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Strength properties of corner joints and extending joints on honeycomb boards

PAVOL JOŠČÁK, PATRIK KRASULA, PETER VIMPEĽ
Department of Furniture and Wood Products, Faculty of Wood Sciences and Technology, Technical University in Zvolen.

Abstract: *Strength properties of corner joints and extending joints on honeycomb boards.* This article deals with strength characteristics of furniture joints, which are made of honeycomb boards. We were determining load carrying capacity, deformation and stiffness of three-types corner joints, which loaded stress and tension by moment in angular plane, and two-types extending joints in the plane of the board by static four-point bending load. For corner joints we used furniture fittings VB 36 HT 50, VB INSERT 50, TAB 20 HC and for extending joints that we used fittings AVB HT a QUICK. The results of experiments and calculations are compared with classical joints which are made of wood-based materials. Strength properties of joints which are made of honeycomb boards are lower than average values of classical joints. Furniture joints which used fittings AVB HT and QUICK reached above the average load carrying capacity on the load by stress and furniture joint TAB 20 HC on the load by tension.
Keywords: honeycomb boards, furniture connecting fittings, load carrying capacity of joint, joint stiffness

INTRODUCTION

Honeycomb board sets new rate for furniture and interior design, while the modernity of contemporary furniture are underlined especially their massive lines. For the fixed furniture fittings on honeycomb boards without frame must be used appropriate furniture fittings for the create a strong and durable connection. And just issue finding strength properties of mechanical joints on honeycomb boards is dedicated relatively low importance. This experiment builds on the work (KOŘENÝ, 2013), which dealt with properties of honeycomb boards. Other group (next) works are focused on the mechanical properties of joints (JOŠČÁK, 1999, JOŠČÁK - GAFF - LANGOVÁ 2011, JOŠČÁK - LANGOVÁ - VALENT, 2012, LANGOVÁ, 2000).

In our work, we focus on detecting strength properties of selected corner joints, which loaded stress and tension by moment in angular plane and extending joints in the plane of the board by static four-point bending load. The results of experiments are compared with classical furniture joints, which are made of wood-based materials.

MATERIALS AND METHODS

Samples of furniture joints were made from honeycomb boards without frame, thickness of 50mm, which are comprised of three layers. The top layers are laminated chipboards thickness of 8mm, and core made of honeycomb cardboard thickness of 34mm.

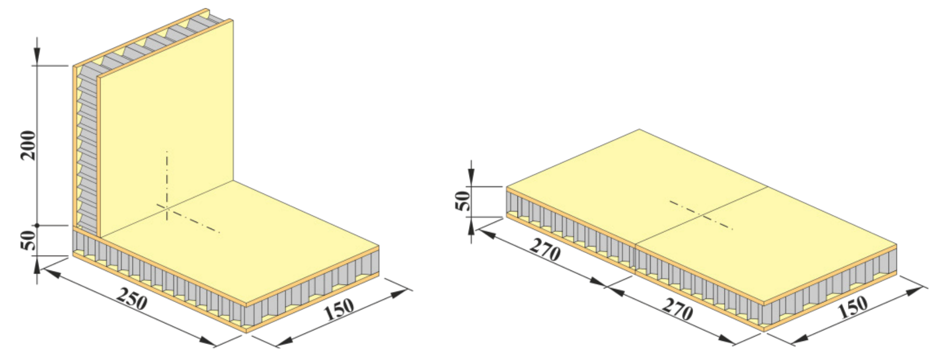
Disassemblable joints are usually provide by different types of multi-pieces fittings, the individual parts may or may not be permanently linked with the connecting part. When joining honeycomb boards without frame, due to their hollow core are created different requirements, as when joining classical wooden materials. Our selected furniture fittings are the most used in practice by supplier and therefore we applied them in our tests (VIMPEĽ, 2014).

a) b) c) d) e)

Fig. 1. Furniture fittings

a) VB 36 HT 50 – cam-lock connection, fixed into the surface of board, b) VB INSERT 50 – cam-lock connection, fixed into the side of board, c) TAB 20 HC – connector housing without tightening force, d) AVB HT – screw and nut with washer, e) QUICK – screw and nut with round cap (HETTICH, DÉMOS TRADE 2014)

Test samples made according to Fig.2a were loaded stress and tension in bending angular plane, and samples made according to Fig.2b by symmetric four-point bending load.

