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Application of 3PHV60 Type Epoxy Resin for the Repair of Timber Structures

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Abstract

This article deals with the issue of repairing wooden structures with 3PHV60 type resin. The first step of the research was to understand the material properties of 3PHV60 resin. The information provided by the resin manufacturer and the tests based on fracture tests have greatly contributed to the proper study of the behaviour of this material. The use of resin for the repair of timber structures is discussed in relation to the type of internal forces.

Keywords: *structural timber, epoxy resin, timber repair, reconstruction, restoration.*

1. Introduction

Many times during the renovation of an existing building, the question of consolidation of the wooden bearing structures arises. To this end, a number of solutions are used in practice, in terms of the use of materials or the degree of intervention.

The central question of the research is whether the resin type 3PHV60 can be suitable for the local repair of wooden structures.

In this paper, I will present experiments on 3PHV60 resins. I will then focus on the consolidation of wood with resins, grouped according to the type of stresses. The tests are based on fracture tests.

2. General description of 3P type epoxy resin

3P resins are two-component systems, which are copolymers of polyisocyanate/waterglass. 3P resins are named after the initial letters of the Anglo-German words for their components: polysilicic acid, polyisocyanates, phosphoric acid esters [1].

The „A" component of hard 3P resins is always Na-waterglass and the „B" component is MDI (methylene diphenyl isothiocyanate and its derivatives) [1].

The production of 3P resin starts with a simple but careful mixing of components A and B. The two components are homogenised in a volume ratio of 1:2 (Figure 1).

The resin is considered homogeneous when the total volume has become a uniform latte colour.

3. Material properties of 3PHV60 type epoxy resin

3PHV60 is a type of hard resin, a subtype of type 3P resins. Break tests were carried out to determine the material properties. Part of the tests were carried out at Polinvent KFT in Gyál, the other part at the Adolf Czakó Laboratory of Strength of Materials of the Budapest University of Tech-

Fig.1. *The „A" and „B" components of 3P resin.*

nology and Economics. All resin specimens were tested at least on the 7th day after their manufacture.

3.1. Determination of tensile strength of resin type 3PHV60

I used a mould to produce the specimens used to determine the tensile strength of the resin. The liquid resin was poured into the mould as shown in **Figure 2** and after 7 days it was broken off using a Zwick Roell Z150 (**Figure 3.**) at the BME Laboratory of Strength of Materials.

3PHV60 is a type of hard resin, a subtype of type 3P resins. Break tests were carried out to determine the material properties. Part of the tests were carried out at Polinvent KFT in Gyál, the other part at the Adolf Czakó Laboratory of Strength of Materials of the Budapest University of Technology and Economics. All resin specimens were tested at least on the 7th day after their manufacture.

Table 1 summarises the force at fracture (F_{max}), from which, knowing the cross-section (A), the normal stress (σ_t) at the moment of fracture can be determined.

The average normal stress at fracture is 19.46 N/mm^2, with a standard deviation of 1.92 N/mm^2.

Table 1. *Tensile test results of resin specimens at fracture*

#	F_{max} (N)	A (mm^2)	σ_t (N/mm^2)
1	719.58	42.36	16.99
2	826.58	41.12	20.10
3	846.67	46.59	18.17
4	861.33	48.29	17.83
5	1063.34	49.08	21.67
6	1102.94	50.14	22.00

3.2. Determination of shear strength of resin type 3PHV60

To determine the shear load capacity of the 3PHV60 resin, 5 specimens of 20×20×120mm geometry were prepared. The breaking test was carried out on day 7 after casting.

Table 2 summarises the force at fracture (F_{max}), from which the maximum shear force (V_{max}), can be calculated and, knowing the sheared area (A), the shear stress (τ) can be calculated.

