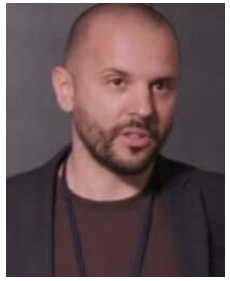
MECHANICAL TESTS OF BEECH WOOD ELEMENTS WITH FLEXIBLE POLYURETHANE ADHESIVE BONDS

Klaudia Śliwa-Wieczorek[1], Jaka Pečnik[2], Arkadiusz Kwiecień[1], Boris Azinovič[2], Mateusz Żołądź[1]




[1] Faculty of Civil Engineering, Cracow University of Technology
[2] The Slovenian National Building and Civil Engineering Institute, Ljubljana, Slovenia

Cracow University of Technology
DIAMONDS
NARODOWE CENTRUM NAUKI
OPUS-22 (LAP)
ZAG Zavod za gradbeništvo Slovenije
INTERNATIONAL CONFERENCE ON WOOD ADHESIVES

• WHY DID WE CHOOSE BEECH WOOD ?

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

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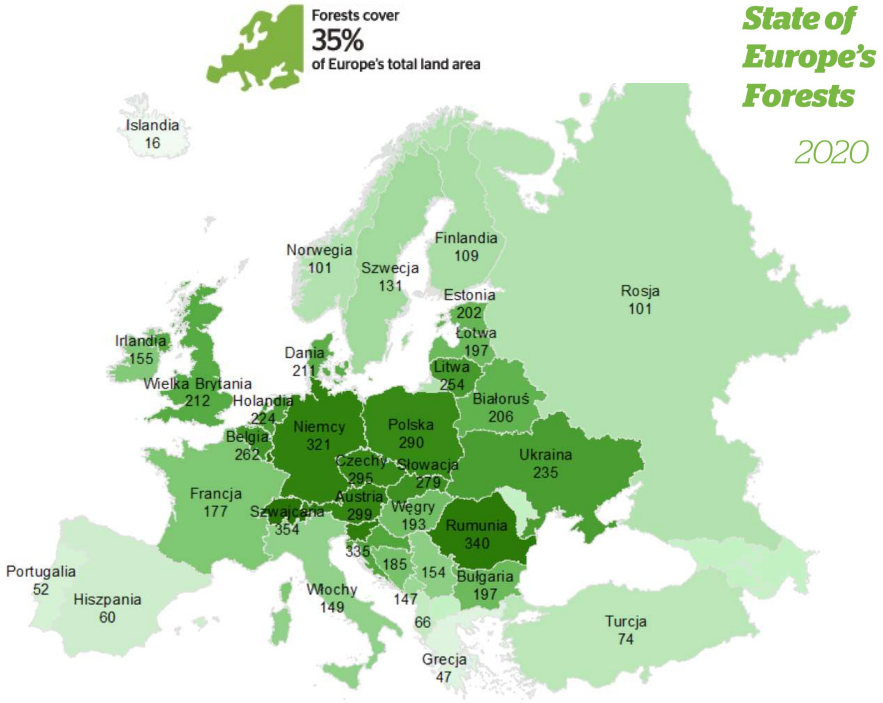


Figure 2: Average amount of forest m^3/h [2]

In Europe, almost 50% of forests are covered with hardwood species.

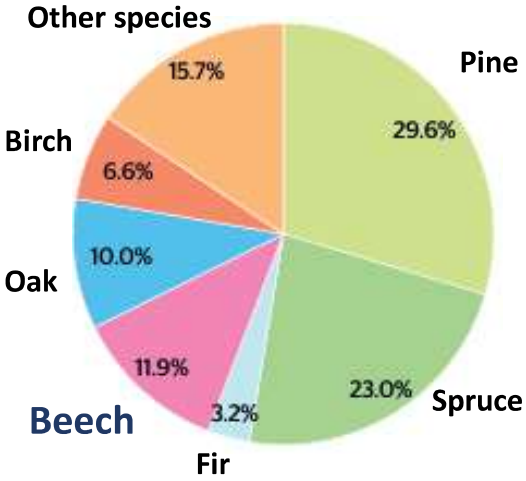


Figure 3: Europe's growing stock by main tree species, 2020 [2]

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

• WHY DID WE CHOOSE BEECH WOOD COMPOSITES ?

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

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

ZAG ZAVOD ZA GRADBENIŠTVO SLOVENIJE SLOVENIAN NATIONAL BUILDING AND CIVIL ENGINEERING INSTITUTE

INNORENEW COE

AGH

Cracow University of Technology

Beech wood – 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)

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

[1] GUS, Analizy Pekao

THE GOALS OF THE DIAMONDS PROJECT ARE:

- **To evaluate properties** of beech-adhesive bond prior and after accelerated and natural weathering (ANW).
- **To evaluate quasi-static**, fatigue, fracture and dynamic mechanical properties and behavior of beech-adhesive bondline prior and after ANW.
- To develop relationships between material quality and technological parameters during bonding on complex mechanical performance of beech-adhesive bondline using multisensory approach and multivariate techniques
- To find out whether **vibro-acoustic techniques** may be utilized to diagnose the damage of the adhesive bondline.
- To comprehend findings for a development of **prediction models** of adhesive bond damage and its diagnostics.

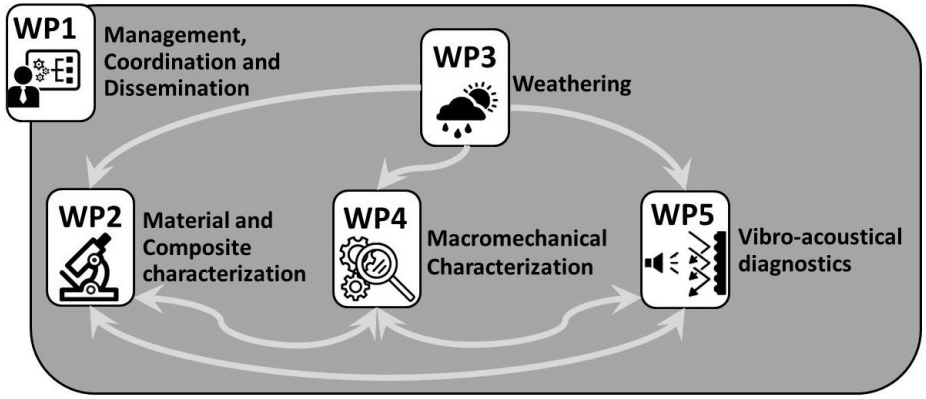
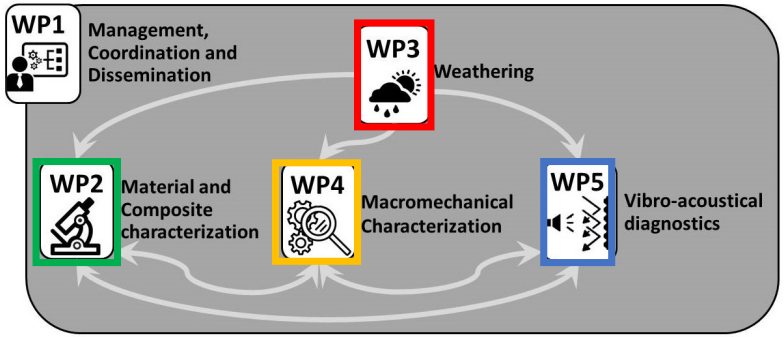