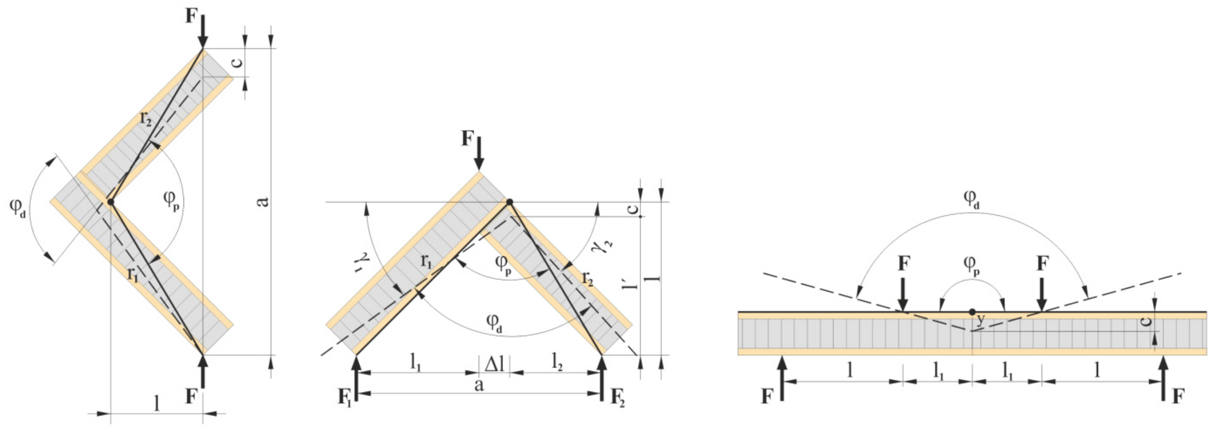


a) b)

Fig. 2. The shape and dimensions of test samples

a) corner joint, b) extending joint in the plane of the board

Strength properties of the tested joints were assessed on the universal testing machine – FPZ 100/1. During the tests was recorded force F (N) and offset jaws of the machine c (mm). This data are used to determinate the moment of force for joint M_u (N.mm), angular deformation on the load carrying capacity φ_{max} (rad) and stiffness coefficient T (N.m/rad) joints. Schemes for different types of loads are shown on Fig. 3.



a) b) c)

Fig. 3. Schemes for different types of load with input parameters (Vimpel', 2014)

a) bending load in angular plane – stress, b) bending load in angular plane – tension, c) stress by four-point bending load – extending joint

F – stress/tension force (N); $r_{1,2}$ – length of the joint shoulder (distance from force location to the pivot point) (m); φ_p, φ_d – angle of joint before (original shape of joint) and after to load (deformed shape of joint) (rad); γ_1 – the angle between the horizontal plane which is passes through point of rotations and the position of the shoulder joint r_1 in the deformed shape; γ_2 – the angle between the horizontal plane which is passes through point of rotations and the position of the shoulder joint r_2 in the deformed shape; c – offset distance the shoulder of joint (m); a – spacing shoulder of joint (m); l – arm of force (m); l′– arm force in the deformed shape (m); l_1 – supports distance from loaded force (m); l_2 – supports distance from the pivot point (m); Δl – distance of point by loaded stress from pivot point (m)