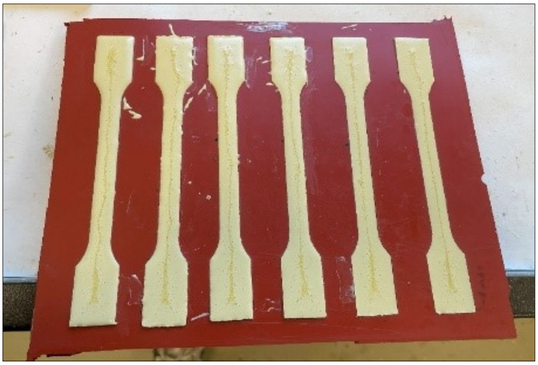

Fig. 2. *Test specimens used to determine the tensile strength of the resin.*

Fig. 3. *Measurement of tensile strength of resin.*

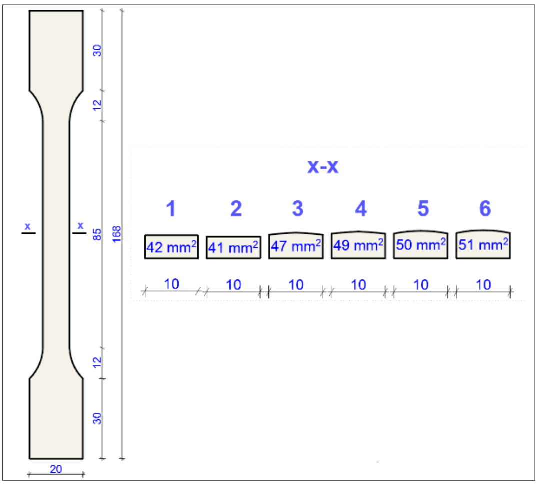

Fig. 4. *Resin specimens tested in tension.*

Table 2. *Shear test results of resin specimens at fracture*

#	F_{max} (N)	V_{max} (N)	A (mm²)	τ (N/mm²)
1	12 884	6442	400	16.11
2	12 114	6057	400	15.14
3	11 935	5967	400	14.92
4	10 882	5441	400	13.60
5	12 272	6136	400	15.34

The average shear stress at fracture is 15.02 N/mm² at a deviation of 0.81 N/mm².

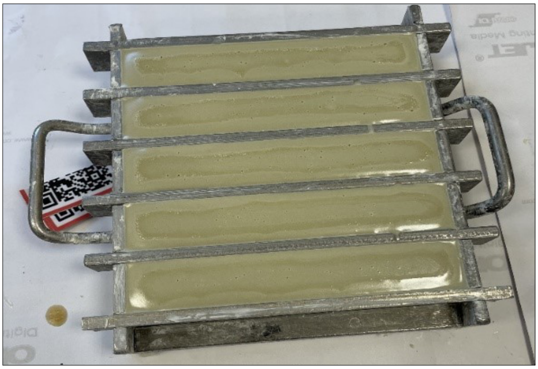

Fig. 5. *Resin specimens to be tested in shear at the beginning of the setting phase.*

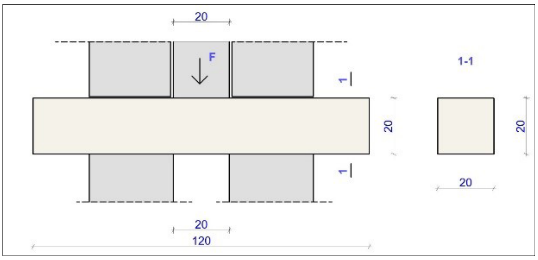

Fig. 6. *Resin test specimen shear test.*

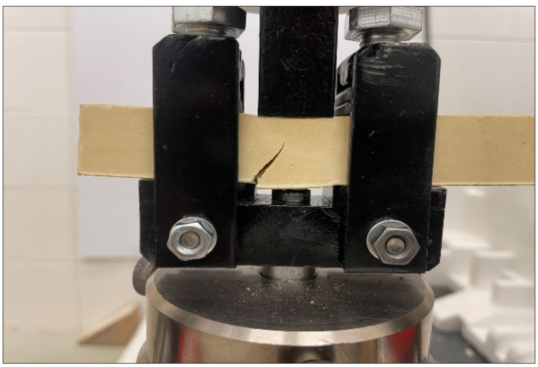

Fig. 7. *Typical fracture pattern of resin specimens tested in shear.*

3.3. Determination of the moment capacity of resin type 3PHV60

For the determination of the moment capacity of the 3PHV60 resin, the standard MSZ EN 13982-2:2003 was used, which provides guidance on the geometry of the specimens and the conduct of the fracture tests.

