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Withdrawal resistance of wood screw in wood-based materials

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Abstract: *Withdrawal resistance of wood screw in wood-based materials.*The aim of this paper is determine the impact of type of wood material and parameters of screws shoulder on withdrawal resistance of wood screw. Mechanical tests were realized in oak solid wood (*Quercus robur L.*), laminated particle board, and honeycomb board using wood screws and confirmate screw. For evaluation of withdrawal resistance of screws, the load carrying capacity, stiffness, and deformation on the ultimate strength were determined. We also evaluated the failure mode of wood material; in the solid wood it was taken into account the direction of screwing of wood screws relative to grain. The measured and calculated results show that the type of material and method of shoulder screws have the largest influence on the withdrawal resistance of wood screw.

Key words: withdrawal resistance of wood screw, stiffness, load carrying capacity of furniture joints

INTRODUCTION

Connections of furniture components are the most important structural node on which the strength, stiffness, safety and integrity of the furniture construction depend. It is important to propose them so they transmit operating loads without excessive deformation or unwanted breaches. The proper functioning of joints is significantly influenced by materials of structural and connecting elements, the type loading of joints and joint operational conditions such as density and material moisture. Attention is given to the screws that have greater strength and load carrying capacity, such as nails or dowels. Screw connections create stronger constructions and due to a large number of shapes and the possibility of applications in wood materials with different densities, they are quite often used.

In most cases, materials with higher density, exhibit higher load capacity of screws, but on the other hand, with increasing moisture content the load bearing is decreased (Eckelman, 1990). Kjucukov and Encev (1977) did experimental tests for determination of screws withdrawal resistance. The tests were performed with screws with the length of 13-60 mm and with different diameters from 1.5 to 8 mm. These screws were screwed into the wood European silver fir (Abies alba) in three basic anatomical directions. The results of the experiment have found that there is no correlation between withdrawal resistance of the screw and the length of the screw, but there is a linear relationship between withdrawal resistance of the screw and the screw diameter (Kjucukov, Encev, 1977). Kjucukov and Encev did experiments with screws with diameter of 1.5 to 6.0 mm in beech wood (*Fagus sylvatica*) and found that there is a linear relationship between the resistance against removal of screws and screw diameter (Kjucukov, Encev, E., 1997).

The main objective of this paper is to determine the withdrawal resistance of wood screws fixed in wood materials. Experimental investigation of withdrawal resistance involves the determination of mechanical properties, namely: strength, deformation on the ultimate load carrying capacity, and stiffness of the joint in the plane axis of the screw.

MATERIALS AND METHODS

In the choice of test specimens were used materials with significantly different densities. The test pieces (Fig. 1) is a top plan as square with the edge of 100 mm long were made of solid wood of summer oak, thickness of 50 mm (ρ = 705 kg / m 3), particle board with formica surface layer thickness 40 mm (ρ = 531 kg / m3) and veneered honeycomb boards with a core thickness of 34 mm (ρ = 253 kg / m3) and two-clad chipboard thickness of 8 mm. Air conditioning of test specimens at 12% moisture was carried out in a climatic chamber at air temperature of 20 ° C and at relative air humidity φ = 65%.

Fig. 1. Test specimens - material, shape and dimensions

In experimental tests, we used bolts with dimensions 4x12, 6x12, 4x35, 6x40 (mm) and confirmat with dimensions 5x40, 7x50 (Fig.2). At honeycomb boards, bolts were fitted on the anchor bolts Hettinject.

Fig. 2. Connecting fasteners used in tests

When using a material with density of 500 kg/m^3 the screw hole must by pre-drilled. Pilot hole for the screw should have the same diameter as the shank diameter and the same depth as determined depth of embedment. Dimensions of pre-drilled holes are in table 1.

