POLYURETHANE FLEXIBLE JOINTS AS A SYSTEM FOR STRUCTURAL AND NON-STRUCTURAL BONDING OF TIMBER ELEMENTS

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Narodowe Centrum Nauki

OPUS-22 (LAP)

Cracow University of Technology

Faculty of Civil Engineering

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PUFJ – PolyUrethane Flexible Joints
innovative solution for high loads and high deformations

FLEX AND ROBUST SYSTEMS

2016 - FlexAndRobust Systems company is a spin – off company set by scientists from Cracow University of Technology

- repairing masonry buildings
- reinforcement of structural elements
- structure security systems for earthquake areas

Figure 1: Value of sold production of the wood industry, 2010-2021 Poland [1]

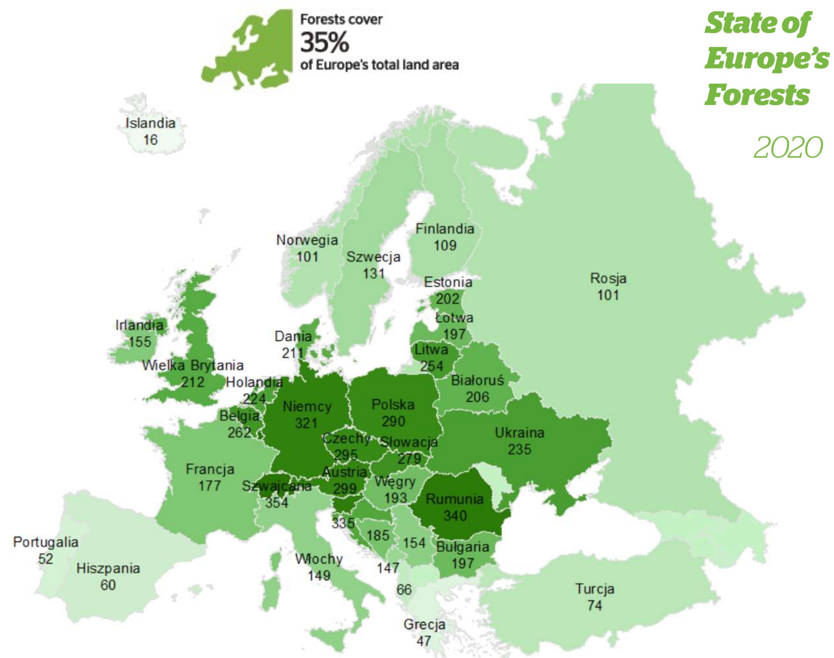

Figure 2: Average amount of forest m^3/h [2]

[1] GUS, Analizy Pekao
[2] https://foresteurope.org/wp-content/uploads/2016/08/SoEF_2020.pdf

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PUFJ (POLYURETHANE FLEXIBLE JOINTS)

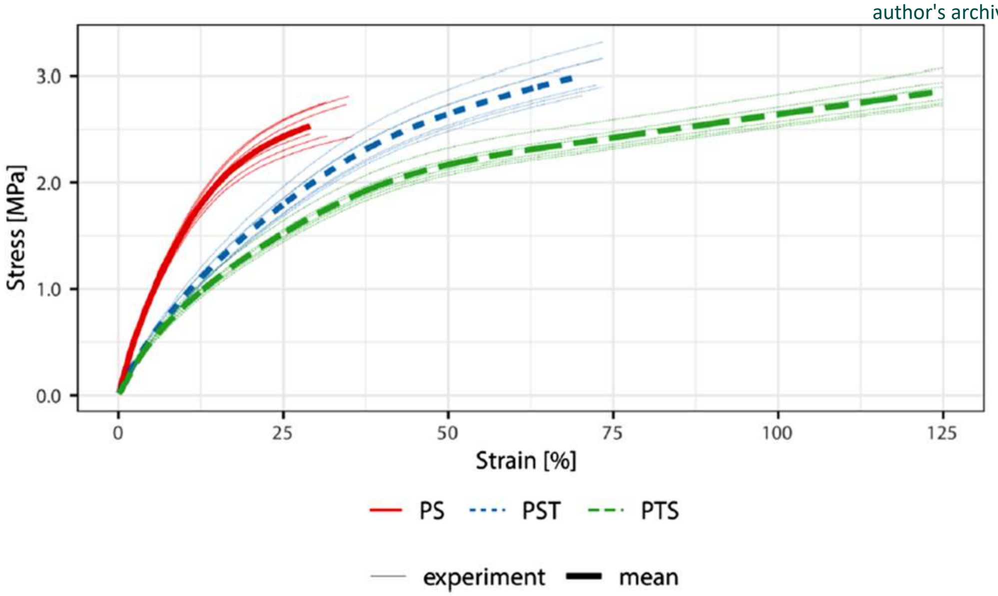
author's archive

7 flexible polyurethane adhesives of various visco-elasto-plastic properties:

- Young modulus 1-700 MPa,
- ultimate elongation 10-600%
- tensile strength 1-25 MPa

Adhesive types	Young modulus E_R [MPa]	Ultimate elongation ε_{max} [%]	Tensile strength R_R [MPa]	Shore'a A hardness [°]
PT	700	10	25	98
PSTF	20	35	4,3	85
PS	20	30	2,6	80
PST	15	65	3,0	75
PTS	12	120	2,9	70
PM	4	110	1,4	55
PBM	1	600	0,7	35

Table. Parameters of adhesives.



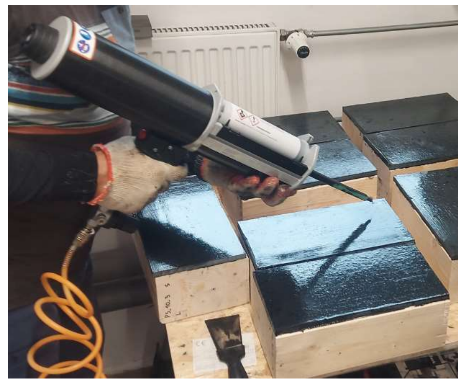
PUFJ (POLYURETHANE FLEXIBLE JOINTS)

APPLICATION METHODS

↓ INJECTION

↓ PREFABRICATION

Thickness from 1 to 30mm



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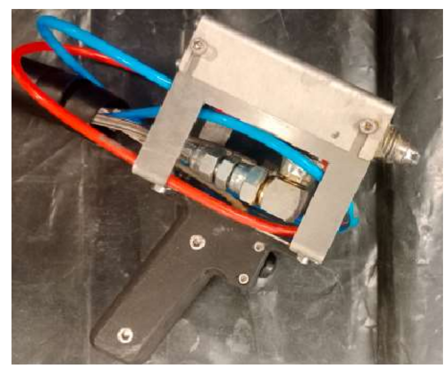

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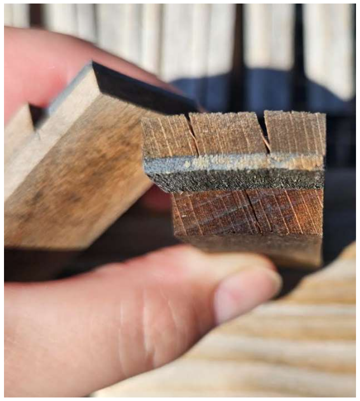
POLYURETHANE FLEXIBLE JOINTS AS A SYSTEM FOR STRUCTURAL AND NON-STRUCTURAL BONDING OF TIMBER ELEMENTS

