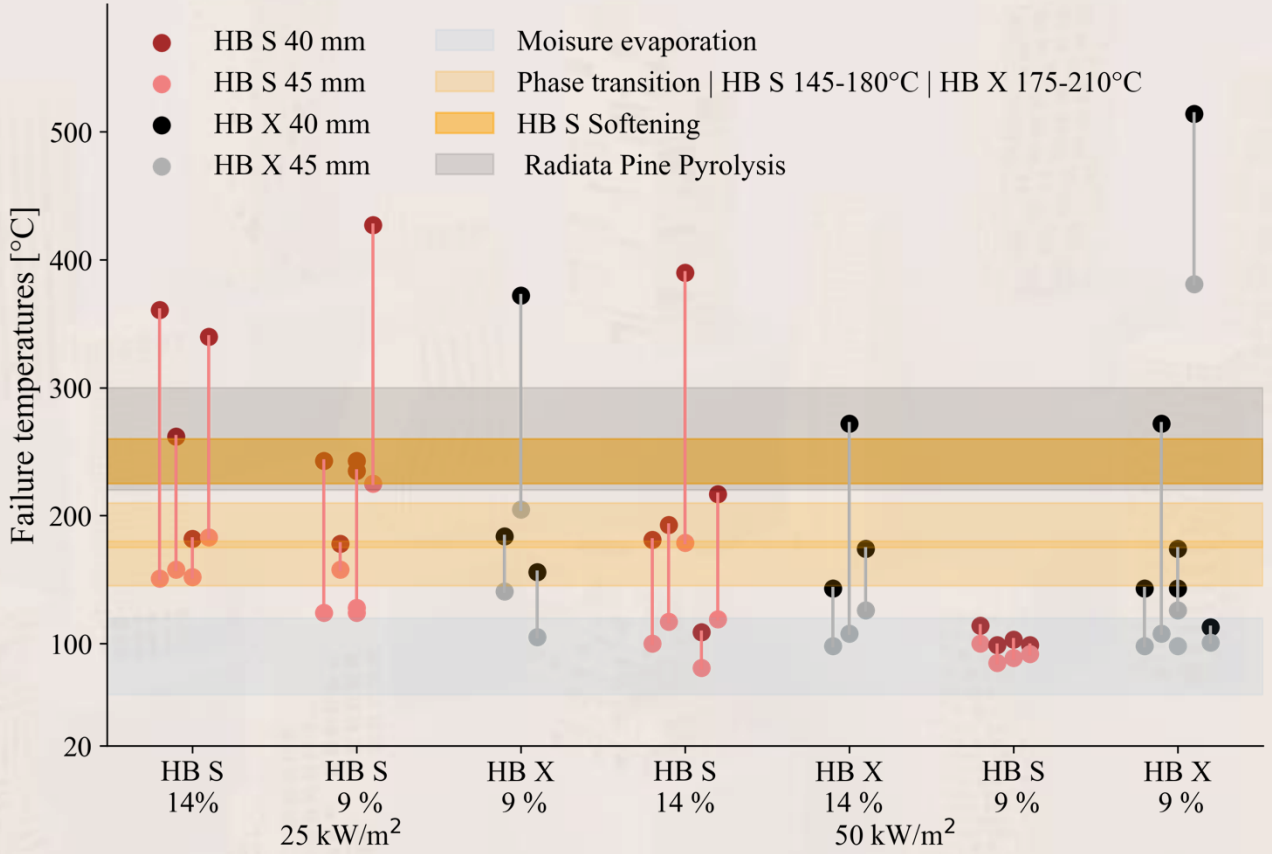
METHOD

RESULTS
SHEAR LAPS

CONCLUSION

Failure Mode

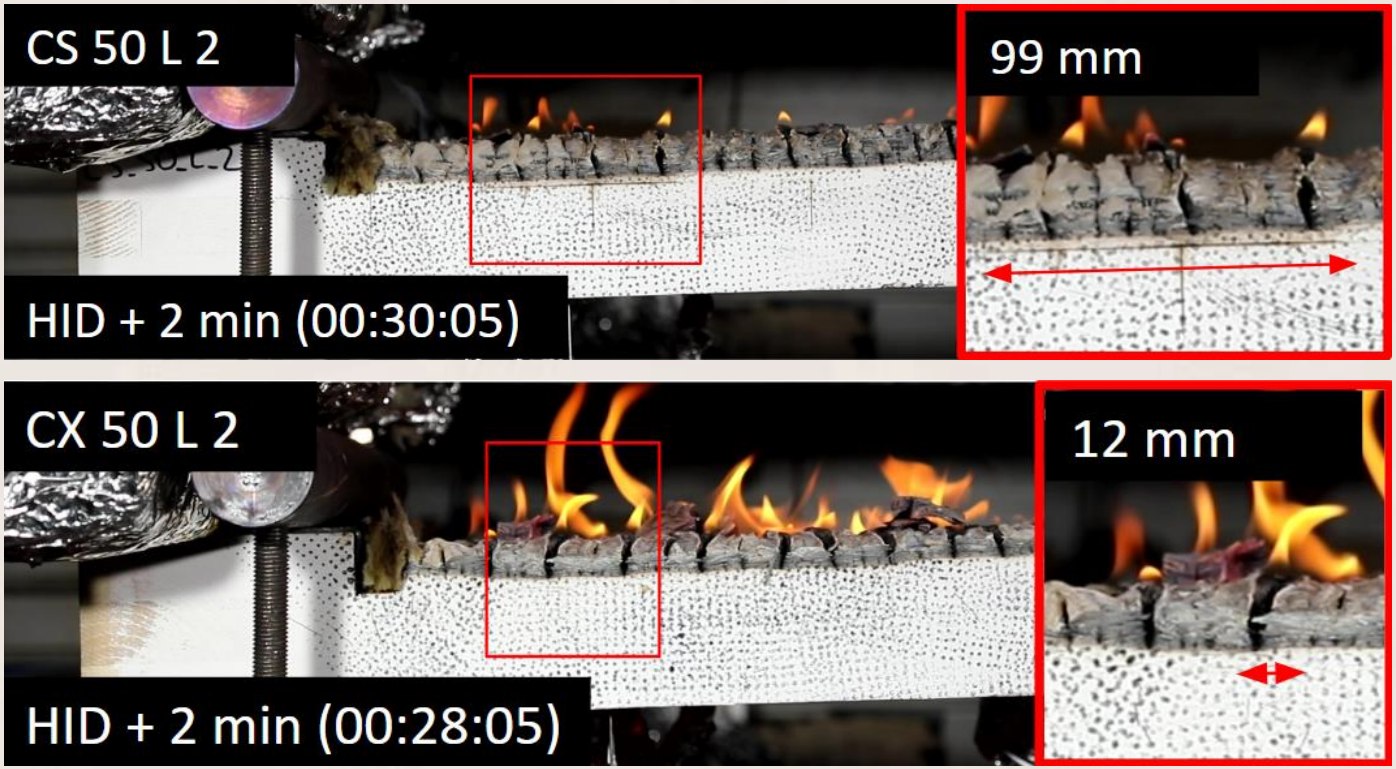

$T_{f\_mean|HB\ S}$ = 100-220 °C
Failure temperature [°C]
500
400
300
200
100
0
40 mm
45 mm
HB S 9 %
HB S 14 %
HB X 9 %
0
25
50
70
Heat flux [kW/m^2]
$T_{f\_mean|HB\ X}$ = 140-190 °C
40 mm
45 mm
HB S 25 kW/m^2
HB S 50 kW/m^2
HB X 50 kW/m^2
0
9
14
20
MC [%]