Table 1: Depth and diameter for drilling holes (mm)

Type and size fastening means (mm)	The diameter of pre-drilled hole (mm)	The depth of the pre-drilled hole (mm)
Screw 4x12	**3,00**	**12,00**
Screw 6x12	**3,50**	**12,00**
Screw 4x35	**3,00**	**25,00**
Screw 6x40	**3,50**	**25,00**
Confirmat Screw 5x40	**3,50**	**25,00**
Confirmat Screw 7x50	**3,00**	**25,00**

Experimental tests were done using a tensile testing machine according to the scheme in Fig. 3. The test piece was fitted in a steel preparation, which provides the force to pull in the direction of the axis of the screw.

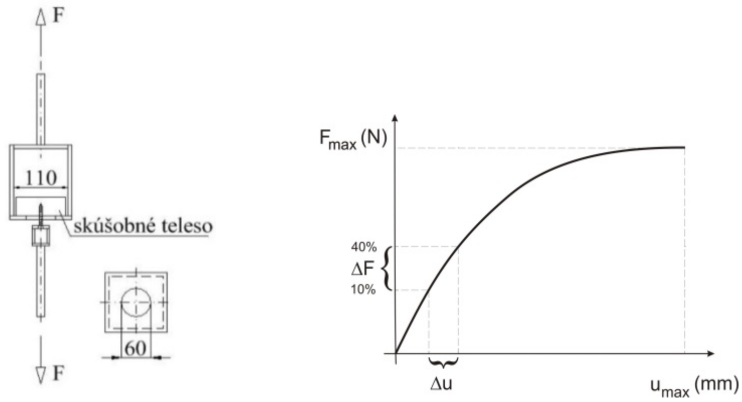

Fig. 3. Experimental test

a) testing scheme, b) working diagram for testing the load carrying capacity; F_{max} (N) – axial load carrying capacity, u (mm) – withdrawal / displacement

On the basis of load scheme during the test, we determined the strength properties of joints:

F_{max} (N) – axial load carrying capacity, the maximum force in which connection was broken, where $\Delta F = 0{,}3F_{\max}$,

u_{40}, u_{10} (mm) – pull the screw at 40% and at 10% of maximum load, where $\Delta u = u_{40} - u_{10}$

t (N/mm) – stiffness of the joints, where $t = \frac{\Delta F}{\Delta u}$

The computational model load capacity (EC5)

The experimental values of load capacity also serve to verify the calculation model. In our case, we used computational model of computing load capacity according to the EC 5, when applicable:

$$R_d = \frac{k_{mod} \cdot ((1{,}5 + 0{,}6 \cdot d) \cdot \sqrt{\rho})}{\gamma_M} \cdot (l_{ef} - d)$$

where: d – outer diameter of the screw thread (mm),
l_{ef} – thread depth of engagement (mm)
ρ – average density of the wood material (kg/m^3)
k_{mod} – the modification coefficient which takes into account the duration of the load (wood 1.2, particle board 1.1)
γ_M – reliability coefficient for material 1,3

RESULTS

Comparison of load carrying capacity according to the computational model and the experiment:

Table 2 shows the values of load carrying capacity according to the calculation model in EC5 and the experiment. For solid wood, this computational model is valid only for load perpendicular to the fibers and considers only the depth of engagement of the threaded part of the screw. According to the computational model, the carrying capacity of for solid wood is on average by 60% higher than the experimental values, which is satisfactory from a security standpoint.

Table 2. Comparison of the load carrying capacity according to the calculation model and experiment, depending on the type of material, size and thread depth of engagement

Size of screw (mm)	Thread depth of engagement (mm)	Material	Load carrying capacity to the experimental tests (N)	Load carrying capacity according to the calculation model EC5(N)
4 x 12	12 mm	oak wood $\perp$	1207,20	903,72
		particleboard	*723,30*	784,32
		honeycomb board	1027,00	541,38
6 x 12	12 mm	oak wood $\perp$	1660,00	886,35
		particleboard	870,10	769,23
		honeycomb board	869,10	530,98
4 x 35	25 mm	oak wood $\perp$	2782,85	2007,32
		particleboard	1042,7	1742,10
		honeycomb board	1050,4	1202,50
6 x 40	25 mm	oak wood $\perp$	3669,80	2806,77
		particleboard	1299,6	2061,20
		honeycomb board	1112,4	1422,73
5 x 40	25 mm	oak wood $\perp$	2344,30	2607,00
		particleboard	1403,1	2262,45
		honeycomb board	1140,6	1561,67
7 x 50	25 mm	oak wood $\perp$	5179,20	2516,63
		particleboard	1415,7	2182,40
		honeycomb board	*849,10*	1506,42