OPUS LAP PROJECT DIAMONS

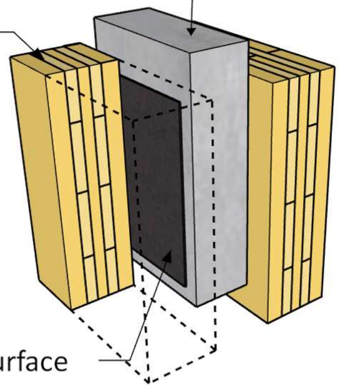
DIAMONDS

The impact of aging

Beech wood



TIMBER CONCRETE COMPOSITE



The impact of the gluing surface

Spruce

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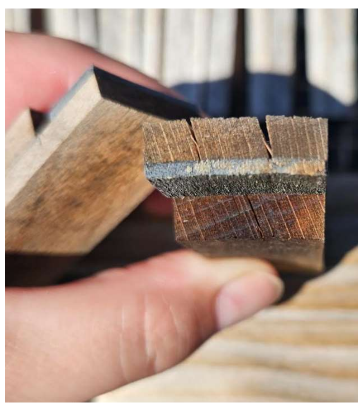
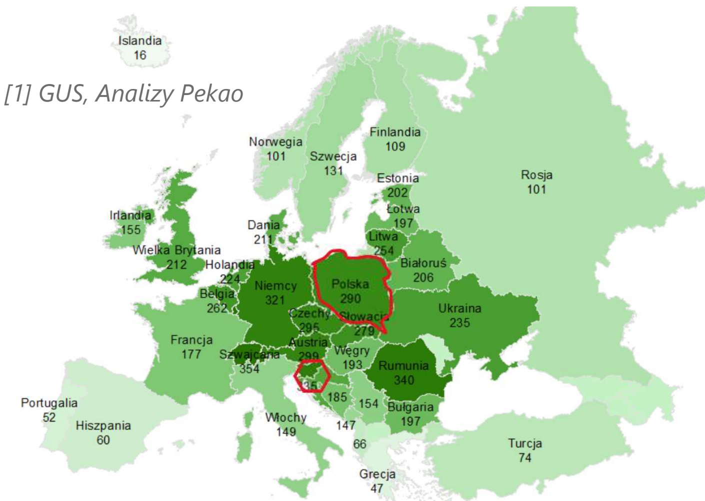


DIAMONDS - "DIAgnostics and Mechanical tests Of aged adhesive layers used in joiNts of wooDen structureS",
Funded by the National Science Centre, Poland under the OPUS call in the Weave programme, No. 2021/43/I/ST8/00554

• WHY HARDWOOD-BASED COMPOSITES ?

OPUS LAP PROJECT DIAMONS



Two countries: Poland and Slovenia

Four research institutes:

- Slovenian National Building and Civil Engineering Institute
- InnoRenew CoE
- AGH University of Science and Technology
- Cracow University of Technology

Figure 3: Europe's growing stock by main tree species,2020 [2]

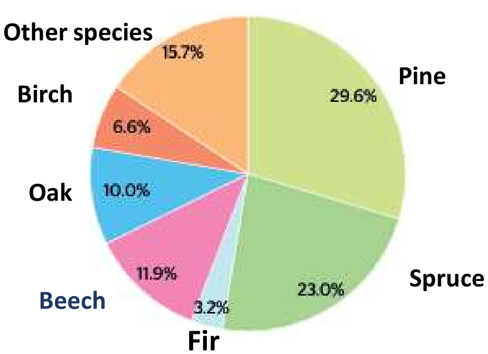


Figure 4: Hardwood-Based Composites with flexible polyurethane adhesive joints

DIAgnostics and Mechanical tests Of aged adhesive layers used in joiNts of wooDen structureS

DIAMONDS

NARODOWE CENTRUM NAUKI

OPUS-22 (LAP)

THE DIAMONDS PROJECT

DIAMONDS

- Characterize and study flexible types of adhesives (FPUR).
- Explore the use of flexible adhesives in beech composites over time.
- Understand and describe adhesive, wood-adhesive joints durability.
- Expand testing of commercial PUR.

- **Adhesives**: join objectives, transfer loads, use in composites, engineered wood products…
- 1C **PUR**: easy to use: cure at room temperature - no need for expensive heating presses, highest adaptability of PUR chemistry, formaldehyde-free...
- **FPUR** - a wide range of flexibility, repairing masonry buildings reinforcements in seismic areas.

Figure : Diamonds project team - working meeting in Izola

FACTORS OF AGEING

- The main factors that influence a high bondline performance throughout the service life of glued products includes:

  -**environmental conditions:** temperature, moisture

  -**material:** adherent-adhesive interaction

  -**type of loading – creep**

Figure Natural weathering test site – Poland/Cracow

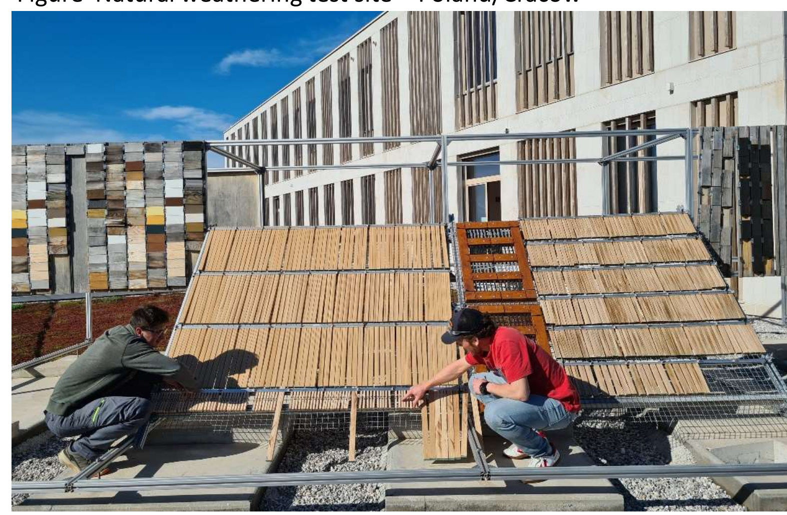


Figure:Natural weathering test site – Slovenia/Izola

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TESTS: 1) LAP SHEAR JOINT

NW period:

- 4 M (May-Sep)
- 8 M (Dec 2025)
- 12 M (May 2026)
- A1 Reference
- FPUR: PS, PTS, PST