Figure 5: Natural weathering test site – Poland/Cracow

THE GOALS OF THE DIAMONDS PROJECT ARE:



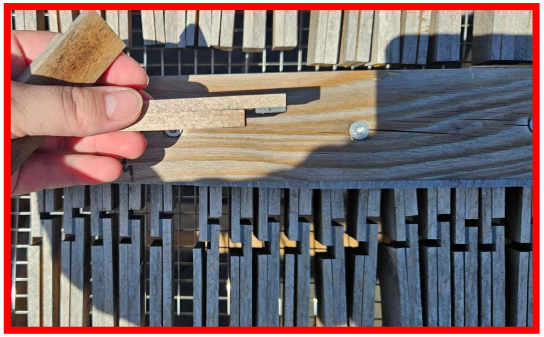


Figure 6: Main work packages in the Diamonds program

• WHY DID WE CHOOSE FLEXIBLE ADHESIVE JOINTS ?

FLEX AND ROBUST SYSTEMS

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

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

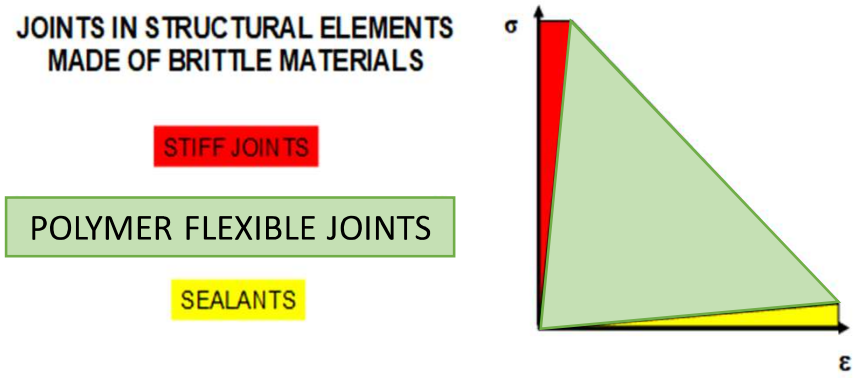
- repairing masonry buildings
- reinforcement of structural elements
- structure security systems for earthquake areas

Figure 7:Example of PM polyurethane application

INNOVATIVE FLEXIBLE BONDING SOLUTION PUFJ

New flexible polyurethane adhesive:

- blocks the transfer of moisture and thermally insulates from the ground
- enables quick assembly and direct connection of elements made of various materials
- ensures tightness of connections along their entire length
- ensures stability of deformation properties under cyclic loads



PolyUrethane Flexible Joints

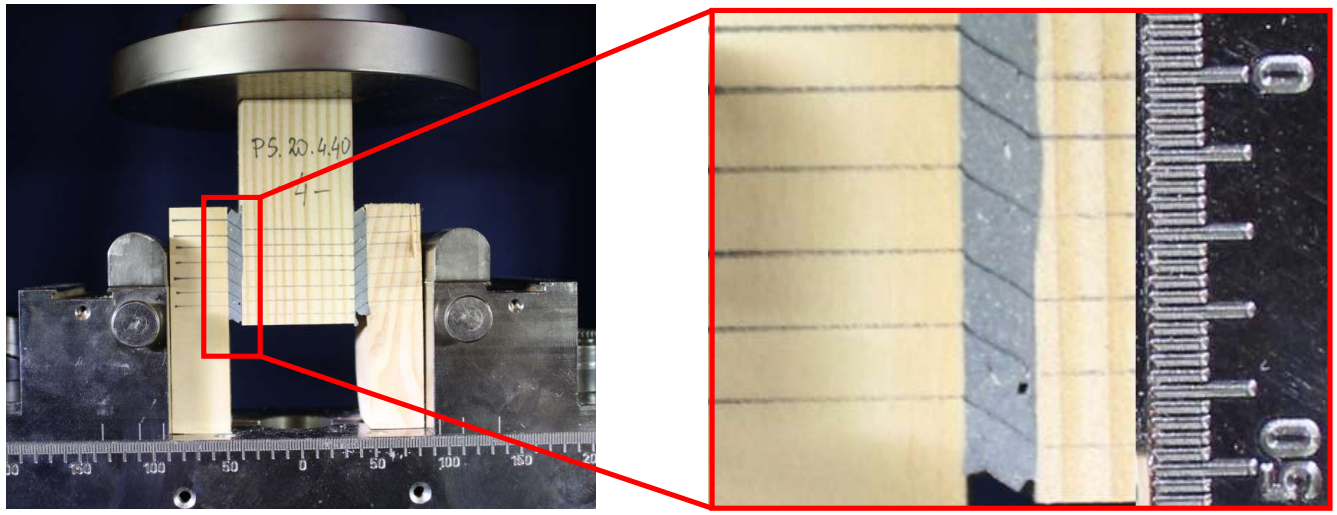
transfer high loads

and high deformations

simultaneously

Material samples	Thermal conductivity coefficient λ [W/(mK)]
Wood	0,1157
PM polymer	0,1013

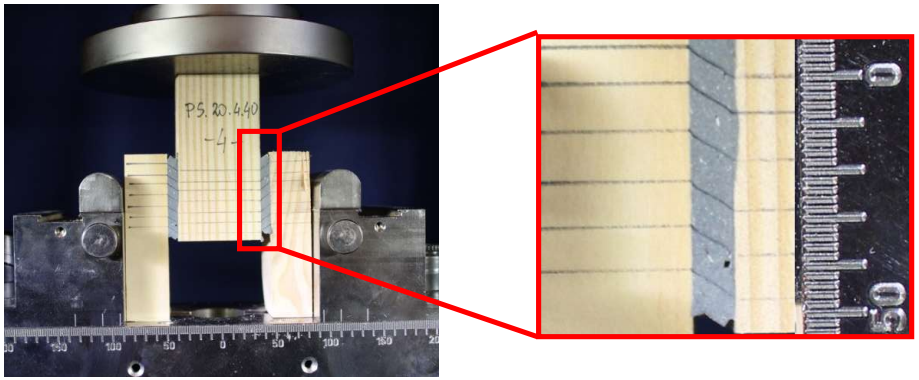
author's archive



PUFJ (POLYURETHANE FLEXIBLE JOINTS)