The Table 3 shows the average values of the joints characteristics and the statistical values, depending on the type of material and the type and size of the connecting fittings.

Load carrying capacity:
In terms of the experiment for embedment depth l = 12 mm, the screw 6x12 mm screwed in solid oak perpendicular to the fibers showed the largest load carrying capacity. The smallest load carrying capacity has the screw 4x12 mm inserted in the particle board. For embedment depth l = 25 mm, the largest load carrying capacity was reached by the confirmat 7x50 mm inserted perpendicular to the fibers in oak sample; the confirmat 7x50 mm in honeycomb board showed the lowest load carrying capacity.

The deformation:
For embedment depth l = 12 mm, the honeycomb board with screws with diameter 4x12 mm has highest deformation. For other screws, deformations are not differing significantly; they did not exceed the limit of 2 mm. The smallest deformation was measured for screw 6x12 mm in oak samples along the fiber. For embedment depth l = 25 mm maximum deformation occurred for confirmat 7x50 mm in oak samples perpendicular to the fibers. The smallest deformation was measured for screw 4x35 mm embedded in the particle board.

The stiffness:
For screwing depth l = 12 mm, screw 6x12 mm in oak sample along the fibre has the highest stiffness. The screw 4x12 mm countersunk in honeycomb board showed the smallest stiffness. The stiffness is more than 4.5 times smaller than the maximum stiffness. For embedment

depth l = 5 mm, the screw 4x35 mm in oak sample perpendicular to the fibers showed the highest stiffness; a slightly lower stiffness was measured in screw 6x40 mm in oak perpendicular to the fibers. The screw 4x35 mm in honeycomb board reached the smallest stiffness.

Tab. 3 Average values of the characteristics of joints and statistical values depending on the type of material and the type and size of the connecting fittings.

Material	Type and size of screw	Load carrying capacity (N)			Deformation (mm)			Stiffness (N/mm)		
		x	s	vk	x	s	vk	x	s	vk
Honeycomb board	**4x12 (sk)**	1027,0	113,53	9,04	2,80	0,133	21,03	411,29	26,65	15,43
	6x12 (sk)	869,28	88,62	9,80	1,505	0,222	6,753	741,15	176,67	4,19
	4x35 (sk)	1050,42	135,53	7,75	2,10	0,179	11,68	605,37	129,63	4,66
	6x40 (sk)	1112,43	168,32	6,60	1,80	0,153	11,69	633,518	88,677	7,144
	5x40 (konf)	1140,20	188,60	6,047	2,095	0,239	8,767	709,422	74,35	9,547
	7x50 (konf)	849,15	214,64	3,955	1,392	0,2928	4,75	746,652	105,42	7,08
Particle board	4x12 (sk)	723,28	54,75	13,20	1,64	0,38	1,34	643	219,5	2,93
	6x12 (sk)	870,15	122,17	7,122	1,41	0,132	10,34	841,98	47,27	17,80
	4x35 (sk)	1042,71	71,14	14,65	1,384	0,103	60,42	901,01	60,42	14,91
	6x40 (sk)	1299,57	114,48	11,35	1,688	0,236	7,14	1042,11	187,99	5,54
	5x40 (konf)	1403,14	91,80	15,28	1,982	0,337	5,875	949,48	220,38	4,308
	7x50 (konf)	1415,74	92,09	15,37	1,64	0,103	15,82	1068,22	80,72	13,23
Oak wood – screw parallel to the fibres	**4x12 (sk)**	1207,14	147,96	8,15	1,461	0,114	12,79	1270,28	162,01	7,84
	6x12 (sk)	1660,57	144,43	11,50	1,268	0,073	17,33	1846,36	128,35	14,38
	4x35 (sk)	2782,85	142,42	19,53	2,03	0,064	31,73	1688,73	258,44	6,53
	6x40 (sk)	3669,85	435,52	8,426	1,791	0,320	5,588	1687,97	378,35	4,461
	5x40 (konf)	2344,38	978,44	2,39	2,05	0,199	10,26	901,35	378,57	2,38
	7x50 (konf)	5179,30	319,10	16,22	3,48	0,345	10,15	1430,33	289,93	4,93
Oak wood – screw perpendicular to the fibres	4x12 (sk)	1718,14	73,02	23,53	1,528	0,084	18,03	1512,13	196,74	7,68
	6x12 (sk)	2217,28	115,44	19,20	1,578	0,068	23,03	172,90	203,85	8,44
	4x35 (sk)	3199,57	448,45	7,13	2,09	0,187	11,14	1964,75	252,53	7,90
	6x40 (sk)	4370,57	291,46	14,99	2,165	0,3788	5,71	1996,52	220,19	8,922
	5x40 (konf)	2616,43	124,408	21,03	3,025	0,238	12,67	1055,39	243,15	4,34
	7x50 (konf)	5974,85	162,13	36,85	5,84	0,282	20,70	911,94	88,11	10,34