Figure: Test stand Izola - start

Figure: Test stand –after 4M

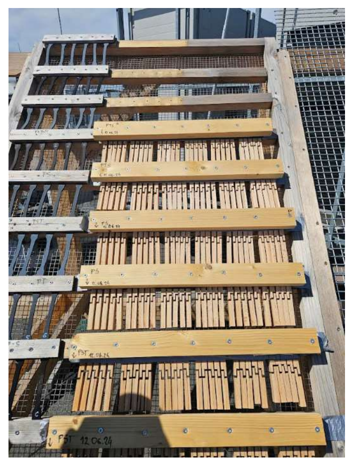


Figure : Test stand Cracow - start

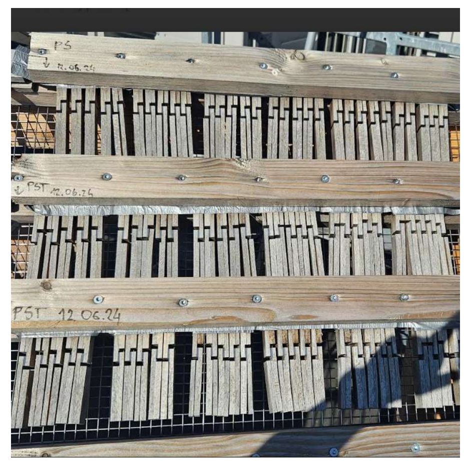


Figure . Test stand –after 4M

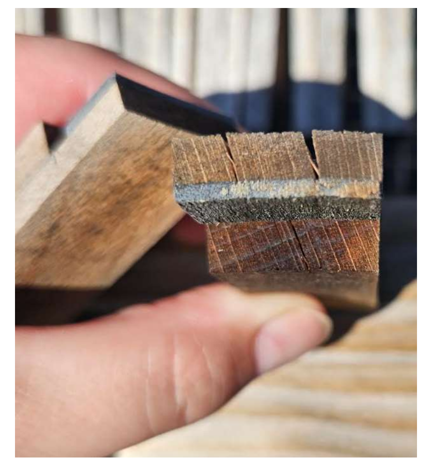
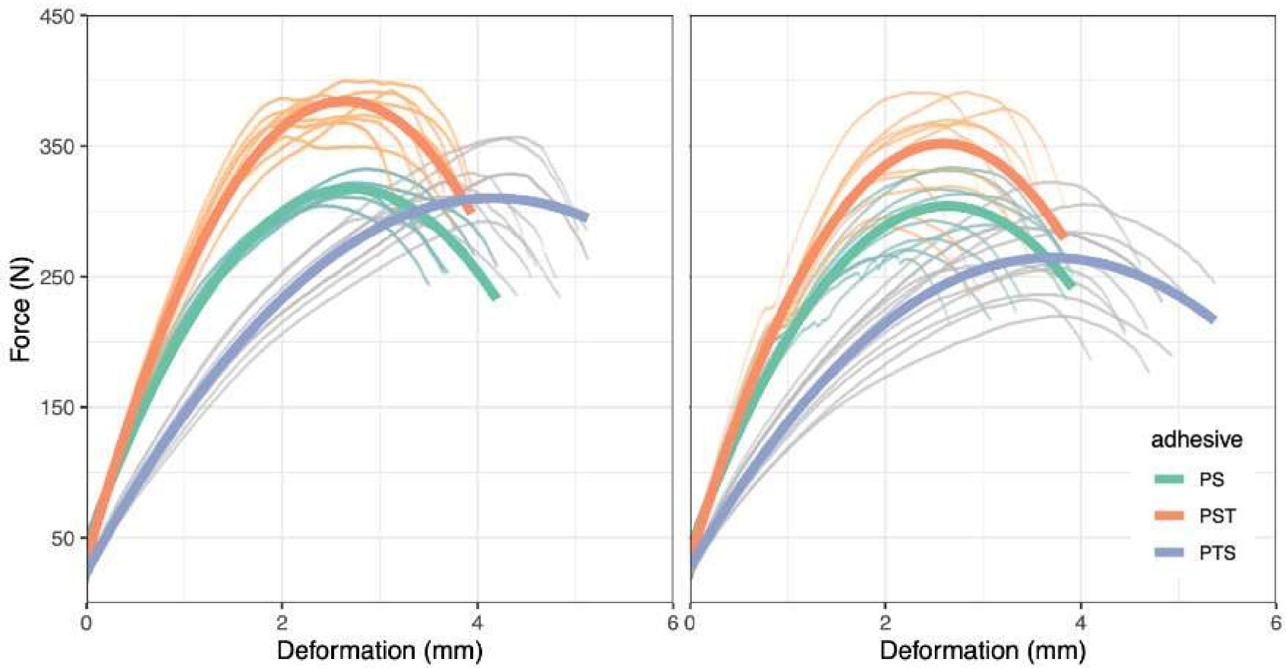


Figure . Sample destruction

The European Standard EN 302-1:2013

LAP SHEAR TESTS: REF, NW 4M

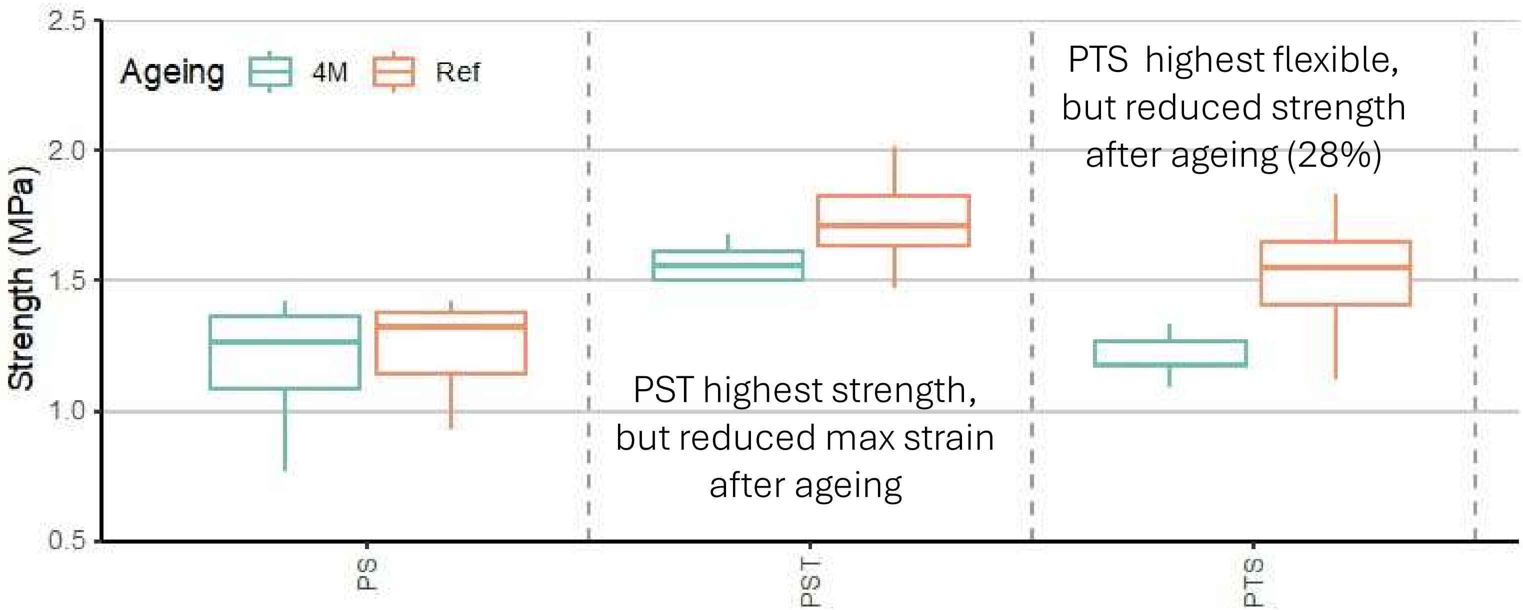


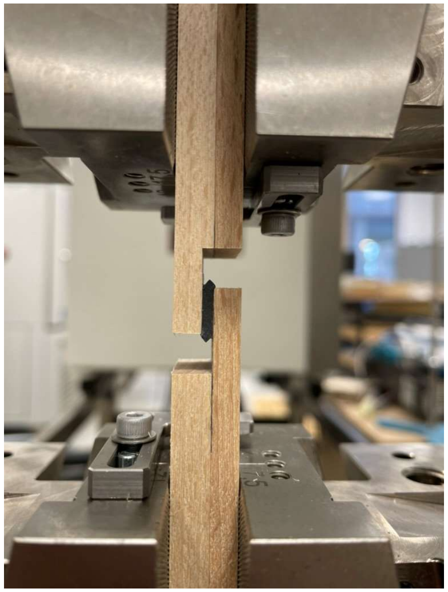
Reference

4 months

Figure 12: View of samples: before and after natural weathering

LAP SHEAR TESTS: REF, NW 4M





LAP SHEAR TESTING:FAILURES IN ADHESIVES

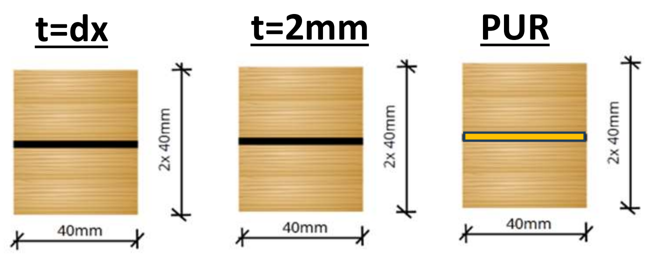
PS

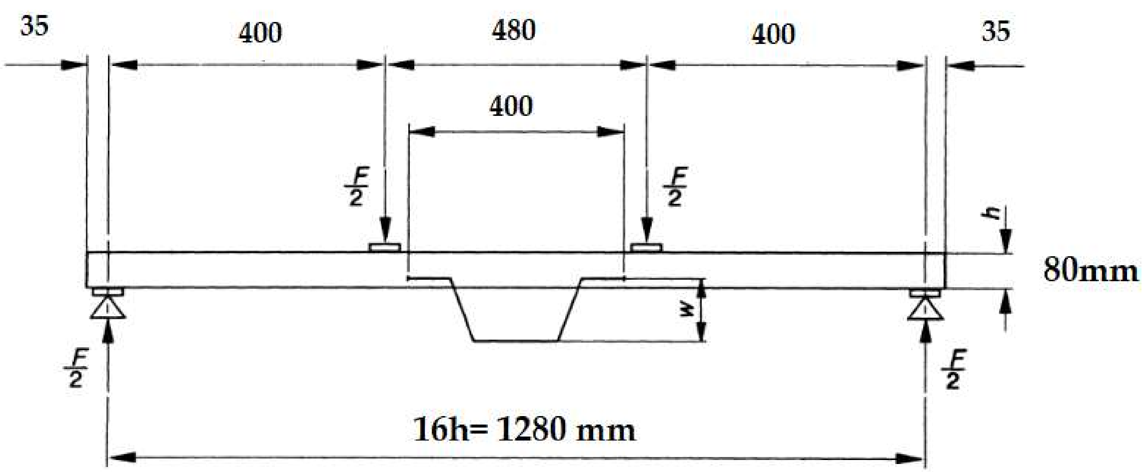
PST

PTS

2) BENDING TESTS:

➯ **Laminated beams**

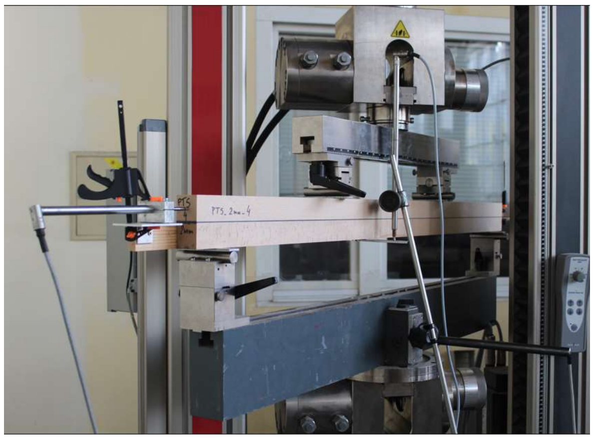


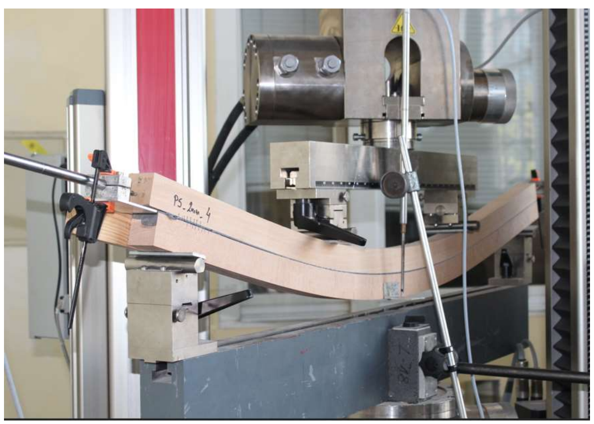


The European Standard EN 408

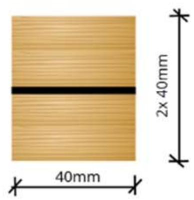
In this test we have three different test periods:
period „0” – natural condition
period „one” - after 6 months of natural aging
period „two” - after 12 months of natural aging

BENDING TESTS:



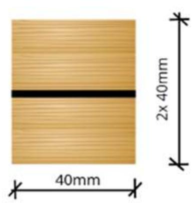


t=dx



t=dx	PUR	PS	PST	PTS
	number of samples (2 battens)			
time "0"	9	9	9	9
time "1"	9	9	9	9
time "2"	9	9	9	9
	total:	**108**	**samples**	

t=2mm



t=2mm	PUR	PS	PST	PTS
	number of samples (2 battens)			
time "0"	0	9	9	9
time "1"	0	9	9	9
time "2"	0	9	9	9
	total:	**108**	**samples**	

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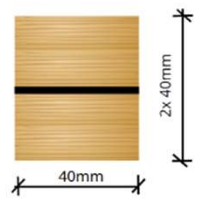
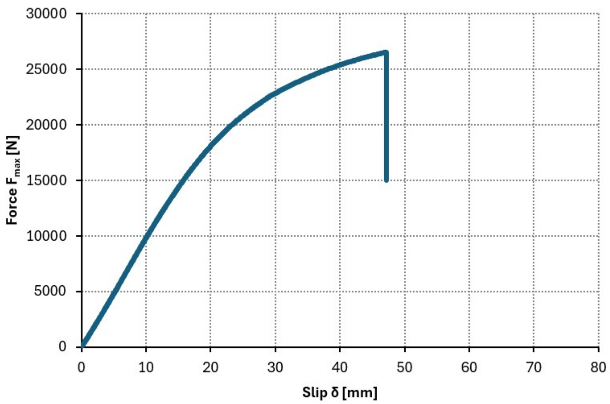
BENDING TESTS:

t=dx

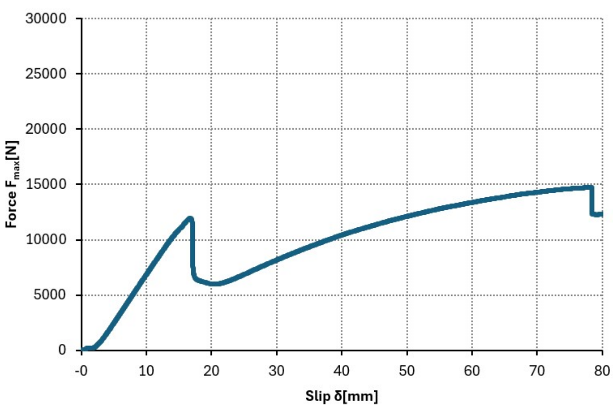


Specimen	PUR F_{max} (kN)	PUR δ_{rel} (mm)	F&R_PS F_{max} (kN)	F&R_PS δ_{rel} (mm)	F&R_PST F_{max} (kN)	F&R_PST δ_{rel} (mm)	F&R_PTS F_{max} (kN)	F&R_PTS δ_{rel} (mm)
1	26,4	53,26	16,1	75,50	15,8	20,96	16,2	68,15
2	25,6	49,15	13,8	89,27	15,8	19,64	14,7	17,12
3	26,2	50,70	16,4	88,61	16,2	80,02	15,2	73,18
4	25,4	51,77	12,8	58,31	16,6	19,91	14,9	74,36
5	27,2	41,58	14,8	78,40	16,5	84,77	17,1	18,63
6	26,6	47,15	14,5	68,02	17,4	82,31	17,2	78,22
7	25,7	40,58	15,5	70,02	17,7	19,18	14,7	22,95
8	23,8	44,39	16,0	83,35	16,8	86,72	14,7	81,94
9	22,9	43,33	14,3	19,26	15,4	18,96	15,0	69,70
Average	**25,5**	**46,9**	**14,9**	**70,1**	**16,5**	**48,1**	**15,5**	**56,0**
CoV (%)	5,0	9,3	7,6	29,0	4,3	66,0	6,3	46,6

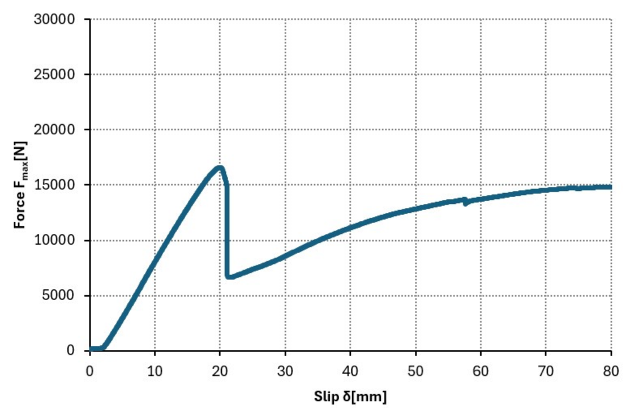
PUR_DX_6



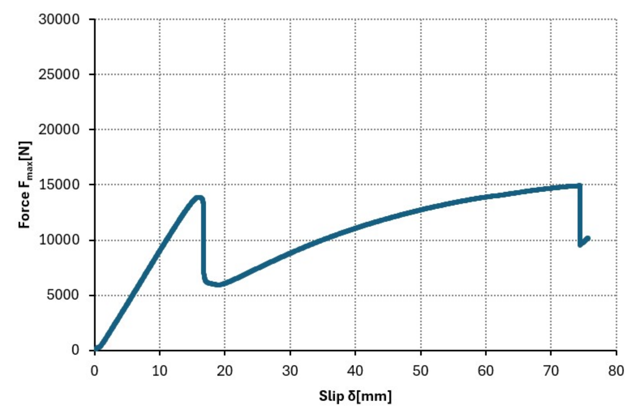
PS_DX_5



PST_DX_4



PTS_DX_4



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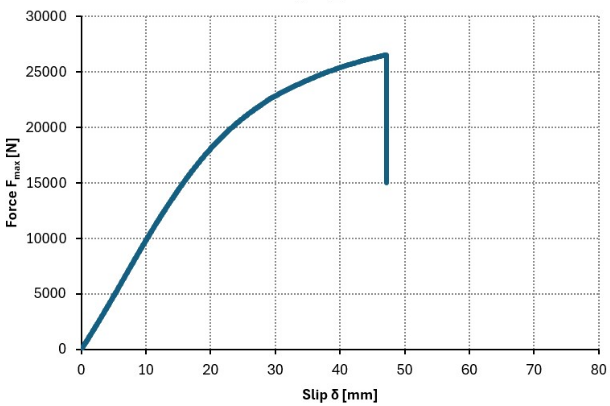
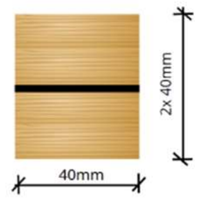
BENDING TESTS:

PUR_DX_6

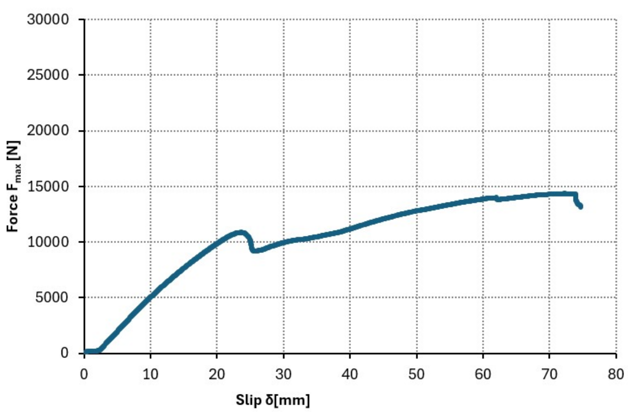


t=2mm

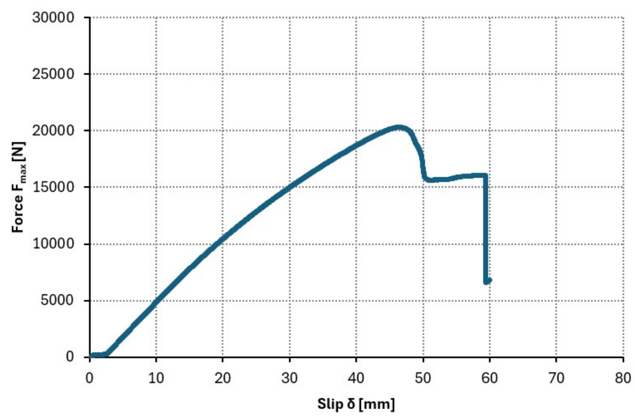


Specimen	F&R_PS		F&R_PST		F&R_PTS	
	F_{max} (kN)	δ_{rel} (mm)	F_{max} (kN)	δ_{rel} (mm)	F_{max} (kN)	δ_{rel} (mm)
1	14,8	91,2	19,1	45,4	16,0	91,2
2	12,5	83,9	18,3	38,9	15,5	83,9
3	14,4	80,5	20,3	46,5	15,2	80,5
4	15,9	40,4	15,9	44,6	17,5	40,4
5	15,2	38,6	14,6	38,3	17,5	38,6
6	15,2	48,9	16,3	46,2	19,6	48,9
7	14,0	78,3	22,5	54,1	13,7	78,3
8	13,4	79,3	22,0	55,9	13,6	79,3
9	19,1	42,2	21,1	56,1	14,6	42,2
Average	**14,9**	**64,8**	**18,9**	**47,3**	**15,9**	**64,8**
CoV (%)	11,8	31,5	14,2	13,4	11,8	31,5

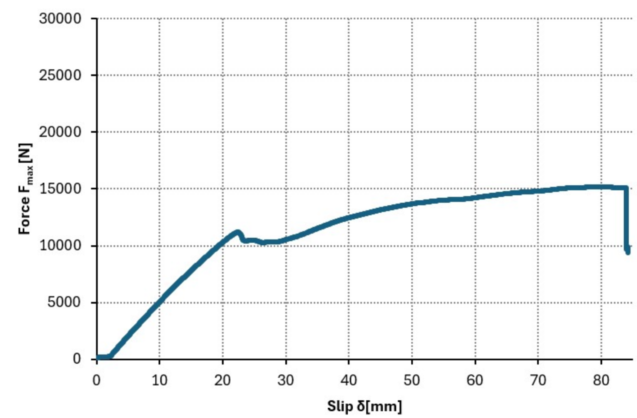
PS_2mm_3



PST_2mm_3



PTS_2mm_3



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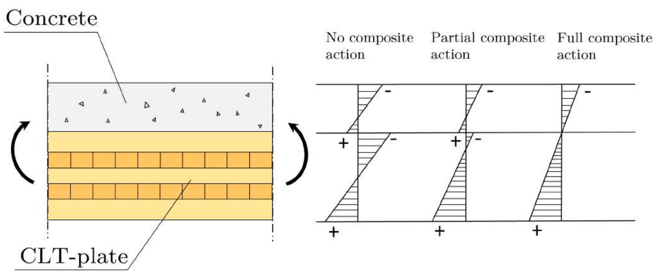

Fig. Strain diagrams for a composite element that is exposed to bending moment.

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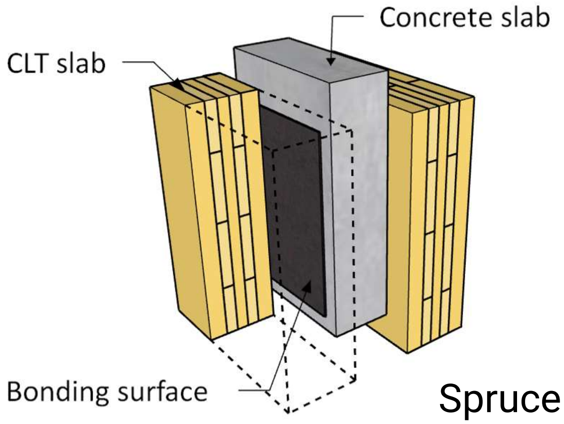
TIMBER CONCRETE COMPOSITE



The impact of the gluing surface

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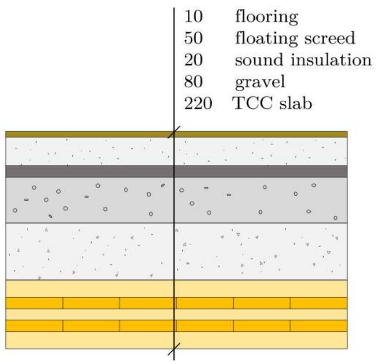
SHEAR TESTS



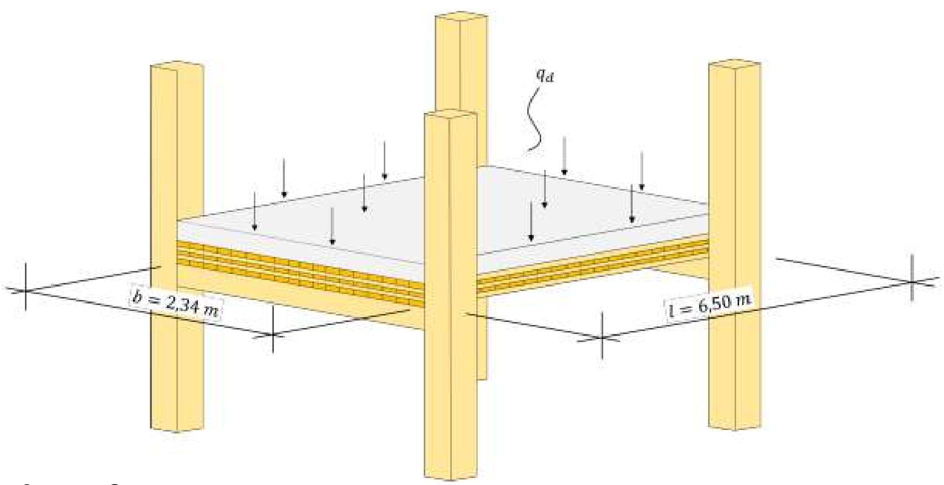


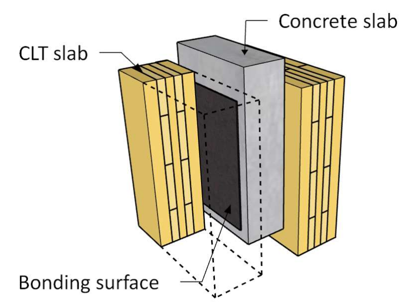
Fig. a) section through the floor layers; **b)** an example of a floor used to calculate a reasonable shear force [1]