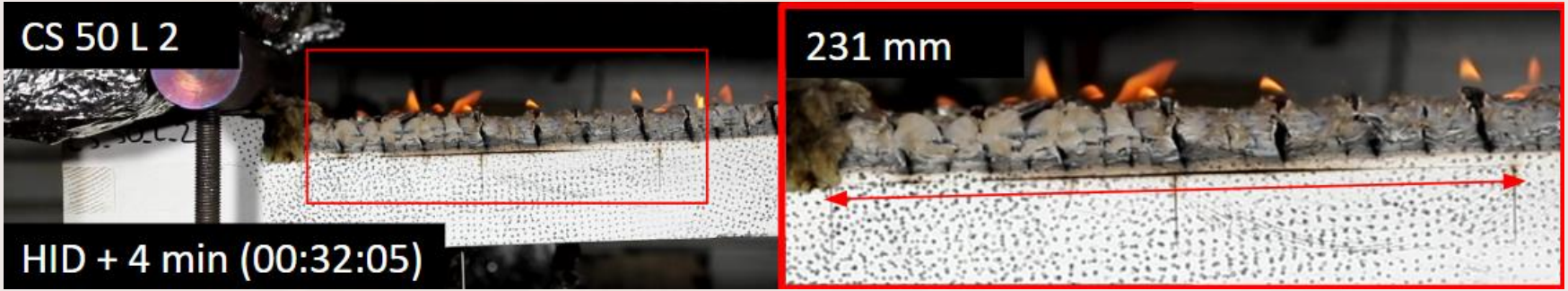

HB S 40 mm
HB S 45 mm
HB X 40 mm
HB X 45 mm
Moisure evaporation
Phase transition | HB S 145-180°C | HB X 175-210°C
HB S Softening
Radiata Pine Pyrolysis
Failure temperatures [°C]
500
400
300
200
100
20
HB S 14%
HB S 9 % 25 kW/m2
HB X 9 %
HB S 14 %
HB X 14 % 50 kW/m2
HB S 9 %
HB X 9 %