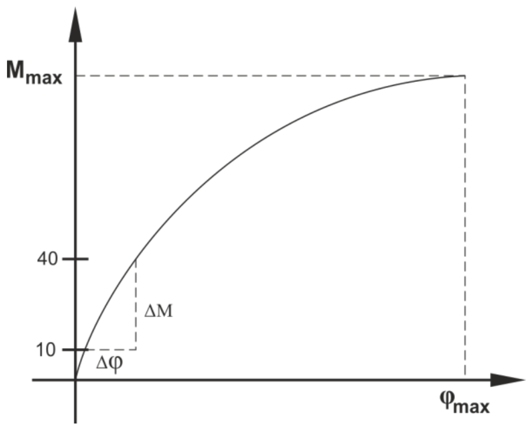


Fig. 4. Diagram of loaded – deformation

Strength properties are expressed by equations:

- load carrying capacity as a maximum moment of force for to the crease in the angular plane – loaded stress (Fig.3a) and stress by four-point bending load – extending joints (Fig.3c).

$$M_{max} = F_{max}.l$$

for scheme of loaded in bending angular plane – tension (Fig.3b):

$$M_{max} = F_{2max}.l_2$$

- maximum rotation of the joint shoulder – angular deformation (Fig.3):

$$\varphi_{max} = \varphi_p - \varphi_{d,max}$$

- stiffness coefficient (Fig.4):

$$t = \frac{\Delta M}{\Delta \varphi}$$

RESULTS

Load carrying capacity (moment of force)

The largest load carrying capacity in loaded stress is achieved furniture fitting of extending joint AVB HT and furniture fitting QUICK. The other three types of furniture fittings designed for corner joints, loaded in bending angular plane with loaded stress, showed a much lower load carrying capacity than first, two furniture fittings, the worst load carrying capacity showed furniture TAB 20 HC. Corner joints had higher load carrying capacity in tension then in loaded stress.

The variability of measured values to stress load carrying capacity is in the range 8 – 13%, values are similar as reported by other authors which studied load carrying capacity of furniture fittings (Table 1).

Table 1. The basic statistical characteristic – load carrying capacity (stress and tension)

Furniture fitting	Average [Nm]	Standard deviation [Nm]	The coefficient of variation [%]	Number of pieces [pc]
				Stress
VB 36 HT 50 – cam-lock connection, fixed into the surface of board	6.31	0.86	13.6	8
VB INSERT 50 – cam-lock connection, fixed into the side of board	13.49	2.83	21.0	7
TAB 20 HC – connector housing without tightening force	4.38	0.66	15.1	8

AVB HT – screw and nut with washer	99.35	12.02	12.1	9
QUICK – screw and nut with round cap	63.71	7.46	11.7	8
Tension				
VB 36 HT 50 – cam-lock connection, fixed into the surface of board	14.60	1.90	13.0	10
VB INSERT 50 – cam-lock connection, fixed into the side of board	16.18	1.45	8.9	8
TAB 20 HC – connector housing without tightening force	25.90	2.07	8.0	9

According to the table 2 we can determinate that the furniture fittings have a statistically important effect on the results.

Table 2. The base table of ANOVA – load carrying capacity (stress and tension)

Source	Sum of squares	Degrees of freedom	Variance	Fisher´s F-test	p-value
Stress					
Average	55738.9	1	55738.9	1218.2	0.000
Furniture fittings	60345.5	4	15086.4	329.7	0.000
Random factors	1601.5	35	45.8		
Tension					
Average	9558.7	1	9558.7	2818.0	0.000
Furniture fittings	684.6	2	342.3	100.9	0.000
Random factors	81.4	24	3.4		

Between the furniture fittings VB 36 HT and TAB 20 HC are not statistically significant difference in the load carrying capacity in loaded stress, as show table 3. Load carrying capacity in tension is not statistically important difference between furniture fittings VB 36 HT 50 and VB INSERT 50.