The breaking tests were carried out with the Instron breaking machine of the resin manufacturer Polinvent Ltd.

5 specimens with a geometry of 20×20×120 mm were made and loaded with a concentrated force at half the span.

Table 3 summarises the force at fracture (F_{max}), from which the maximum bending moment can be calculated (M_{max}), and, knowing the section modulus (W) the bending stress (σ_m) can be calculated.

Fig. 8. *Resin specimen tested for bending.*

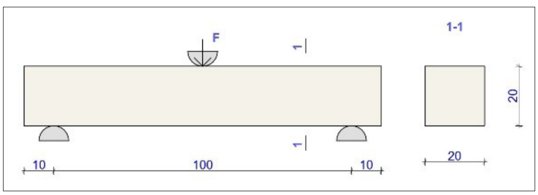

Fig. 9. *The sketch of the bending strength test of resin.*

Table 3. *Fracture results of resin specimens tested for bending*

#	F_{max} (N)	M_{max} (Nmm)	W (mm^3)	σ_m (N/mm^2)
1	2228	55 710	1.333	41.78
2	2433	60 825	1.333	45.63
3	2496	62 400	1.333	46.82
4	2420	60 500	1.333	45.39
5	2467	61 675	1.333	46.26

The resin has an average bending strength of 45.63 N/mm^2 at a standard deviation of 1.76 N/mm^2.

From the force-displacement diagram, we can observer that a brittle fracture has occurred here too.

3.4. Determination of the local compressive strength of resin type 3PHV60

To determine the local compressive strength of the resin, I tested the specimens used in the bending strength experiments. Again, the behaviour of 5 specimens was measured, loaded on a 20×20 mm surface.

In **Table 4** I have summarized the compression at maximum force (dH) and the normal stress value from local compression (σ_{pecset}).

Table 4. *Results of local compression tests on resin specimens.*

#	F_{max} (kN)	A (mm)	dH (mm)	σ_{pecset} (N/mm^2)
1	2228	400	1.333	73
2	2433	400	1.333	75
3	2496	400	1.333	76
4	2420	400	1.333	74
5	2467	400	1.333	76

The average value of the stresses from local compression is 75 N/mm^2, with a standard deviation of 1.16 N/mm^2.

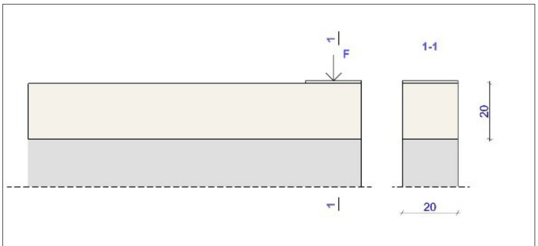

Fig. 10. *Outline of the local compression strength test of resin.*

4. Use of 3PHV60 epoxy resin on softwood structural elements

To determine the applicability of the resin on wood, I carried out the following experiments:

- Adhesion tests of wood-epoxy resin (sectional, parallel to grain and perpendicular to grain);
- Shear load tests;
- Bending load capacity tests.

At the time of writing, a compression load test is still in preparation, and the resin is in the process of setting.

For the experiments I used specimens of common spruce (picea abies) below 12% relative humidity.

4.1. Adhesion test of 3PHV60 type resin and wood on the sectional side

The test specimens illustrated in **Figure 11** were used to test the adhesion of the resin and wood on the sectional side of the wood. The 2 20×40 mm sectional faces of the wood were coated with resin and the two specimens were then joined together to give a 1600 mm^2 adhesion area. After the 7 day resin curing period, the fracture tests were carried out.

In terms of resin consistency, this study was split into two parts. In the first series, a very liquid resin, at the very beginning of the setting phase, was applied to the sectional side of the wood. In the second series, a more viscous resin, more advanced in the setting phase, was applied to the sectional faces of the wood specimens.