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

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



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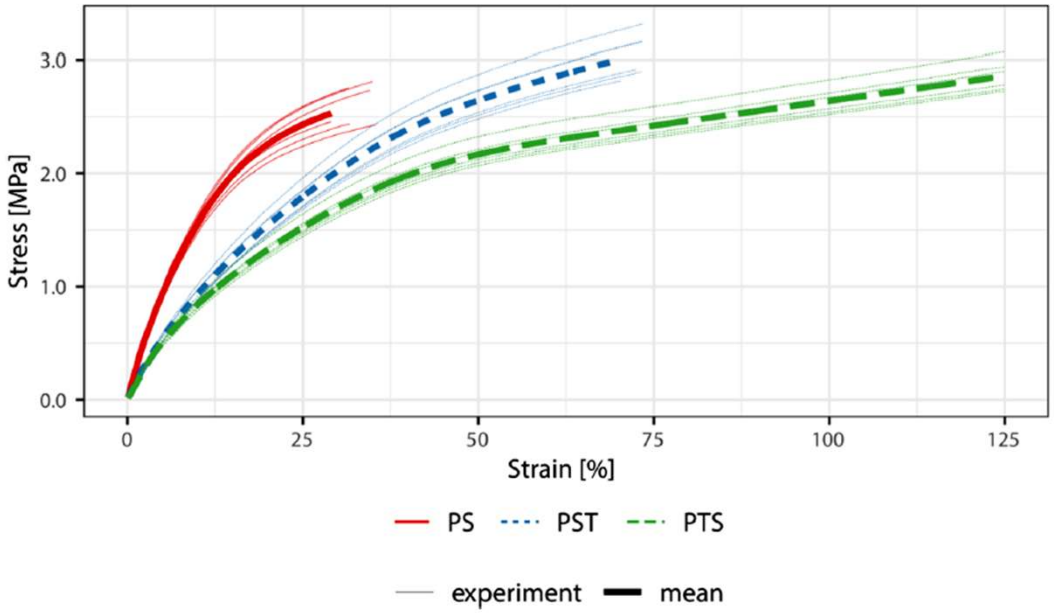
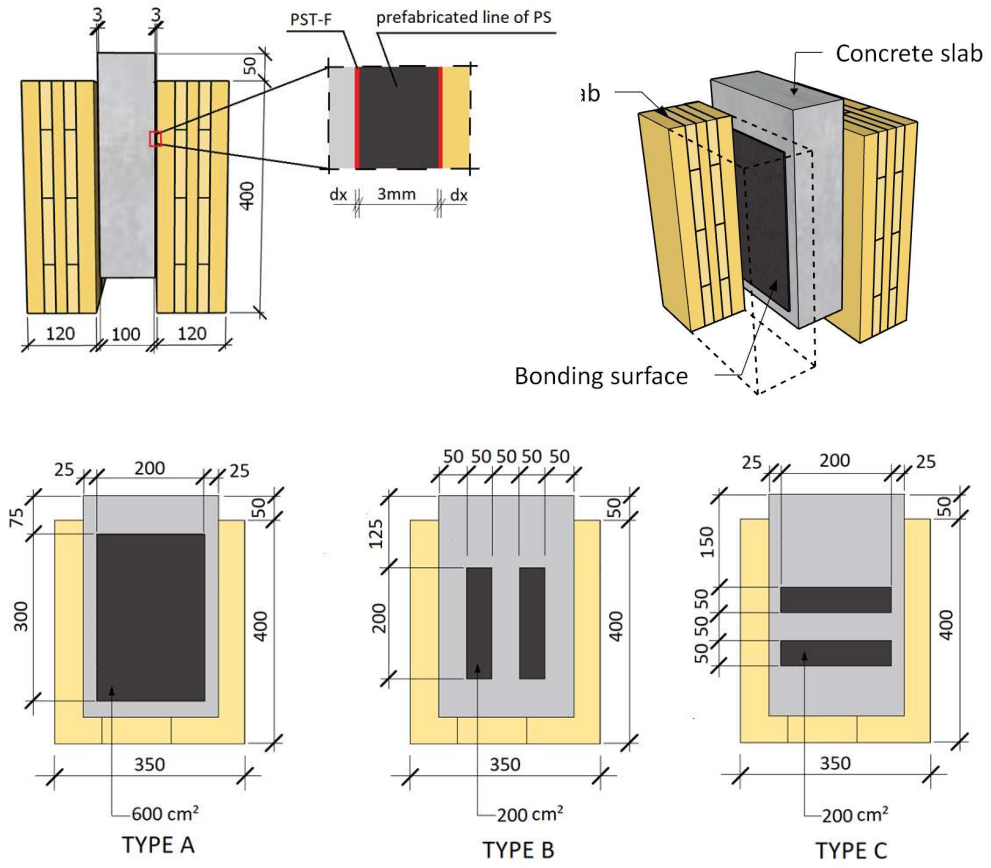
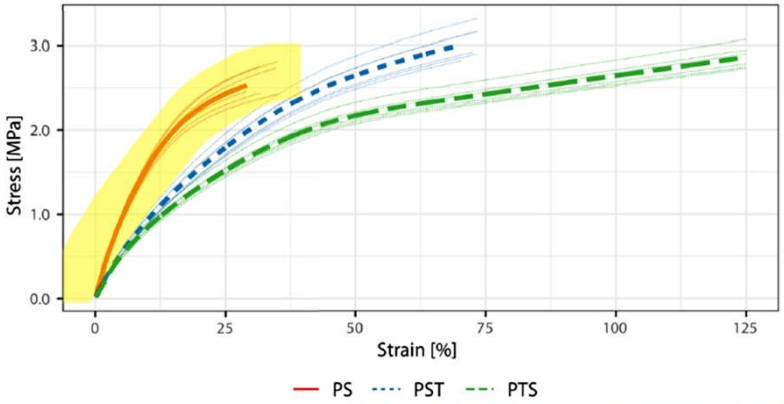
Adhesive types	Young modulus E_R [MPa]	Ultimate elongation ε_{max} [%]	Tensile strength R_R [MPa]	Shore'a A hardness [°]
PT	700	10	25	98
PSTF	20	35	4,3	85
PS	20	30	2,6	80
PST	15	65	3,0	75
PTS	12	120	2,9	70
PM	4	110	1,4	55
PBM	1	600	0,7	35

Table. Parameters of adhesives.