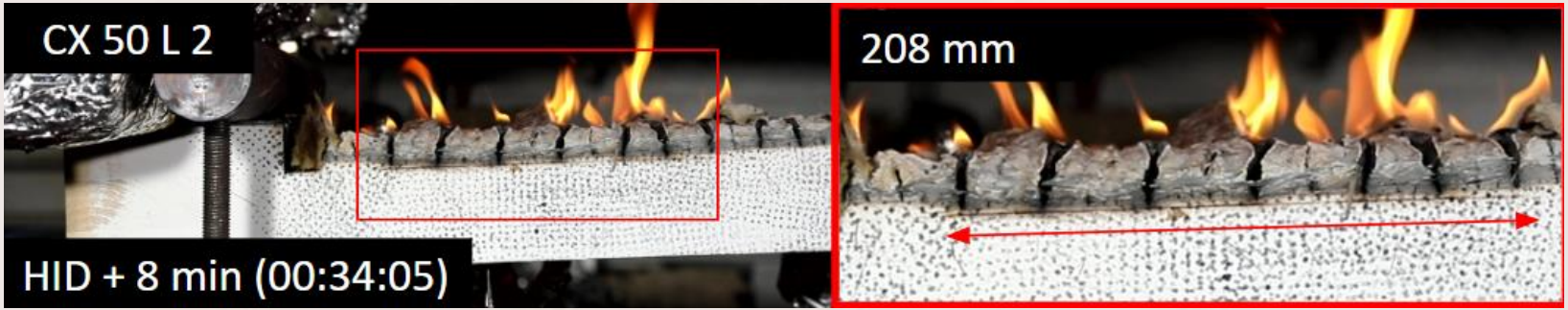
METHOD

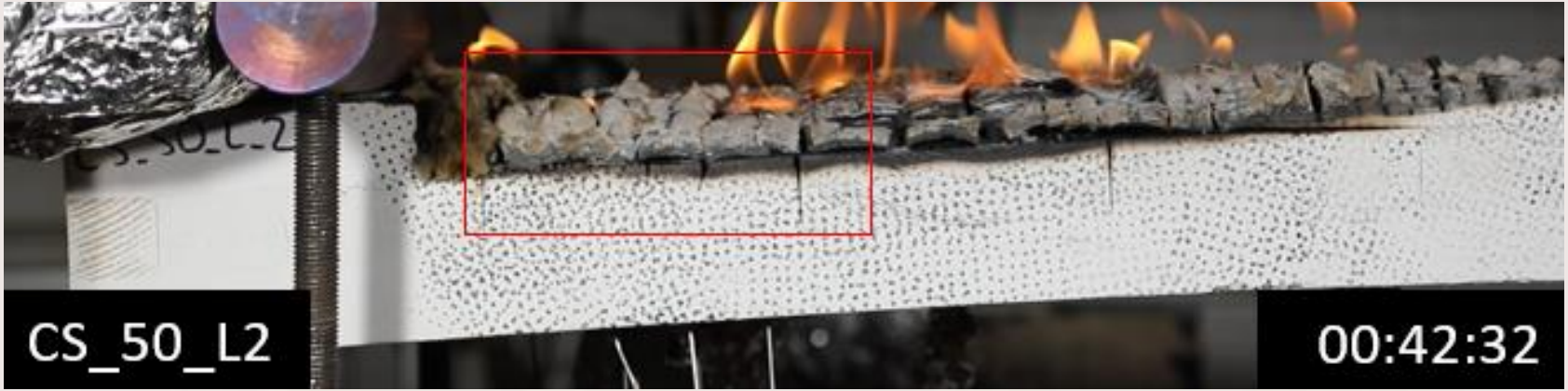
RESULTS
BEAMS

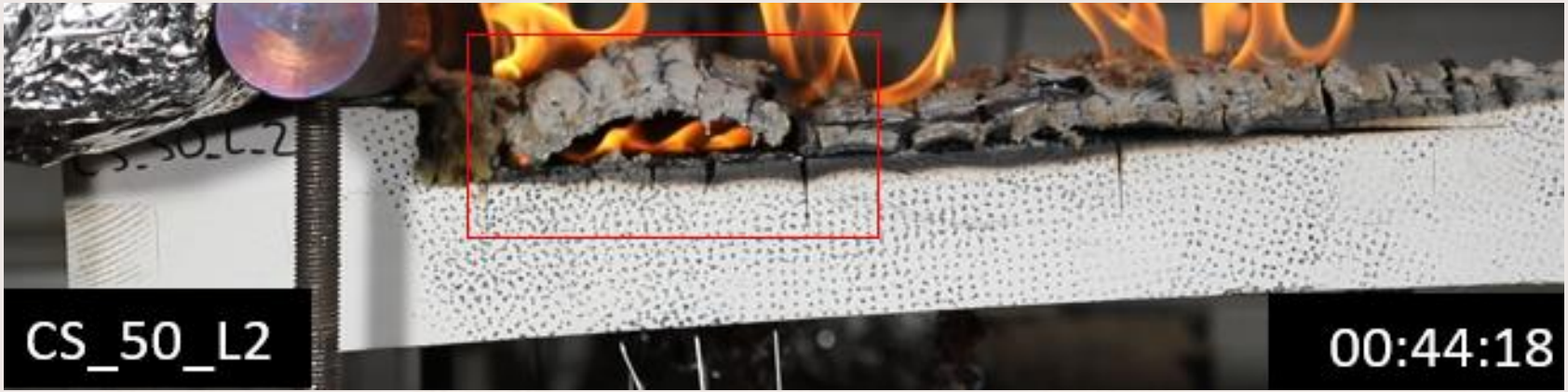