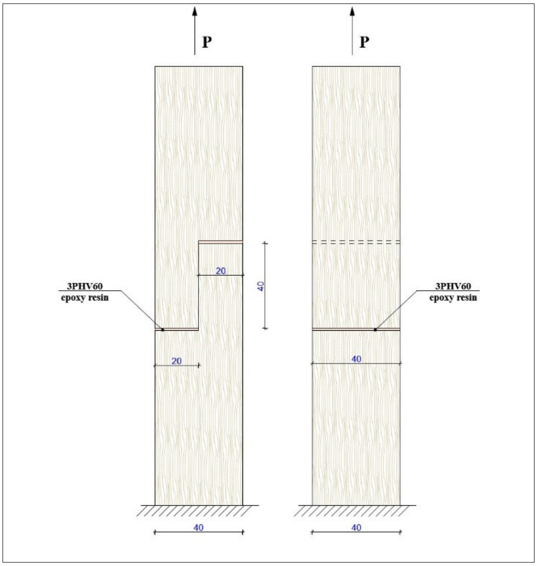

Fig. 11. *Adhesion test of the resin and wood on the sectional side of the wood.*

Fig. 12. *Adhesion testing of resin applied on the sectional side of the wood.*

Table 5. *Result of the adhesion testing ont the sectional side, Series 1.*

#	F_{max} (N)	A (mm)	Sectional adhesion (N/mm²)	Average adhesion (N/mm²)
1	2756	1600	1.72	2.70
2	4286	1600	2.67	
3	5263	1600	3.28	
4	5056	1600	3.16	
5	3850	1600	2.40	
6	4909	1600	3.06	
7	3367	1600	2.10	
8	5172	1600	3.23	

Table 6. *Result of the adhesion testing ont the sectional side, Series 2.*

#	F_{max} (N)	A (mm)	Sectional adhesion (N/mm²)	Average adhesion (N/mm²)
9	6977	1600	4.36	5.04
10	6102	1600	3.81	
11	7988	1600	4.99	
13	10248	1600	6.40	
14	9070	1600	5.66	

The average adhesion on the sectional side of the wood obtained in the second series is 86% higher than the average value obtained in the first series.

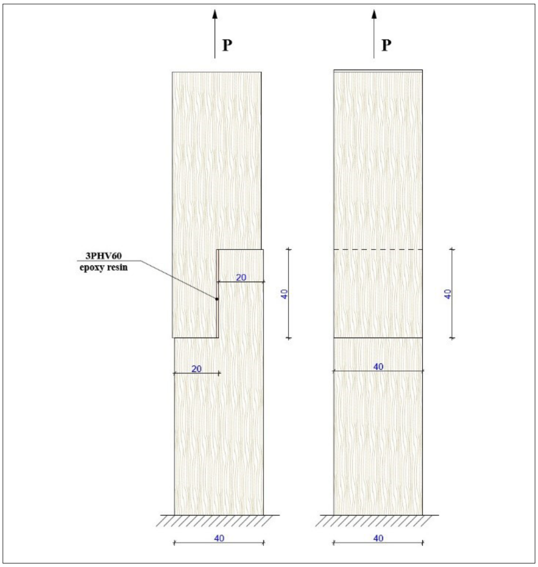

Fig. 13. *Test specimens for fibre adhesion testing of resinous wood.*

4.2. Adhesion test of resin type 3PHV60 and wood parallel to grain

For the fibre direction adhesion test of resin and wood, similar specimens were used as in the previous test, except that this time the sides of the wood specimens parallel to the fibre direction were coated with resin (**Figure 13**). After waiting for 7 days of curing time, the specimens were loaded with the breaking machine until the resin-timber bond was destroyed.

In the case of the fibre adhesion test, 8 specimens were taken and the fracture results are summarised in **Table 7**.

The results of the second series of adhesion test on the sectional side of the wood are similar to the results of the fibre adhesion tests.

Table 7. *Resin-timber fibre directional adhesion*

#	F_{max} (N)	A (mm)	Fibre directional adhesion (N/mm²)	Average adhesion (N/mm²)
1	7865	1600	4.91	4.80
2	7049	1600	4.40	
3	7753	1600	4.84	
4	4631	1600	2.89	
5	7529	1600	4.70	
6	10692	1600	6.68	
7	7488	1600	4.68	
8	8494	1600	5.30	

4.3. Adhesion tests of resin type 3PHV60 and wood perpendicular to grain

In this experiment, 8 specimens were also made with the same adhesion surface (A), as in the previous two adhesion tests. The bonded specimens have an adhesion area of 40×40 mm^2.