Shear force:

Load Type	Design Situation / Layer	TCC Slab Thickness [mm]	Load [kN/m²]
Imposed load, q_k	characteristic ultimate Category B (office)	- -	2.50 2.50
Self weight, g_k			$7.70 \frac{kN}{m^2}$
SLS load, q_{sls} ULS load, q_{uls}	characteristic ultimate		$9.95\ kN/m^2$

TIMBER CONCRETE COMPOSITE

The impact of the gluing surface



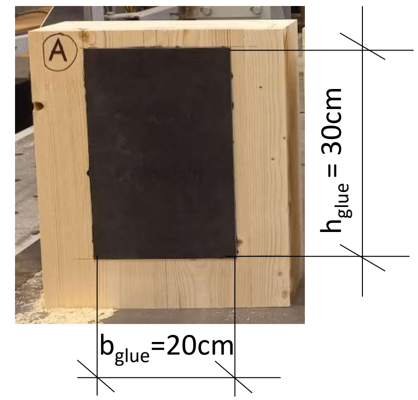
The push-out tests were performed following EN 26891

$$V_{sls} = \frac{q_{sls} \cdot s \cdot l}{2}$$

$$V_{uls} = \frac{q_{uls} \cdot s \cdot l}{2},$$

The shear stress in the joint i.e. connection between the CLT and concrete layer were calculated by equation:

$$\tau(x,z) = \frac{V_z(x)}{(EI)_{ef}\, b}\left[\sum_{i=1}^{n-1} E_i\, b\, h_i\, a_i + E_n\, b\left(z - \sum_{i=1}^{n-1} h_i\right)\cdot\left(z_{NA} - z + \frac{z - \sum_{i=1}^{n-1} h_i}{2}\right)\right]$$



for the two design situations SLS and ULS. Calculated values can be seen in Table

Property		Concrete	Timber 0	Timber 90	Timber 0	Timber 90	Timber 0
E_i	[MPa]	33 000	11 000	0	11 000	0	11 000
h_i	[mm]	100	30	20	20	20	30
t_i	[mm]	1 000	1 000	1 000	1 000	1 000	1 000
A_i	[mm^2]	100 000	30 000	20 000	20 000	20 000	30 000
$\bar{z}_i$	[mm]	170	105	80	60	40	15
z_{NA}	[mm]			146.842			
a_i	[mm]	23.158	41.842	66.842	86.842	106.842	131.842
I_i	[mm^4]	$8.333 \cdot 10^7$	$2.250 \cdot 10^6$	$6.667 \cdot 10^5$	$6.667 \cdot 10^5$	$6.667 \cdot 10^5$	$2.250 \cdot 10^6$
$(EI)_{ef}$	[N·mm^2]			$12.55 \cdot 10^{12}$			
τ_{sls}	[MPa]			0.159			
τ_{uls}	[MPa]			0.205			

$F_{sls.exp} = 2 \cdot \tau_{sls} \cdot b_{glue} \cdot h_{glue} = \mathbf{18.3\ kN}$

$F_{uls.exp} = 2 \cdot \tau_{uls} \cdot b_{glue} \cdot h_{glue} = \mathbf{23.6\ kN}$

where:

b_{glue} and h_{glue} - represents the width and height of the glued surface.

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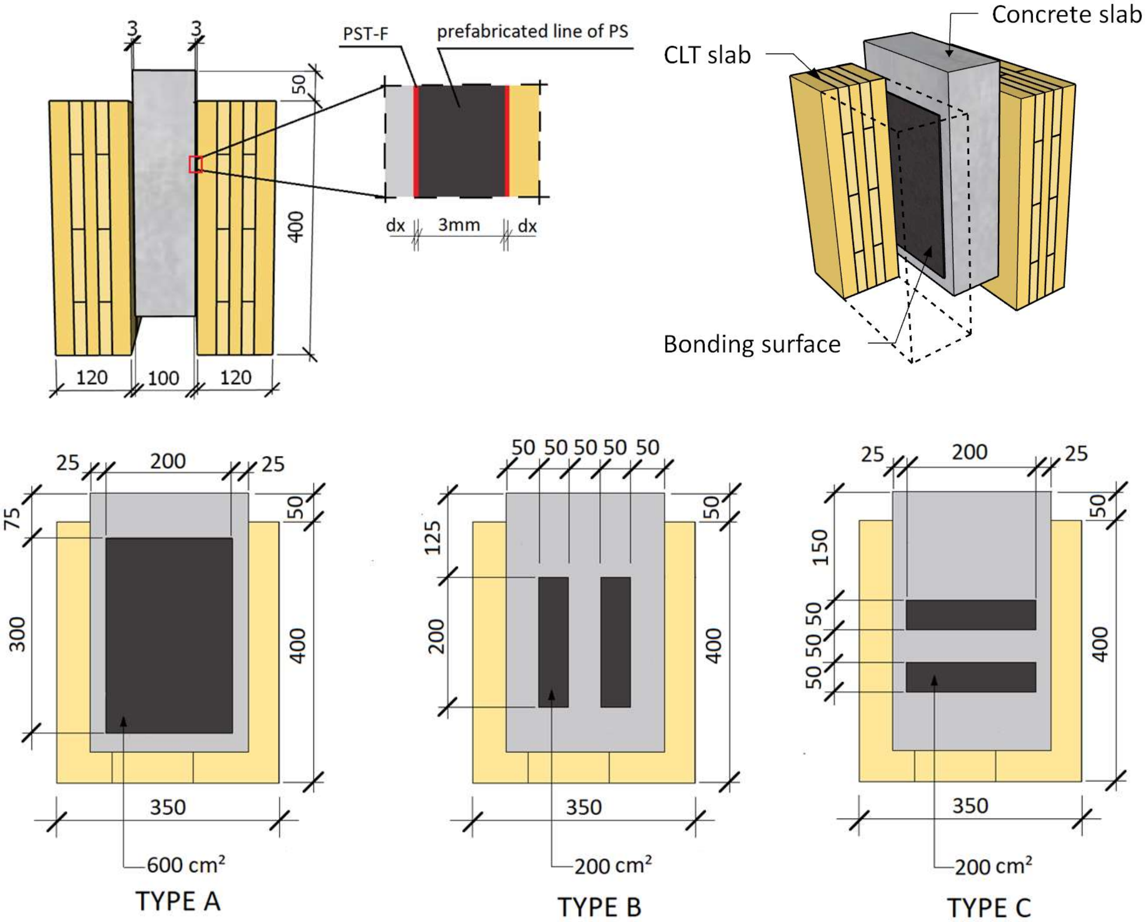

Figure. Geometry of the specimens: (**a**) 3D view; (**b**) Front view; (c) view of the three types of bonding surface.

Five replicates were tested for each of the three types of TCC connections, providing sufficient data to analyse the mechanical properties of the joints

The loading procedure for the test was programmed on the computer which controlled the MTS machine and consisted of four different steps