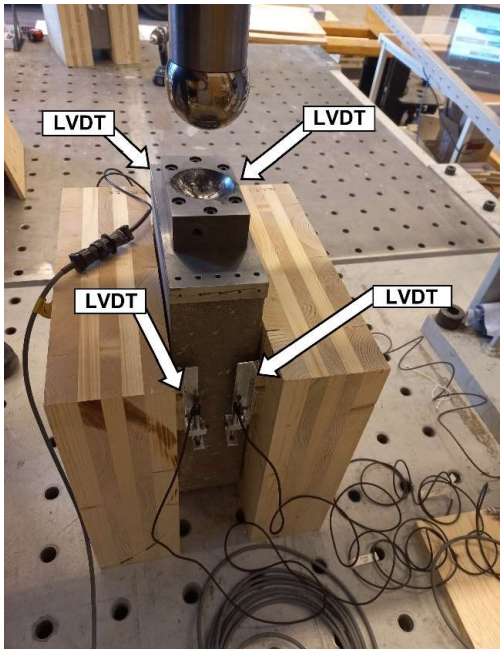
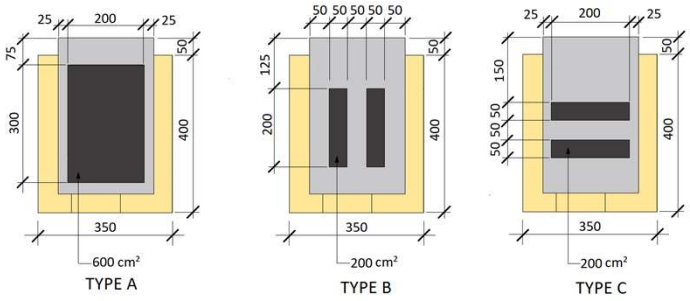


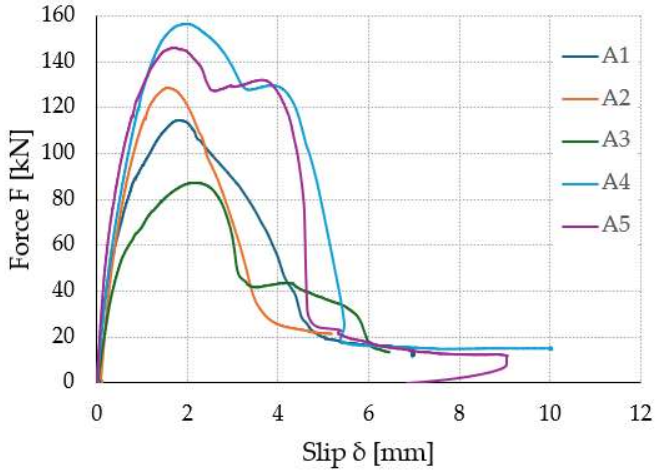
Figure. Geometry of the specimens: (**a**) 3D view; (**b**) Front view; (c) view of the three types of bonding surface.

Load -bearing capacity and load-slip behavior

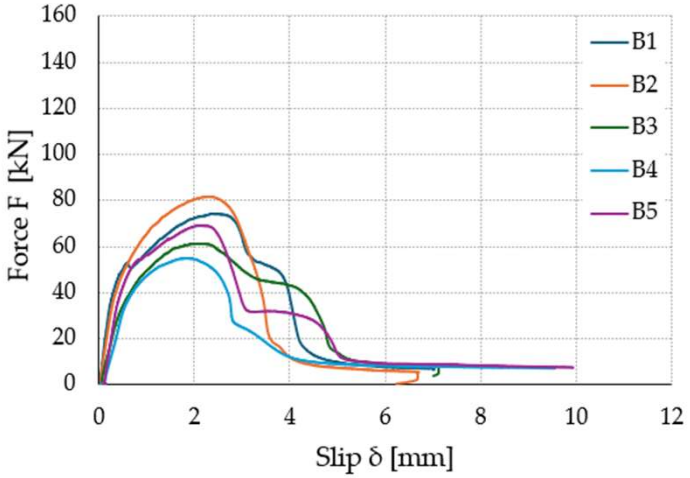


Specimen	Type A		Type B		Type C	
	F_{max} (kN)	δ_{rel} (mm)	F_{max} (kN)	δ_{rel} (mm)	F_{max} (kN)	δ_{rel} (mm)
1	114.7	1.81	74.1	2.36	69.5	2.15
2	128.5	1.59	81.7	2.30	51.3	1.60
3	87.0	2.18	61.0	2.19	75.7	2.07
4	156.7	1.95	54.8	1.83	77.9	2.23
5	146.3	1.72	68.8	2.12	76.8	2.32
Average	126.6	1.85	68.1	2.16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