Table 8. *Epoxy-resin wood adhesion perpendicular to grain*

#	F_{max} (N)	A (mm)	Adhesion perpendicular to grain (N/mm^2)	Average adhesion (N/mm^2)
1	5379	1600	3.36	3.20
2	4705	1600	2.94	
3	5054	1600	3.15	
4	6941	1600	4.33	
5	4449	1600	2.78	
6	4912	1600	3.07	
7	4437	1600	2.77	
8	5032	1600	3.14	

In the case of the perpendicular adhesion test, the wooden test specimens are used for tension perpendicular to grain. In this test, failure typically occurs in the wood and not at the interface between the resin and the wood. This is not surprising, as the strength properties of wood are the lowest in the perpendicular tensile load.

4.4. Testing of shear loads

To test the shear load capacity of resin reinforced wood, 3 series of measurements were taken and compared after the measurements.

4.4.1. Shear load test of a full cross-section timber specimen

In this series, my goal was to obtain data on the average shear load of the tested wood. Then, in the following series, using this wood, we will model weakening on the test specimens, followed by improvement of weakening in practice.

8 wooden specimens of 40×40×120 mm solid cross-section were produced, the test is illustrated in Figure 17.

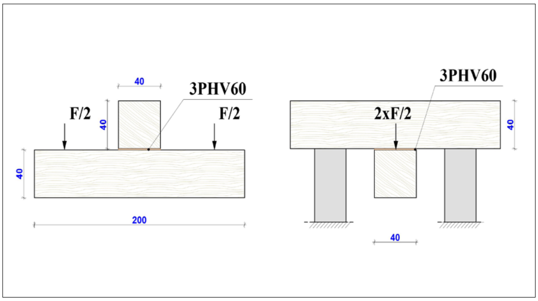

Fig. 14. *Adhesion test of the resin 3PHV60 and wood perpendicular to grain/*

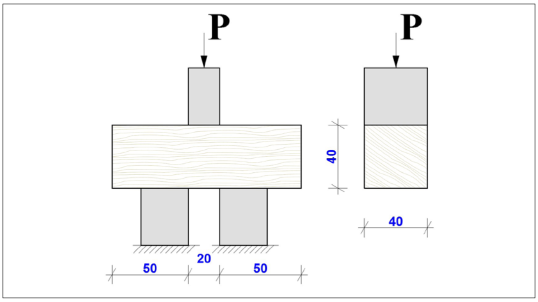

Fig. 16. *Outline of the full cross-section sheared wood test specimen experiment.*

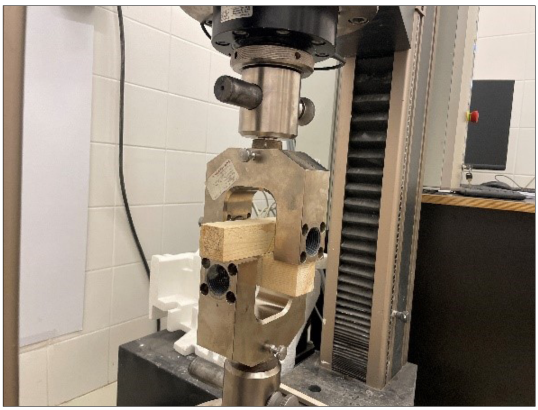

Fig. 15. *Measuring the adhesion of resin and wood perpendicular to grain.*

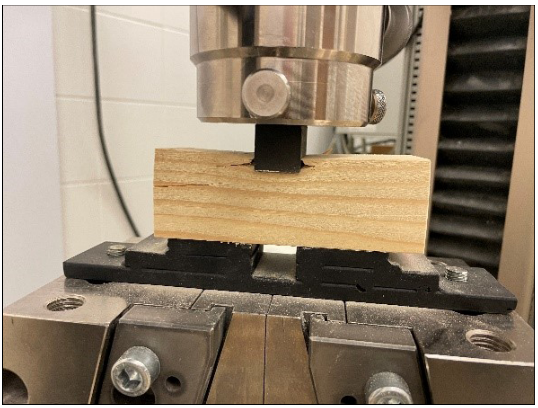

Fig. 17. *The full cross-section sheared wood specimen.*

Table 9 summarises the measured shear load values. The average shear stress at the moment of failure is 5.03 N/mm^2, with a standard deviation of 0,45N/mm^2.