Table 3. Level of significance by Duncan's test – load carrying capacity (stress and tension)

Stress					
Furniture fitting	VB 36 HT 50 6.31 Nm	VB INSERT 50 13.49 Nm	TAB 20 HC 4.38 Nm	AVB HT 99.35 Nm	QUICK 63.71 Nm
VB 36 HT 50		0.042	0.573	0.000	0.000
VB INSERT 50	0.042		0.015	0.000	0.000
TAB 20 HC	0.573	0.015		0.000	0.000
AVB HT	0.000	0.000	0.000		0.000
QUICK	0.000	0.000	0.000	0.000	

Tension			
Furniture fitting	VB 36 HT 50 14.60 Nm	VB INSERT 50 16.18 Nm	TAB 20 HC 25.90 Nm
VB 36 HT 50		0.084	0.000
VB INSERT 50	0.084		0.000
TAB 20 HC	0.000	0.000	

Comparing the results with dates of classical furniture joints made of particleboards and fiberboards, we found that the highest load carrying capacity in loaded stress have our tested furniture fitting AVB HT which was loaded by four-point bending. For classical corner joints has the highest load carrying capacity of the mitre joints with dowel (65Nm), our values of testing samples made of honeycomb boards were considerably lower. Their value was at the level of cam-lock joints (9Nm). The highest load carrying capacity in tension has mitre joints with dowel (36Nm). From our samples it was furniture fitting TAB 20 HC, which as at level of screw and cylinder nut joint (DTD 18) and confirmat (27Nm) (JOŠČÁK, 1999).

Angular deformation (maximum rotation of joint shoulder)

Extending joints created with furniture fittings AVB HT and QUICK achieved the highest angular deformation in loaded stress. The lowest angular deformation had corner joint created with furniture fitting VB INSERT 50. When testing of angular deformation in tension proved to be the best furniture fitting VB 36 HT 50 which creates a corner connection. Conversely, the lowest angular deformation had furniture fitting TAB 20 HC.

The variability of measured values to angular deformation in loaded stress is in the range 13.3 – 35% and an angular deformation in tension 17.6 – 23%, which are comparable to the values measured by other authors (Table 4).

Table 4. The basic statistical characteristic – deformation (stress and tension)

Furniture fitting	Average [Nm]	Standard deviation [Nm]	The coefficient of variation [%]	Number of pieces [pc]
				Stress
VB 36 HT 50 – cam-lock connection, fixed into the surface of board	0.0937	0.0157	16.7	8
VB INSERT 50 – cam-lock connection, fixed into the side of board	0.0752	0.0243	32.3	7
TAB 20 HC – connector housing without tightening force	0.1075	0.0143	13.3	8
AVB HT – screw and nut with washer	0.2602	0.0809	31.3	9
QUICK – screw and nut with round cap	0.2531	0.0886	35.0	8
				Tension
VB 36 HT 50 – cam-lock connection, fixed into the surface of board	0.1713	0.0395	23.0	10
VB INSERT 50 – cam-lock connection, fixed into the side of board	0.0929	0.0179	19.3	8
TAB 20 HC – connector housing without tightening force	0.0682	0.0120	17.6	9

Even in the case of angular deformation in loaded stress and tension in Table 5 we can based on a one-factor analysis of variance to say that the furniture fittings have a statistically important effect on the results.

Table 5. The base table of ANOVA – deformation (stress and tension)

Source	Sum of squares	Degrees of freedom	Variance	Fisher´s F-test	p-value
					Stress
Total average	0.991	1	0.991	304.4	0.000
Furniture fittings	0.267	4	0.067	20.5	0.000
Random factors	0.114	35	0.003		
					Tension
Total average	0.329	1	0.329	452.8	0.000
Furniture fittings	0.055	2	0.028	38.1	0.000
Random factors	0.017	24	0.001		

According to the results of Duncan's test at angular deformation in loaded stress between furniture fittings VB 36 HT 50, VB INSERT 50 a TAB 20 HC difference is not statistically important. The same applies to the angular deformation in tension between furniture fittings VB INSERT 50 a TAB 20 HC (Table 6).