CONCLUSION

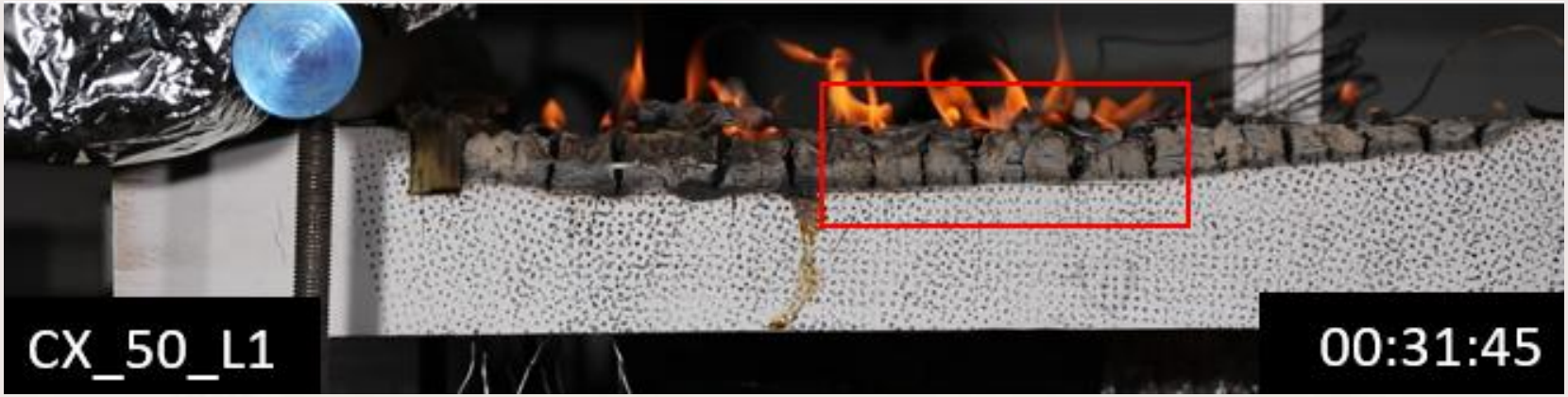

CS 50 L 2
99 mm
HID + 2 min (00:30:05)
CX 50 L 2
12 mm
HID + 2 min (00:28:05)