The value of the maximum shear force (V_{max}) is equal to half the force P_{max} applied at the moment of fracture.

Table 9. *Shear strength of full section timber specimens*

#	V_{max} (N)	A (mm)	Shear strength (N/mm^2)	Average shear strength (N/mm^2)
1	8693	1600	5.43	5.03
2	7664	1600	4.79	
3	8148	1600	5.09	
4	9187	1600	5.74	
5	7518	1600	4.70	
6	6817	1600	4.26	
7	7743	1600	4.84	
8	8623	1600	5.39	

The average of breaking forces measured here are 16 098 N.

4.4.2. Investigation of the shear strength of weakened cross-sectional timber specimens

For the measurement, seven specimens of 40×40×120 mm, as used in the previous subsection, were prepared, on which a regular geometry cross-section reduction was applied in the shear-loaded section. In the loaded section, I removed a 20×20×40 mm section of the wood.

In this case, the shear-resistant wood cross-section area is reduced to 800 mm^2.

Table 10. *Shear strength of weakened cross-sectional timber specimens*

#	P_{max} (N)	V_{max} (N)	A (mm)	Shear strength (N/mm^2)	Average shear strength (N/mm^2)
1	13 378	6689	800	8,36	8,53
2	15 329	7664	800	9,58	
3	16 570	8285	800	10,35	
4	17 110	8555	800	10,69	
5	11 542	5771	800	7,21	
6	11 747	5873	800	7,34	
7	9 861	4930	800	6,16	

The average breaking forces measured here are 13648 N.

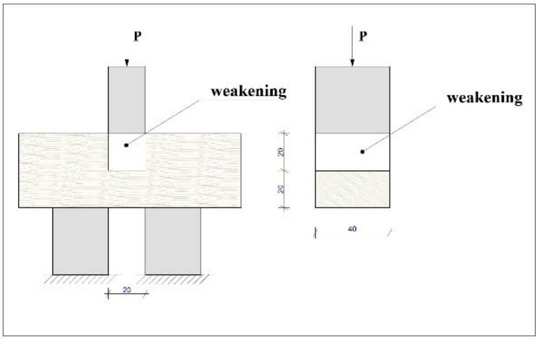

Fig. 18. *Shear load test with weakening.*

Fig. 19. *Shear load test with weakening.*

4.4.3. Shear strength testing of resin supplemented weakened wood specimens

Regular „weakened” specimens formed on the test specimens described in section 4.4.2 were filled with 3PHV60 resin and then these specimens were also broken while waiting for the resin to set.

Table 11. *Shear strength of weakened cross-section timber specimens filled with epoxy resin*

#	P_{max} (N)	V_{max} (N)	Average shear force (N)	Average breaking force (N)
1	20 531	10 265	9 313	18 626
2	18 096	9 048		
3	21 734	10 867		
4	17 129	8 564		
5	15 327	7 663		
6	18 014	9 007		
7	18 204	9 102		
8	19 983	9 991		

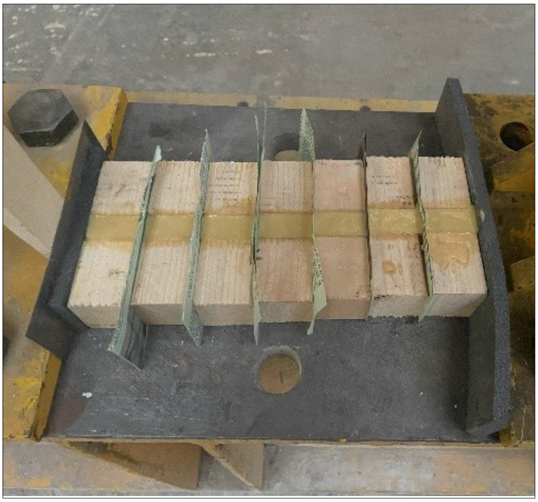

Fig.20. *Shear test specimens supplemented with resins.*

Fig. 21. *Shear test specimens supplemented with resins.*

The average value of the breaking forces for the resin-filled weakened specimens was 18626 N, while for the full cross-section intact wood specimens it was 16098 N.