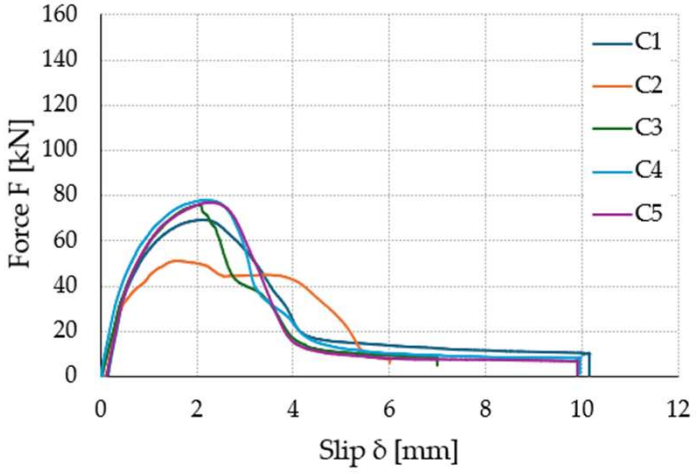
Type A



Type B



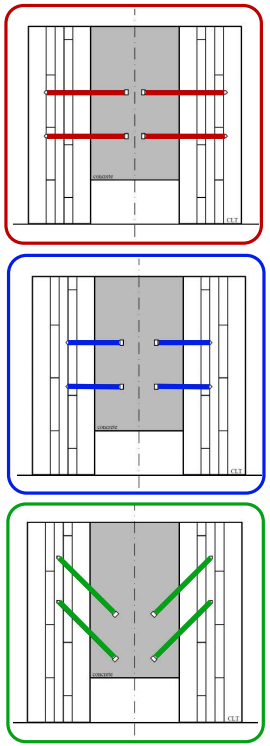
Type C

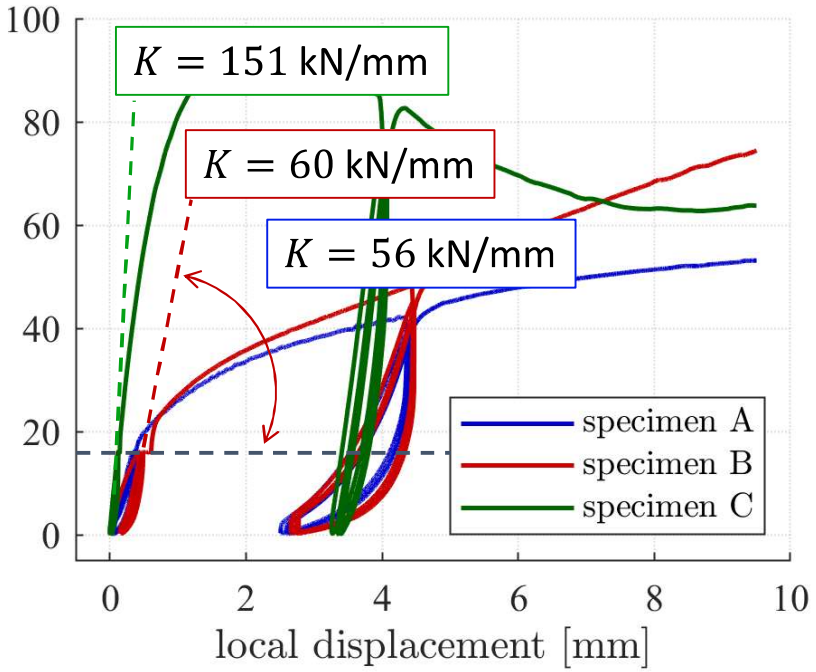


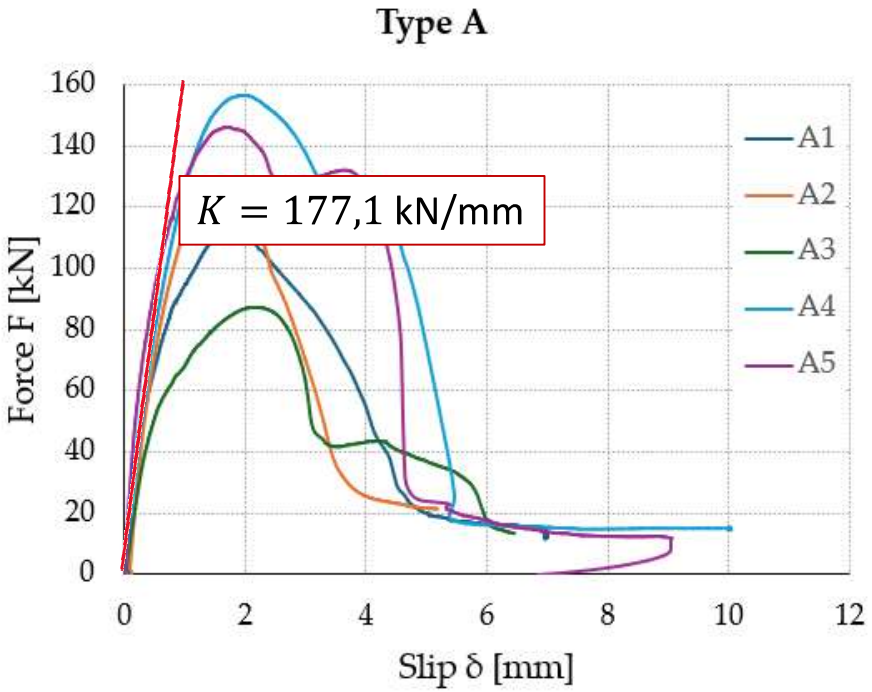
Träskruv SW-D 8.0x190 - 90°

Träskruv SW-D 8.0x130 - 90°

Träskruv SW-D 8.0x190 - 45°







Type B K = 115,5kN/mm

PUFJ (POLYURETHANE FLEXIBLE JOINTS)

APPLICATION METHODS

INJECTION

PREFABRICATION

Thickness from 1 to 30mm

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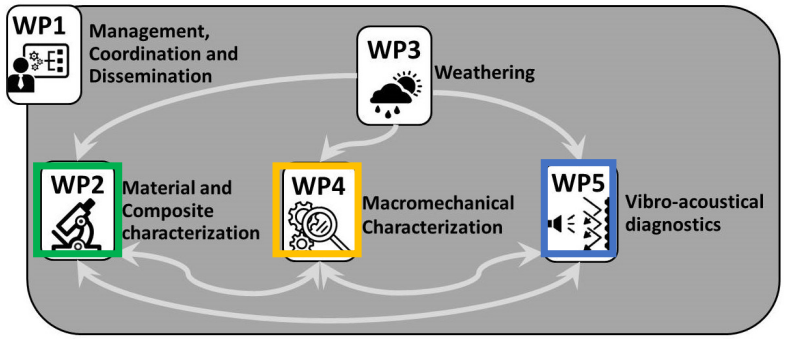


Figure 8: View of the test stand - four-point bending

BENDING TESTS:

⇨ Laminated beams

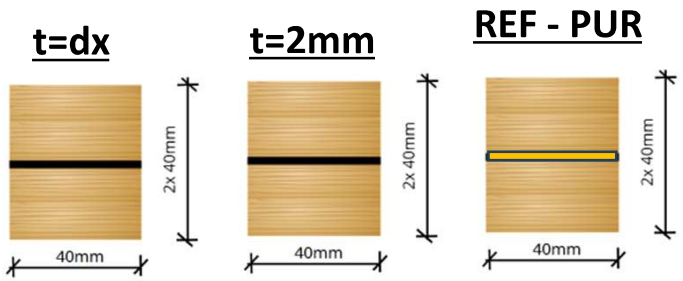
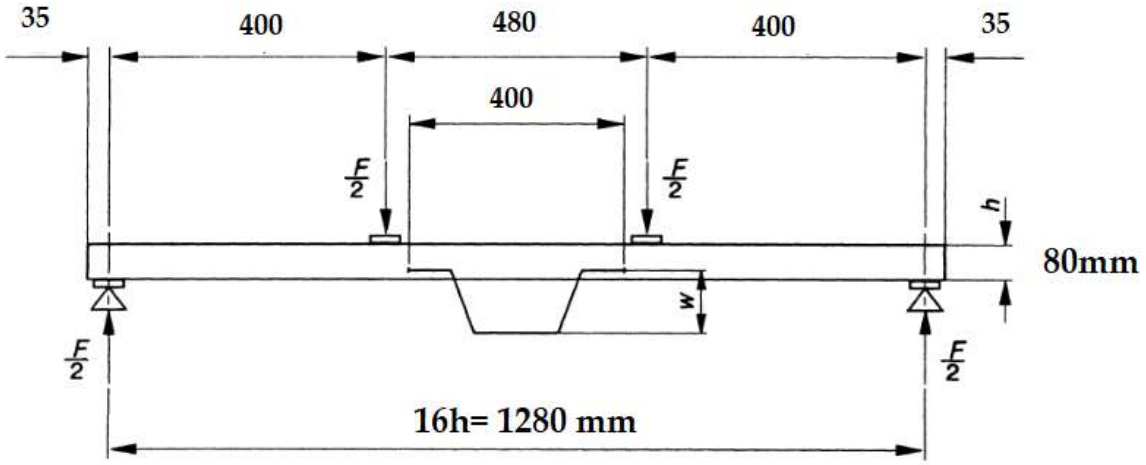
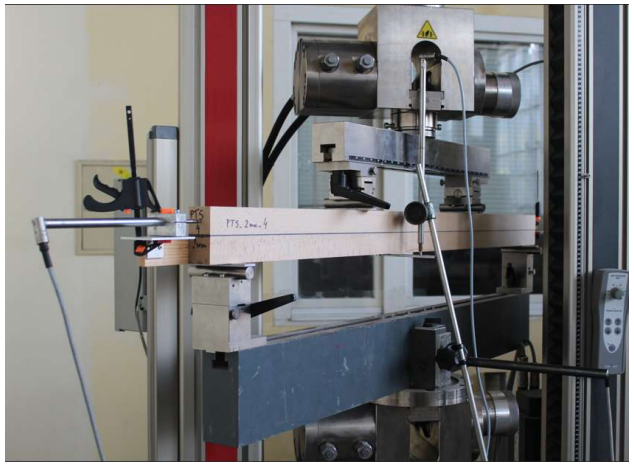