Table 6. Level of significance by Duncan's test – deformation (stress and tension)

Furniture fitting	VB 36 HT 50 0.094 rad	VB INSERT 50 0.075 rad	TAB 20 HC 0.107 rad	AVB HT 0.260 rad	QUICK 0.253 rad
					Stress
VB 36 HT 50		0.522	0.635	0.000	0.000
VB INSERT 50	0.522		0.296	0.000	0.000
TAB 20 HC	0.635	0.296		0.000	0.010
AVB HT	0.000	0.000	0.000		0.806
QUICK	0.000	0.000	0.010	0.806	
					Tension
Furniture fitting	VB 36 HT 50	VB INSERT 50	TAB 20 HC		

	0.1713 rad	0.0929 rad	0.0682 rad
VB 36 HT 50		0.000	0.000
VB INSERT 50	0.000		0.064
TAB 20 HC	0.000	0.064	

The values to compare of classic and our testing joints, shows that furniture fittings AVB HT and QUICK have a slightly higher angular deformation in loaded stress as a joint created with cam-lock. Other furniture fittings tested in loaded stress and tension, achieved average angular deformation (JOŠČÁK, 1999).

Stiffness coefficient (module of rotation)

Corner connection of honeycomb boards created by VB INSERT 50 achieved the highest stiffness coefficient at loaded stress. Lowest values achieved extending joints in the plane of the board AVB HT and QUICK. The best results of stress on angular plane in tension achieved furniture fitting TAB 20 HC. Furniture fitting VB INSERT 50 had lower stiffness coefficient in tension about 60%.

By the coefficient of variation is the variability of measured values by stiffness coefficient in loaded stress is relatively higher 18 – 50.1% for future research would be appropriate to increase the number of measurements. The same is applies for stiffness coefficient in tension 19.4 – 30.7% (Table 7).

Table 7. The basic statistical characteristic – stiffness (stress and tension)

Furniture fitting	Average [Nm]	Standard deviation [Nm]	The coefficient of variation [%]	Number of pieces [pc]
				Stress
VB 36 HT 50 – cam-lock connection, fixed into the surface of board	97.86	19.99	20.4	8
VB INSERT 50 – cam-lock connection, fixed into the side of board	275.79	51.16	18.6	7
TAB 20 HC – connector housing without tightening force	68.22	12.29	18.0	8
AVB HT – screw and nut with washer	32.58	15.98	49.1	9
QUICK – screw and nut with round cap	31.38	15.71	50.1	8
				Tension
VB 36 HT 50 – cam-lock connection, fixed into the surface of board	145.41	28.15	19.4	10
VB INSERT 50 – cam-lock connection, fixed into the side of board	312.41	95.77	30.7	8
TAB 20 HC – connector housing without tightening force	756.75	186.19	24.6	9

Analysis of variance confirms that the furniture fittings have a statistically important effect on the results in loaded stress and tension too (Table 8).

Table 8. The base table of ANOVA – stiffness (stress and tension)

Source	Sum of squares	Degrees of freedom	Variance	Fisher´s F-test	p-value
					Stress
Total average	406802.1	1	406802.1	610.2	0.000
Furniture fittings	302042.4	4	75510.6	113.3	0.000
Random factors	23334.0	35	666.7		
					Tension
Total average	4388936.4	1	4388936.4	302.1	0.000
Furniture fittings	1854890.9	2	927445.5	63.8	0.000
Random factors	348665.3	24	14527.7		

Between the furniture fittings AVB HT and QUICK are not statistically important difference. Other furniture fittings are different and this also applies to the values measures for stiffness coefficient in tension too (Table 9).