4.5. Bending load capacity tests

For the bending load tests, I used the standard [4] MSZ EN 408:2010+A1:2012, which specifies the geometrical and loading parameters required for the bending load tests. Several series were performed for this test as well as for the determination of shear load capacities. By comparing the series I try to draw conclusions about the effectiveness of the methods. In these tests I compare the forces at the moment of fracture, not the bending stresses.

4.5.1. Bending load capacity of the specimens weakened in the bottom side

I measured 5 specimens of 40×40×800 mm geometry with a span of 720 mm. I loaded the specimens at the thirds of the span. At half of the span, a regular cross-section weakening was carried out by cutting a 40×20×20 mm body from the bottom side of the specimens.

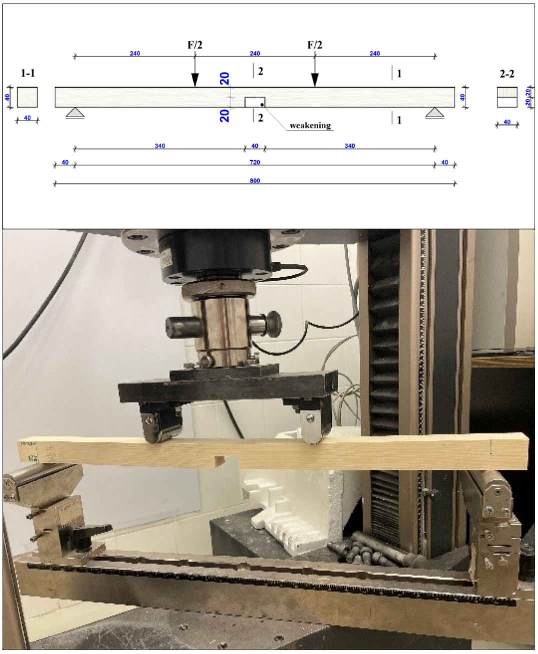

Fig. 22. *Bend capacity test of resin-filled specimens weakened in the bottom side.*

Table 12. *Breaking forces for weakened test specimens in the bottom side*

#	P_{max} (N)	Average of breaking forces (N)
1	1395	801.30
2	411	
3	658	
4	549	
5	991	

4.5.2. Bending load capacity of resin-filled specimens weakened in the bottom side

The specimens used in section 4.5.1 were taken as a basis. The weakened section was filled with resin and the forces at the moment of fracture were measured after the 7-day setting time.

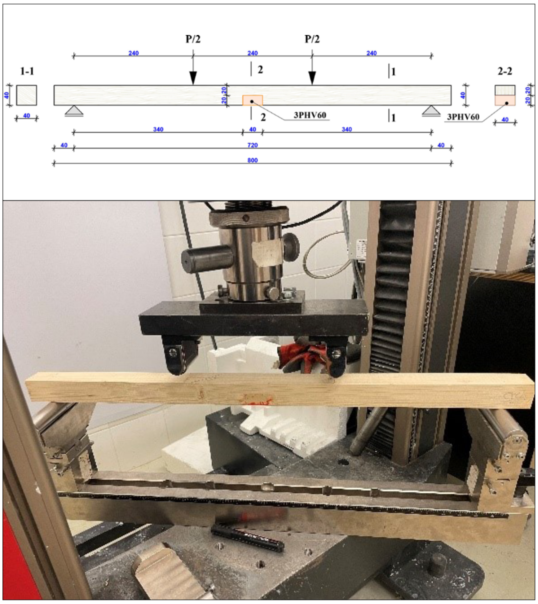

Fig. 23. *Bend capacity test of resin-filled specimens weakened in the bottom side.*