Figure 9. View of samples for four-point bending

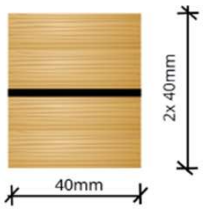


The European Standard EN 408

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

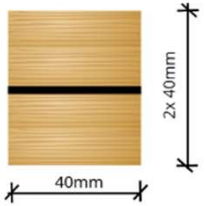


t=dx



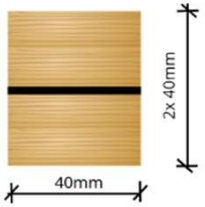
t=dx	PUR	PS	PST	PTS
	number of samples (2 battens)			
time "0"	9	9	9	9
time "1"	9	9	9	9
time "2"	9	9	9	9
	total:	**108**	**samples**	

t=2mm



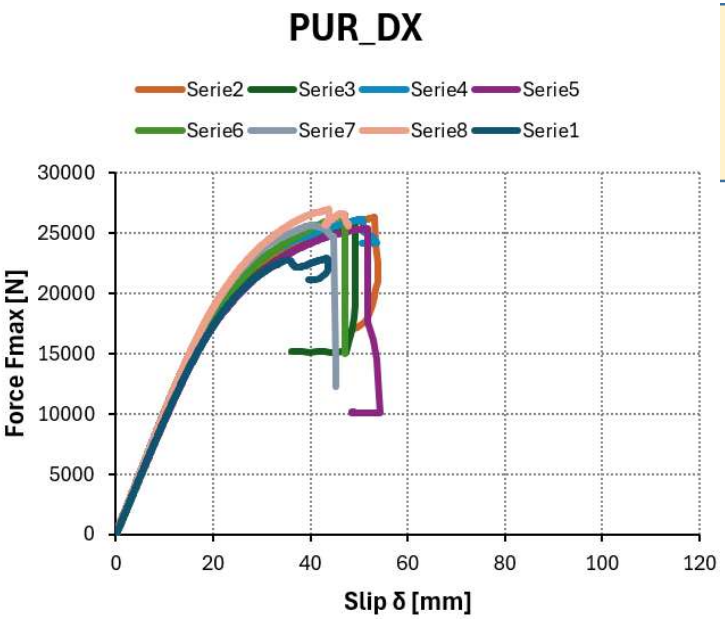
t=2mm	PUR	PS	PST	PTS
	number of samples (2 battens)			
time "0"	0	9	9	9
time "1"	0	9	9	9
time "2"	0	9	9	9
	total:	**81**	**samples**	

t=dx



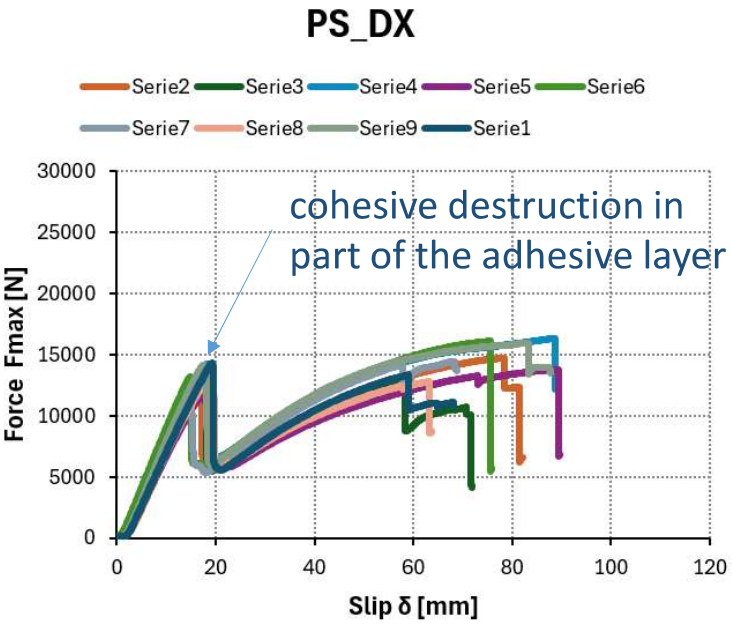
Specimen	PUR		F&R_PS		F&R_PST		F&R_PTS	
	F_{max} (kN)	δ_{rel} (mm)	F_{max} (kN)	δ_{rel} (mm)	F_{max} (kN)	δ_{rel} (mm)	F_{max} (kN)	δ_{rel} (mm)
1	26,4	53,26	16,1	75,50	15,8	20,96	16,2	68,15
2	25,6	49,15	13,8	89,27	15,8	19,64	14,7	17,12
3	26,2	50,70	16,4	88,61	16,2	80,02	15,2	73,18
4	25,4	51,77	12,8	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