Table 9. . Level of significance by Duncan's test – stiffness (stress and tension)

					Stress
Furniture fitting	VB 36 HT 50 97.86 Nm/rad	VB INSERT 50 275.79 Nm/rad	TAB 20 HC 68.22 Nm/rad	AVB HT 32.58 Nm/rad	QUICK 31.38 Nm/rad
VB 36 HT 50		0.000	0.028	0.000	0.000
VB INSERT 50	0.000		0.000	0.000	0.000
TAB 20 HC	0.028	0.000		0.009	0.010
AVB HT	0.000	0.000	0.009		0.927
QUICK	0.000	0.000	0.010	0.927	

			Tension
Furniture fitting	VB 36 HT 50 145.41 Nm/rad	VB INSERT 50 312.41 Nm/rad	TAB 20 HC 756.75 Nm/rad
VB 36 HT 50		0.008	0.000
VB INSERT 50	0.008		0.000
TAB 20 HC	0.000	0.000	

From our samples achieved the highest stiffness coefficient of furniture fitting VB INSERT 50 which was compared to mitre joints with dowel (970Nm/rad) lower by up to 70%. The highest stiffness coefficient in tension achieved furniture fitting TAB 20 HC which is equivalent to the joint created of cam-lock or mitre joint with dowel (735.2Nm/rad). Furniture fitting VB 36 HT 50 achieved the lowest stiffness coefficient which is equivalent to the joint created of confirmat Ø7x70mm in plain MDF board (170Nm/rad) (JOŠČÁK, 1999).

CONCLUSIONS

From the results by the test of furniture fittings we can deduced these finding:

- **corner joints** – value of the *load carrying capacity* in stress is from 4.38 to 13.49Nm and in tension is from 16.60 to 25.90Nm; cam-lock connection fittings achieved higher value of load carrying capacity in stress than connector housing but in the tension, it was contrary; *angular deformation* in loaded stress is from 0.0752 to 0.1075rad and in tension is from 0.0682 to 0.1713rad; for cam-lock connection fittings is *stiffness coefficient* in loaded stress from 97.86 to 275.79Nm/rad and for connector housing is about 68.22Nm/rad; stiffness coefficient in tension achieved the highest value with connector housing connection – 756,75Nm/rad; values of cam-lock connection fitting was from 145.44 to 312.41Nm/rad.

- **extending joints** – the *load carrying capacity* in stress for joints created of screw and nut was from 63.71 to 99.35Nm and *stiffness coefficient* was from 31.38 to 32.58Nm/rad; testing of these joints on tension for the practice are not importance because these furniture fittings are using on worktops only, which are during their lifetime loaded only stress forces.

In conclusion we can say that the results will be suitable for application in practice, especially for designing furniture construction but also for manufacturer of furniture fittings who can continue to improve their technical properties.

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Streszczenie: Własności wytrzymałościowe połączeń narożnikowych i czołowych w płytach komórkowych. Praca dotyczy charakterystyk wytrzymałościowych połaczeńw płytach komórkowych z wypełnieniem plaster miodu. Zbadano własności wytrzymałościowe trzech typów połączeń narożnikowych oraz dwóch typów czołowych. Do połączeń narożnikowych użyto VB 36 HT 50, VB INSERT 50, TAB 20 HC, zaś do czołowych AVB HT i QUICK. Porównano wyniki z klasycznymi połączeniami materiałów drzewnych. Własności wytrzymałościowe połączeń w płytach komórkowych są niższe, niż przy tradycyjnych połączeniach płyt drewnopochodnych. Połączenia AVB HT i QUICK wykazały ponadprzeciętną nośność, zaś połączenie TAB 20 HC wytrzymałość na rozciąganie.

Corresponding authors :

Pavol Joščák, Patrik Krasula, Peter Vimpeľ, Technical University in Zvolen, Faculty of Wood Sciences and Technology, Department of Furniture and Wood Products, T.G. Masaryka 24, 960 53, Zvolen, Slovak Republic, tel.: +421 45 5206401, e-mail: joscak@tuzvo.sk