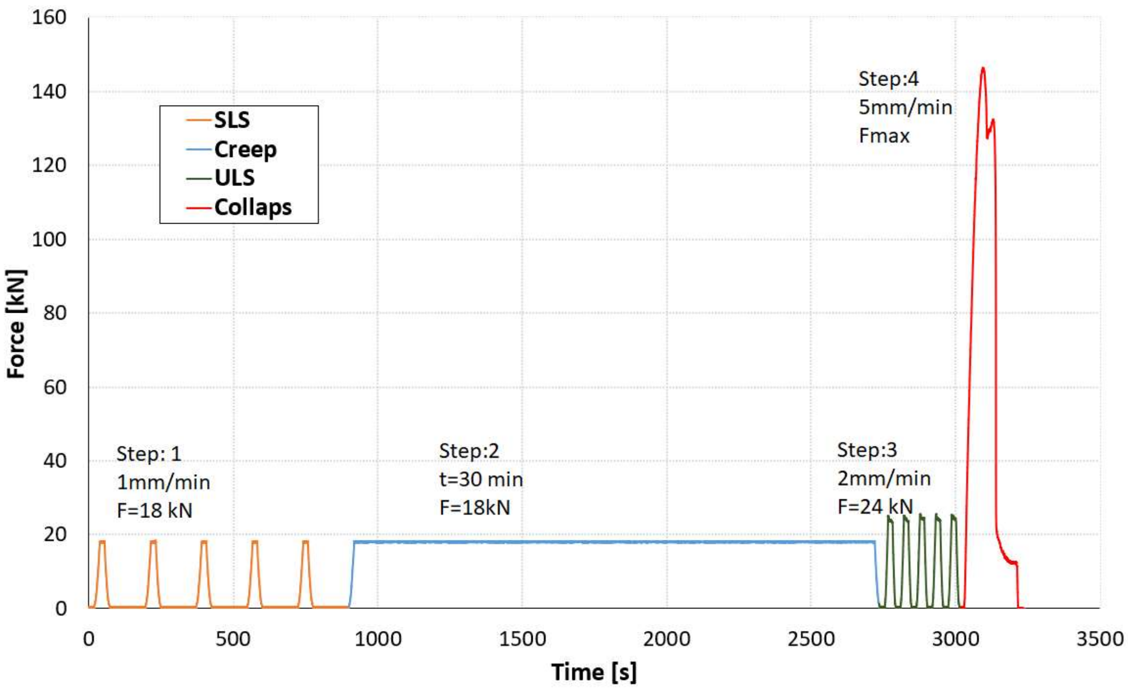

Fig. The loading procedure, according to [1].

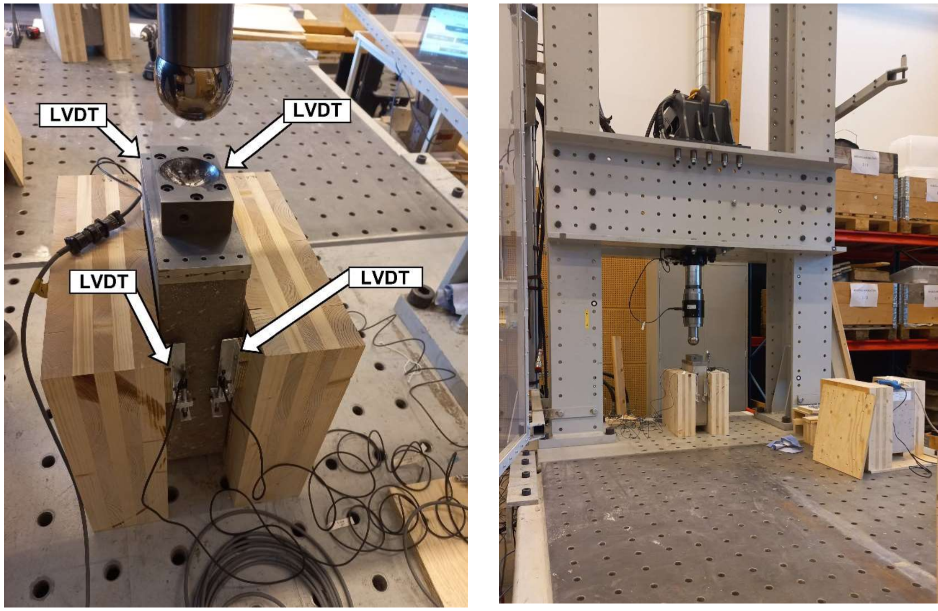

Fig. Experimental test setup for double shear push-out test.

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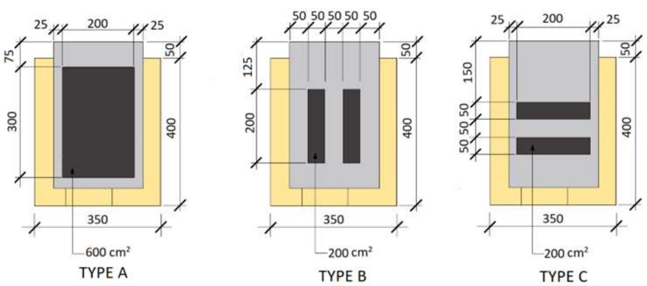
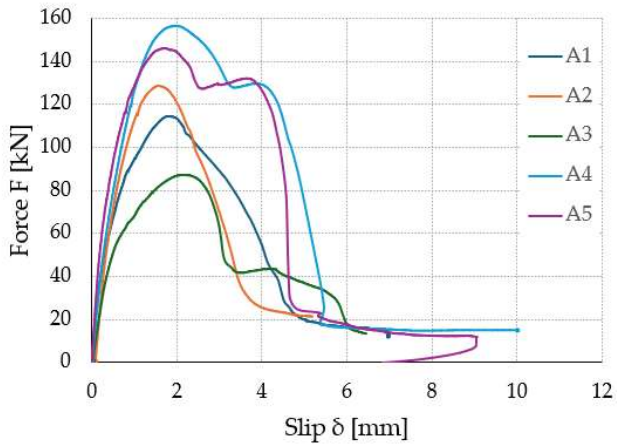
Load -bearing capacity and load-slip behaviour

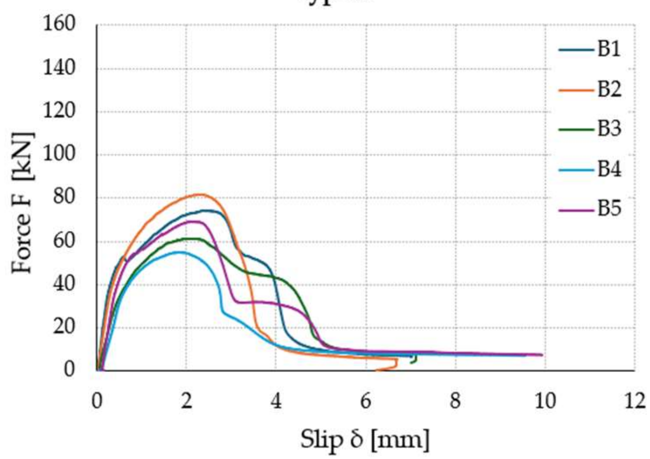


Specimen	Type A		Type B		Type C	
	F_{max} (kN)	δ_{rel} (mm)	F_{max} (kN)	δ_{rel} (mm)	F_{max} (kN)	δ_{rel} (mm)
1	114.7	1.81	74.1	2.36	69.5	2.15
2	128.5	1.59	81.7	2.30	51.3	1.60
3	87.0	2.18	61.0	2.19	75.7	2.07
4	156.7	1.95	54.8	1.83	77.9	2.23
5	146.3	1.72	68.8	2.12	76.8	2.32
Average	126.6	1.85	68.1	2.16	70.2	2.08
CoV (%)	21.7	12.2	15.6	9.6	15.8	13.5