Evaluation a breach of samples:

Due to the anisotropy of wood and wood based materials, we evaluated the damage of the test specimens (Fig. 4). In the case of screwing the screws perpendicular to the fibers, it tends to develop tangential and normal stress wood around the screw.

A breach of honeycomb boards is related to pulling the affixed support pin hettinject. There was a local breach of a circle shape, which is conditioned by the auxiliary preparations, respectively the hole diameter of preparation in which the test piece is stored. In the case of particleboard, the breach is similar to honeycomb boards, where if the screw is pulling out a local breach occurs in the circle shape.

Fig. 4. Demonstration of damage of the test specimens for screws 6 x 40 mm loaded by axial force

CONCLUSIONS

- The measured and calculated values showed that the resistance against removal of wood screws, embedded in the wood material, is mainly dependent on the screw diameter and material density. Resistance values increase with increasing density of the material. The highest values of resistance are achieved in oak wood perpendicular to the fibres, where an increase – compared to the resistance of the particle board screw with a diameter of 4 mm – is by about 59% and with the screw with a diameter of 6 mm increase by 39%.
- With increasing diameter, embedment depth of screw, and density of the material the axial stiffness of the joint is increasing. Maximum stiffness is reached in the oak perpendicular to the fibres with a screw diameter of 6 mm and embedment depth of screw 25 mm (1996,52N/mm), which is in this aspect by 68.30% over the honeycomb board (633,51N/mm) and by 47,80% more than the chipboard (1042.11 N/mm). The minimum value of stiffness is achieved in the honeycomb boards with a screw diameter of 4 mm (605.37 N / mm).
- In terms of computational models, there is necessary to review the honeycomb board, where the computational model according to EC 5 has not been confirmed and it is necessary to find a mathematical dependence of the above parameters and structure of the material of honeycomb board.

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Streszczenie: *Odporność na wyrwanie wkrętów w materiałach drzewnych.* Praca dotyczy wpływu typu materiału drzewnego i parametrów wkrętów na zdolność ich utrzymywania. Przeprowadzono testy na drewnie dębu (*Quercus robur L.*), płycie laminowanej oraz komórkowej, używając wkrętów i konfirmatów. Oznaczono zdolność utrzymywania wkrętów, nośność, sztywność i wytrzymałość. laminated particle board, and honeycomb board using wood screws and confirmate screw. Opisano także typ złomu, w drewnie litym brano pod uwagę przebieg włókien. Wyniki wskazują że typ materiału i wkrętów ma największy wpływ na zdolność ich utrzymywania.

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