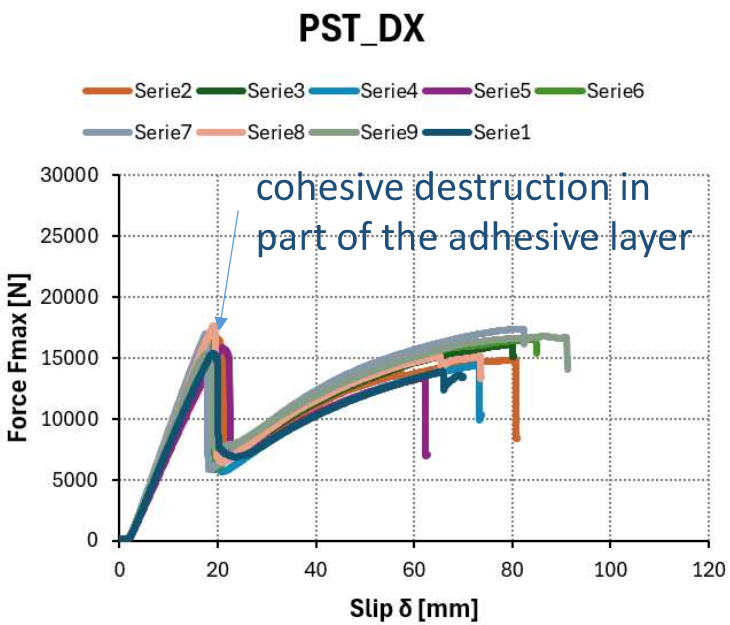
42 % **35 %** **39 %**

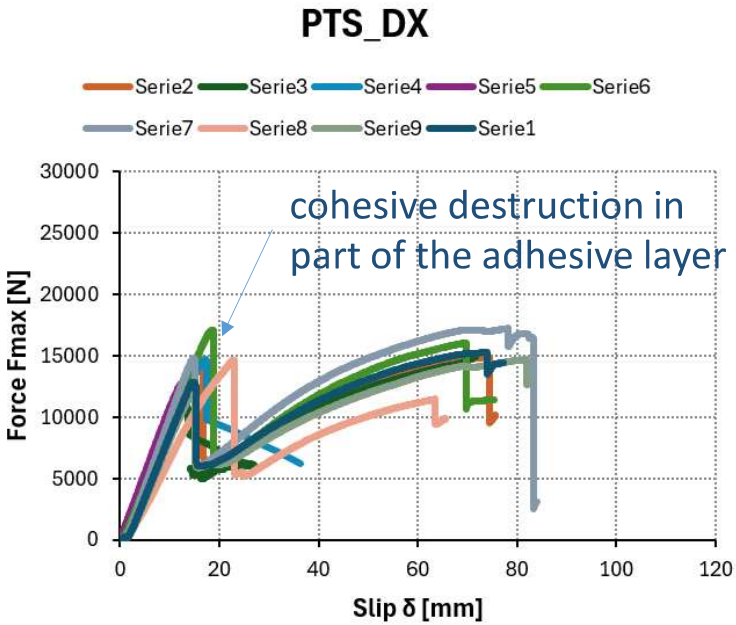


INTERNATIONAL CONFERENCE ON WOOD ADHESIVES

Specimen	PUR		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)	F_{max} (kN)	δ_{rel} (mm)
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







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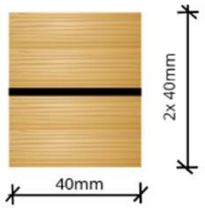


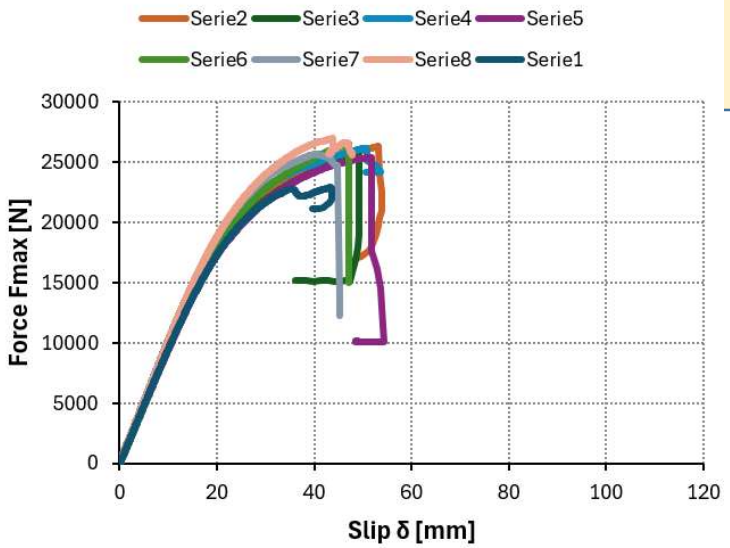
Specimen	F&R_PS		F&R_PST		F&R_PTS	
	F_{max} (kN)	δ_{rel} (mm)	F_{max} (kN)	δ_{rel} (mm)	F_{max} (kN)	δ_{rel} (mm)
1	14,8	91,2	19,1	45,4	16,0	91,2
2	12,5	83,9	18,3	38,9	15,5	83,9
3	14,4	80,5	20,3	46,5	15,2	80,5
4	15,9	40,4	15,9	44,6	17,5	40,4
5	15,2	38,6	14,6	38,3	17,5	38,6
6	15,2	48,9	16,3	46,2	19,6	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

↓ 42 %

+10 %
↓ 25 %

↓ 38 %

PUR_DX



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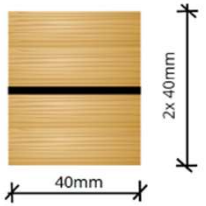
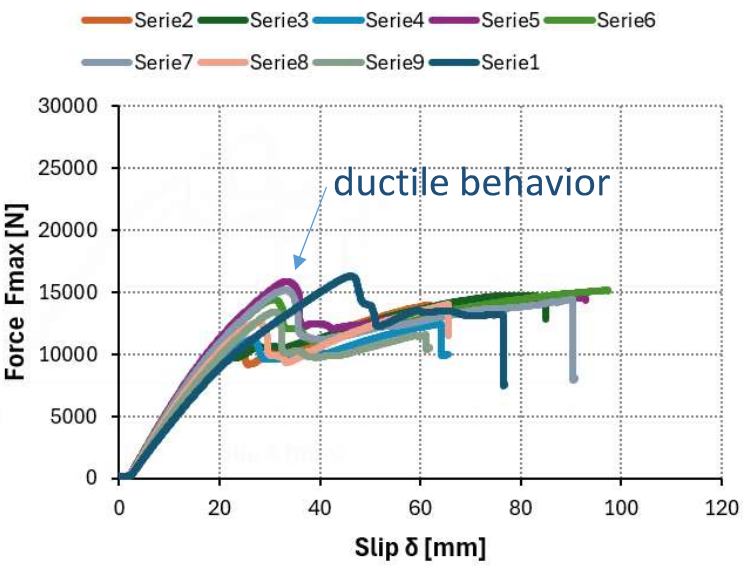
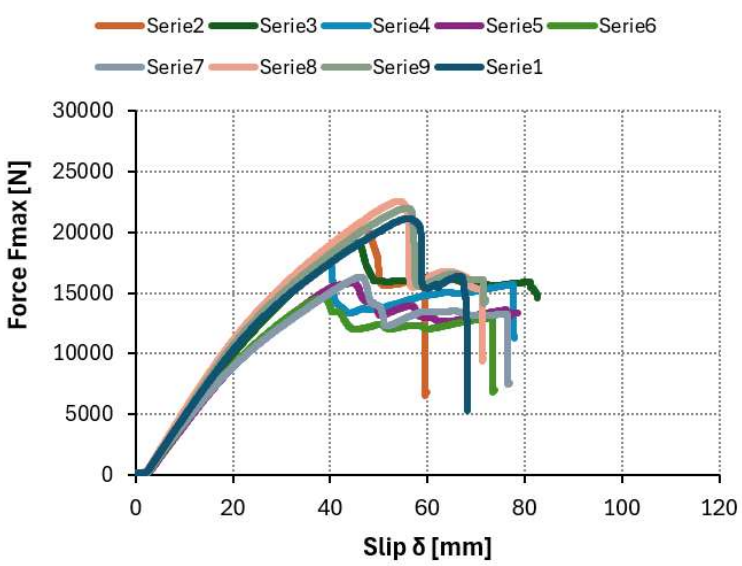