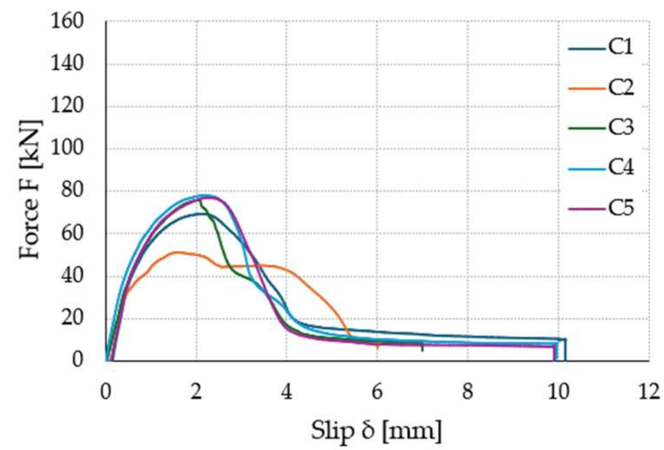
Type A



Type B



Type C



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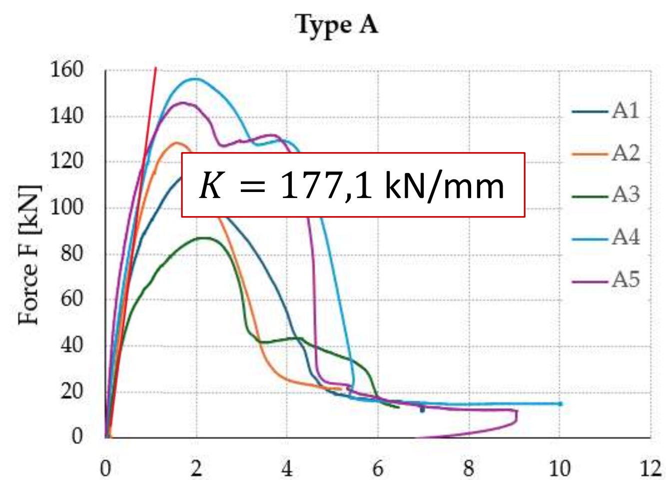
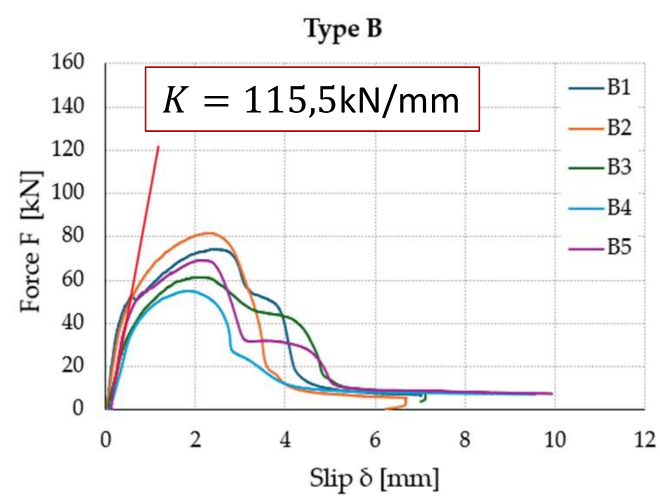
Slip modulus and stiffness

$$K_s = \frac{0{,}4 \cdot F_{est}}{v_{i,mod}} \qquad v_{i,mod} = \frac{4}{3}(v_{0.4} - v_{0.1})$$

Specimen	Type A					
	$0{,}4F_{max}$ (kN)	$v_{0.1}$ (mm)	$v_{0.4}$ (mm)	K_s (kN/mm)	K_u (kN/mm)	k (N/mm/mm²)
1	45.9	0.056	0.266	164.0	109.3	2.79
2	51.4	0.151	0.353	190.6	127.1	2.85
3	34.8	0.076	0.286	124.1	82.8	2.07
4	62.7	0.077	0.361	166.0	110.7	2.22
5	58.5	0.044	0.227	240.8	160.5	3.01
Average	50.66	0.08	0.30	177.10	118.1	2.59
CoV (%)	21.7	51.3	19.3	24.2	24.2	16.1
FEM-A	51.7	0.129	0.368	170.5	113.7	-

Specimen	Type B					
	$0{,}4F_{max}$ (kN)	$v_{0.1}$ (mm)	$v_{0.4}$ (mm)	K_s (kN/mm)	K_u (kN/mm)	k (N/mm/mm²)
1	29.6	0.048	0.184	162.4	108.3	4.45
2	32.7	0.071	0.260	129.2	86.2	3.71
3	24.4	0.112	0.335	82.0	54.7	2.46
4	21.9	0.159	0.377	75.2	50.1	2.52
5	27.6	0.164	0.325	128.5	85.7	4.09
Average	27.23	0.11	0.30	115.5	77.0	3.45
CoV (%)	15.5	46.7	25.4	31.5	31.5	26.3
FEM-B	32.8	0.076	0.263	127.8	85.2	-

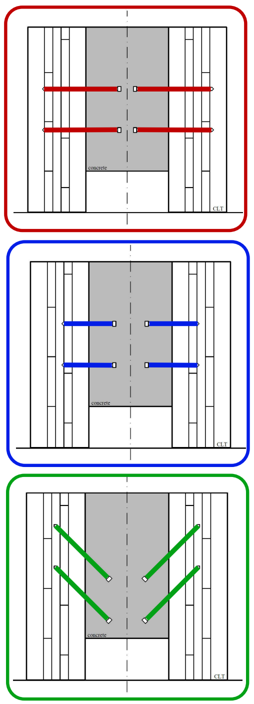


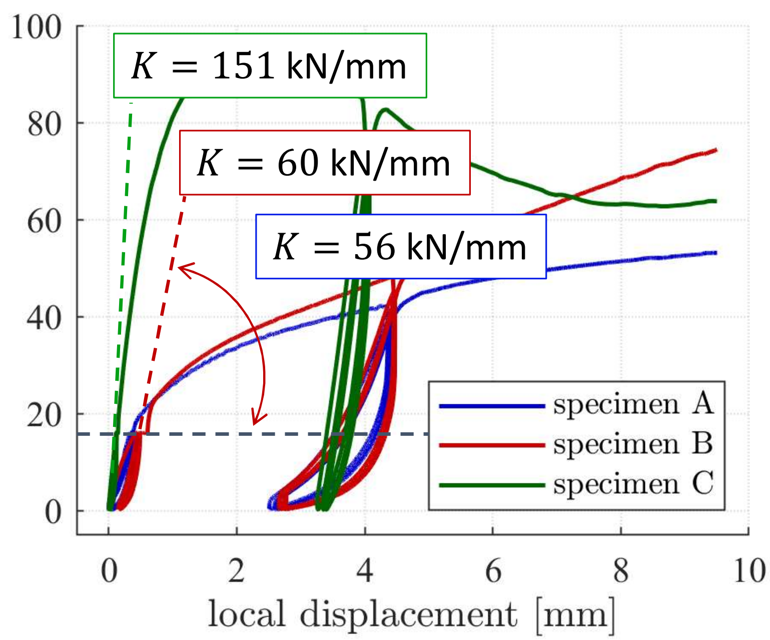


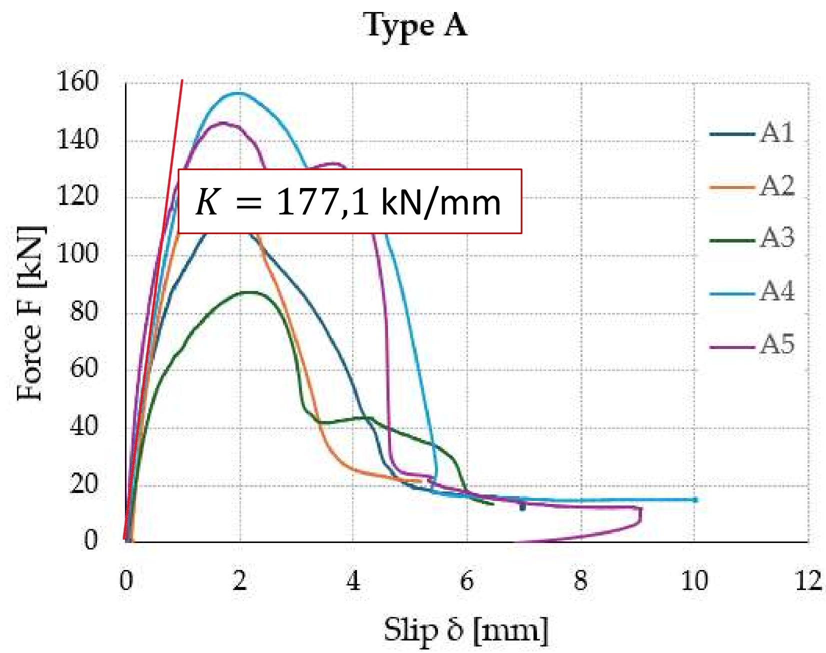
Träskruv SW-D 8.0x190 - 90°

Träskruv SW-D 8.0x130 - 90°

Träskruv SW-D 8.0x190 - 45°







Type B $K = 115{,}5$kN/mm

Eva Binder - Shear connection tests 2022

CONCLUSION

- The shear resistance of a prefabricated adhesive joint does not grow directly proportional to the bonding area - a threefold increase in bonding area led to only an 80% increase in failure load**. This points to the validity of using more efficient adhesive joints with smaller surface areas, which can help minimize material consumption.**

- the recommended thickness for a flexible joint should be no less than 2 mm

- the initial stiffness of the tested joints is dependent on the surface area of the bonding, as well as the orientation of the prefabricated adhesive fasteners

- The highest stability of the results after aging for connections with beech wood is shown by PS

- Flexible polyurethane adhesives transfer high loads and high deformations simultaneously

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THANK YOU FOR YOUR TIME !

DIAMONDS - "DIAgnostics and Mechanical tests Of aged adhesive layers used in joiNts of wooDen structureS",
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NARODOWE CENTRUM NAUKI
OPUS-22 (LAP)