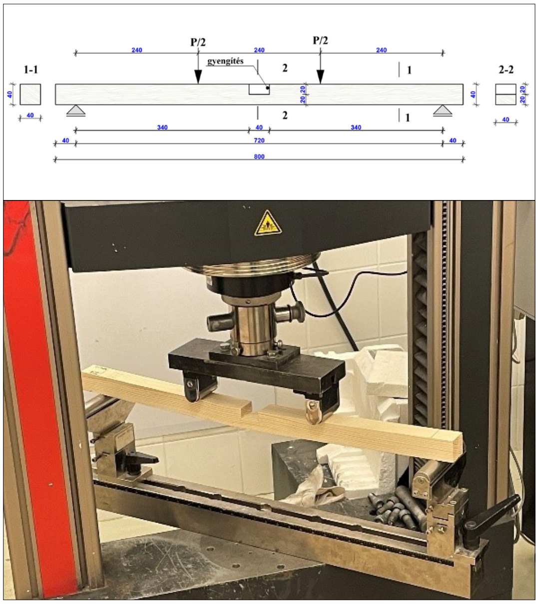

Fig. 24. *Test of the bending capacity of timber specimens weakened in the upper side.*

Table 13. *Summary of lower-belt weakened, resin-reinforced test specimens*

#	P_{max} (N)	Average of breaking loads (N)
1	1730	1243.17
2	1064	
3	1650	
4	1285	
5	1032	
6	696	

4.5.3. Bending load capacity of specimens weakened in the upper side

As in section 4.5.1, 5 specimens were made, with the difference that this time the weakening was applied in the upper belt.

Table 14. *Summary of upper-side weakened test specimen breaking loads*

#	P_{max} (N)	Average of breaking loads (N)
1	942	1304
2	1024	
3	1581	
4	1578	
5	1386	

4.5.4. Bending load capacity of resin-filled specimens weakened in the upper side

7 test specimens similar to 4.5.3 were prepared, with cross-sectional weakening filled with resin. In my study *A Régi fa tartószerkezeti elemek állapotfelmérése roncsolásmentes, illetve töréseken alapuló vizsgálatokkal* [5], presented at the Conference on Civil Engineering and Architecture in 2019, the average value of the breaking forces of the unweakened specimens (32 specimens) was 4566N.

Fig. 25. *Filling the weakened timber parts with epoxy resin.*

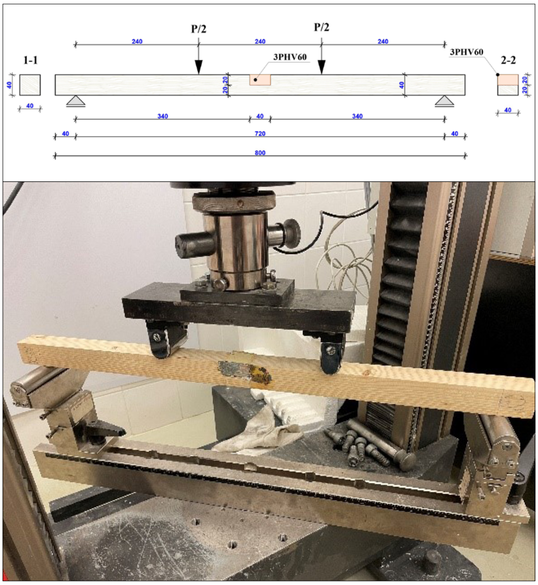

Fig. 26. *Investigation of the bending capacity of resin reinforced timber specimens weakened in the upper side.*

Table 15. *Summary of upper-side weakened resin-filled timber test specimens*

#	P_{max} (N)	Törési erők átlaga (N)
1	4009	4387
2	4092	
3	4860	
4	4446	
5	3413	
6	4194	
7	5693	

5. Conclusions

Through the measurements presented in this study, I gained insight into the potential of using 3PHV60 resin in the restoration of damaged timber structures.

The primary objective of the adhesion test measurements was to investigate the use of resin to repair tensioned timber structural members and joints.

For the reinforcement of weakened or, in practice, mechanically damaged wood elements subject to shearing, the use of the 3PHV60 resin I have tested may be a good alternative. The addition of resin to the reduced timber cross-section resulted in higher shear load capacities than the full cross-section timber specimens.

For timber structural members subjected to bending, a very important issue is whether the damage is on the tension or compression side of the timber. If the damage is on the compressive side, the original bending strength of the wood can be recovered by filling with resin. If the damage is on the tensile side, filling the mechanically damaged area with resin may improve the bending strength, but other applications (e.g. glued steel or composite sheet) to be tested later may be required to restore the original strength.

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