CS 50 L 2
HID + 4 min (00:32:05)
231 mm

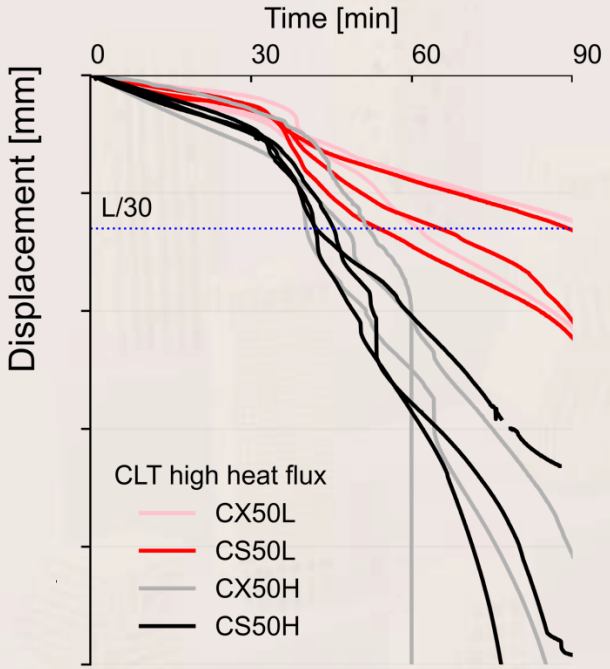

CX 50 L 2
HID + 8 min (00:34:05)
208 mm

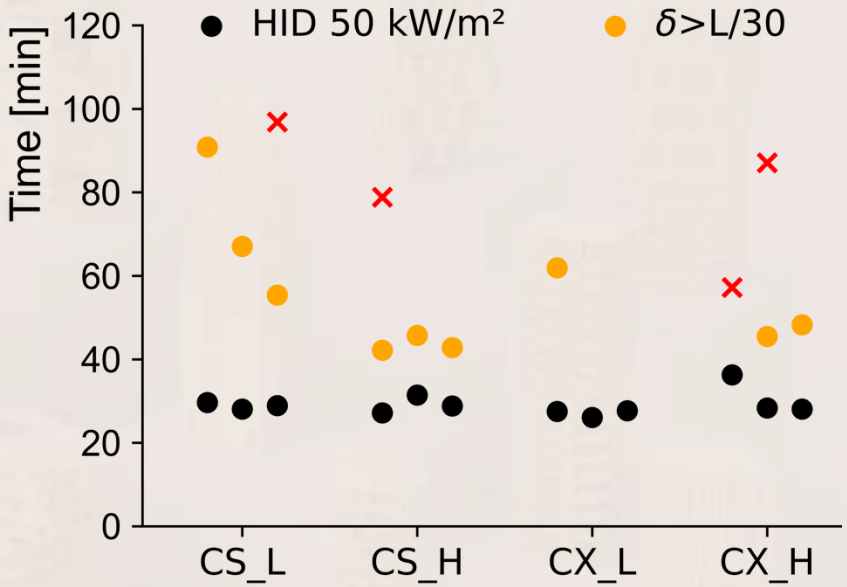

CS_50_L2
00:42:32

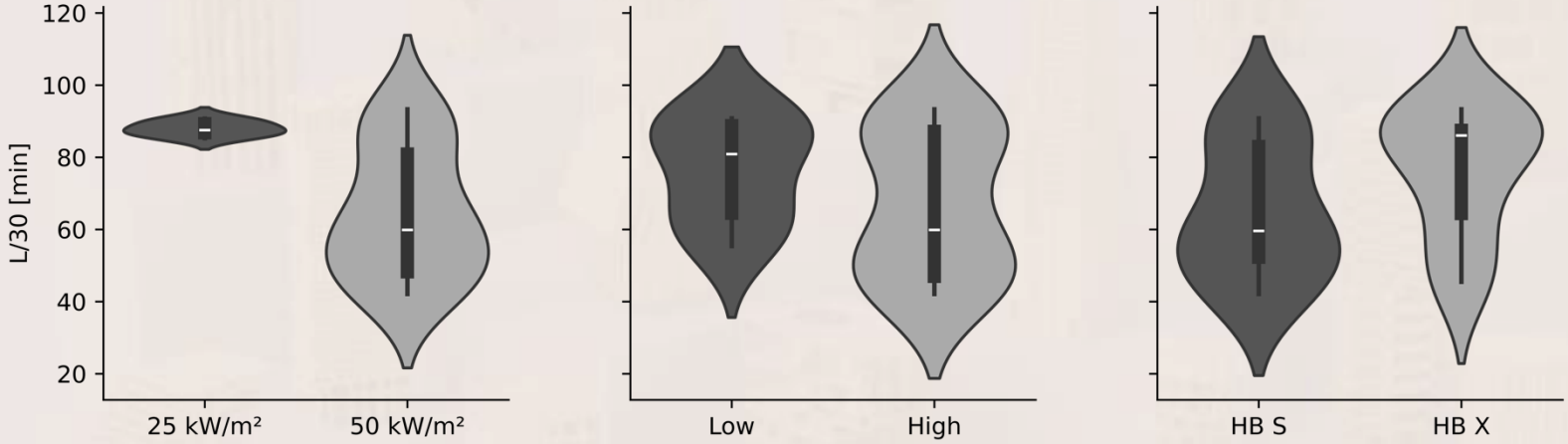

CS_50_L2
00:44:18

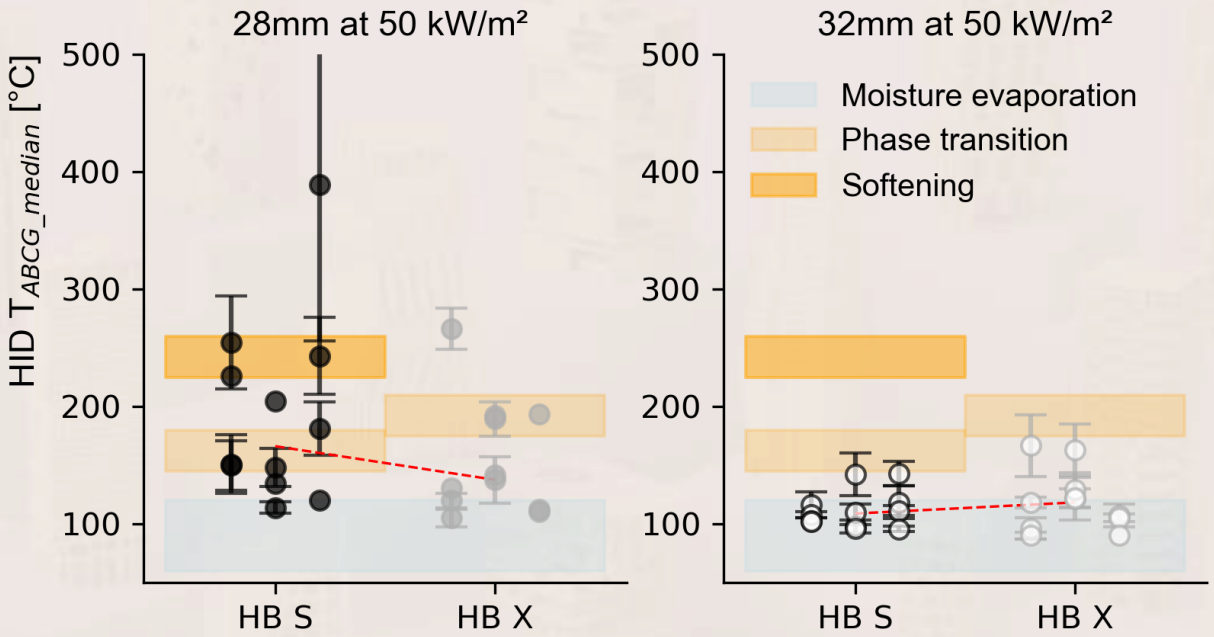

CX_50_L1
00:31:45


CX_50_L1
00:31:51


Time [min]
0
30
60
90
Displacement [mm]
L/30
CLT high heat flux
CX50L
CS50L
CX50H
CS50H


HID 50 kW/m²
δ>L/30
Time [min]
120
100
80
60
40
20
0
CS_L
CS_H
CX_L
CX_H


120
100
80
60
40
20
L/30 [min]
25 kW/m²
50 kW/m²
Low
High
HB S
HB X


28mm at 50 kW/m²
32mm at 50 kW/m²
HID T_{ABCG_median} [°C]
500
400
300
200
100
HB S
HB X
Moisture evaporation
Phase transition
Softening

METHOD