Specimen	F&R_PS		F&R_PST		F&R_PTS	
	F_{max} (kN)	δ_{rel} (mm)	F_{max} (kN)	δ_{rel} (mm)	F_{max} (kN)	δ_{rel} (mm)
Average	**14,9**	**64,8**	**18,9**	**47,3**	**15,9**	**64,8**
CoV (%)	11,8	31,5	14,2	13,4	11,8	31,5

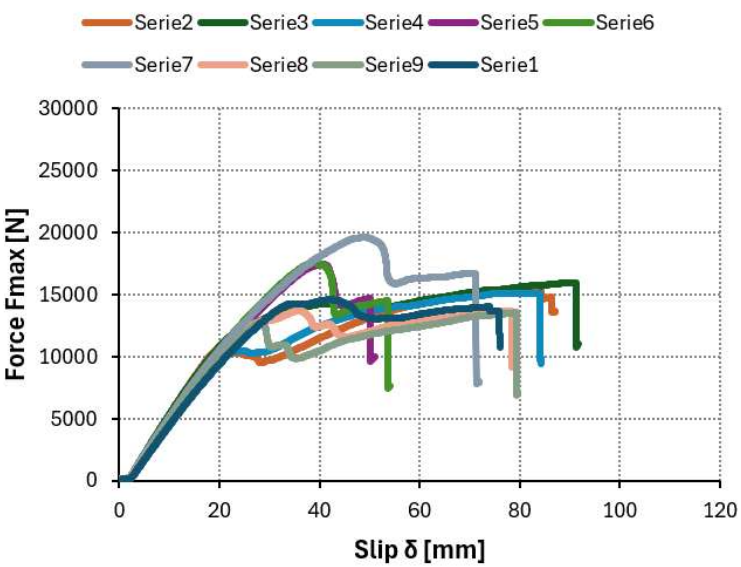
PS_2mm

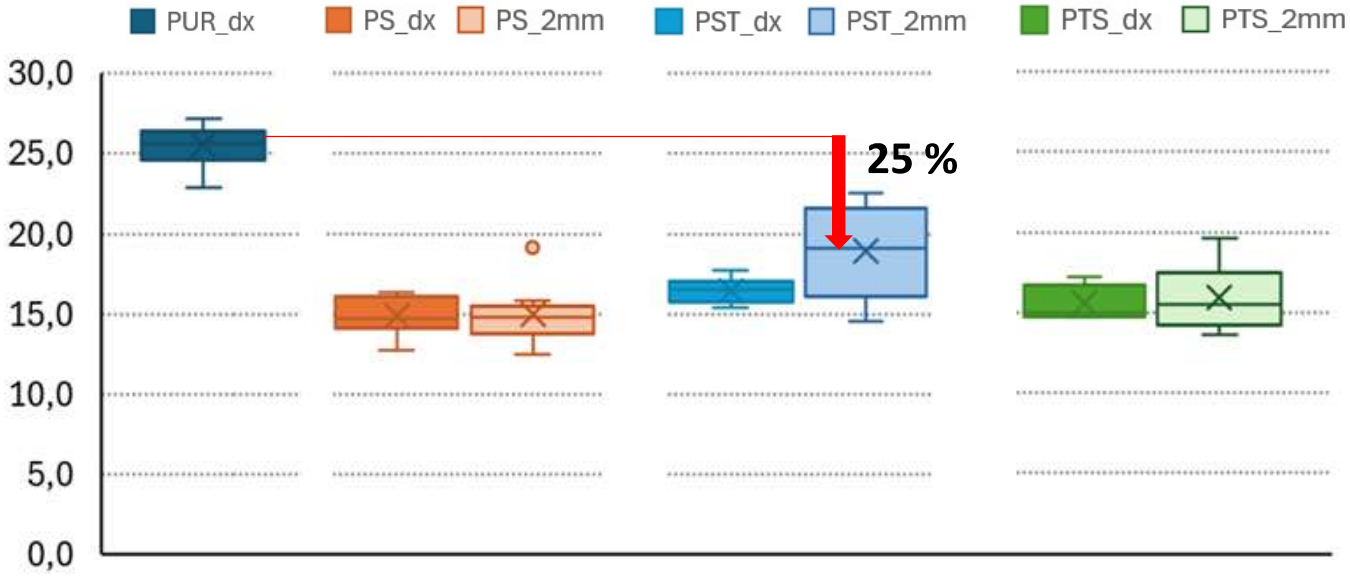


PST_t =2mm



PTS_2mm




PUR_dx
PS_dx
PS_2mm
PST_dx
PST_2mm
PTS_dx
PTS_2mm
30,0
25,0
20,0
15,0
10,0
5,0
0,0
25 %

BENDING TESTING:FAILURES IN ADHESIVES

PS -dx

PS -2mm

CONCLUSION

- The effect of the glue thickness on the beam load-bearing capacity was observed only for PST polyurethane (for this size of specimens)
- The recommended thickness of the PST flexible joint should be no less than 2 mm
- The first decrease in load-bearing capacity occurred due to cohesive failure in the adhesive layer
- Iincreasing the thickness of the adhesive layer changes the type of destruction

THANK YOU FOR YOUR TIME !

DIAMONDS

NARODOWE CENTRUM NAUKI

OPUS-22 (LAP)

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