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Heat Induced Delamination

Effects Fire Dynamics

Addition of new fuel

Reradiation

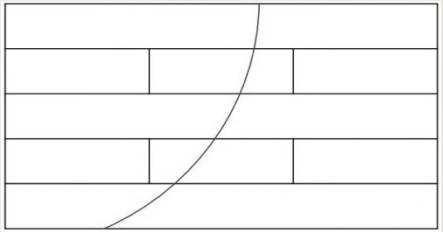
Prolonged fire duration due to continuous burning

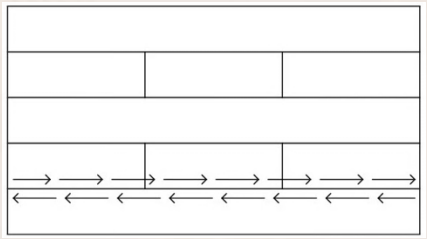
Effects Structural Capacity

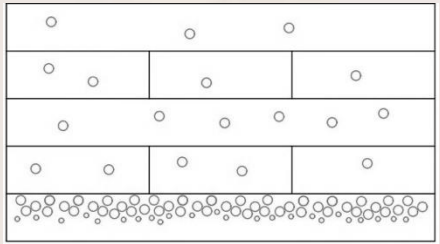
Progressive cross section loss

Loss of composite action in cooling phase

Conclusion: Understanding heat induced delamination







Method assessment

Bond line behaviour cannot be captured with one testing condition

Performance criteria assessment

There is no one critical bond line temperature

Adhesive assessment

Condition dependent

Q & ”A”

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April, 2025