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Strength comparative analysis of furniture joints made of various materials

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Abstract: *The strength comparative analysis of furniture joints made of various materials*. The influence of the load on the angular deformation of the furniture joint samples made of various materials was studied. The tests were carried out for six types of furniture materials: chipboard, MDF, hardwood plywood, glued pine wood, glued oak wood and HPL and for three types of fasteners with different ways of fixing in connected elements: shape-thread, expansion-expansion and expansion-thread way of anchoring in material of boards. The joint samples were loaded with a bending moment only (without inducing transverse loadings). The maximum load capacity and load capacity at the 3° (0.052 rad) sample rotation was measured and then the stiffness coefficients were calculated. Considerable differences were found between HPL and others lignocellulosic materials. Expansion fasteners offer incredibly low joint rigidity. This was observed for all tested furniture materials, from soft (chipboard) to very hard (HPL). Expansion connectors work better in soft lignocellulosic materials than in hard materials. The main advantage of expansion fasteners, in comparison to shape-thread fasteners, is its low visibility in the joint and the technological ease of assembly. On the other hand, thread-shaped connectors offer much greater strength and stiffness of joints.

Keywords: furniture fastener, particle board, MDF, plywood, pine, oak, HPL

INTRODUCTION

Manufactured lignocellulosic boards are widely used as a material for the furniture (Antov et al., 2020). A technical challenge is joining board furniture elements (Branowski et al., 2018; Langová et al., 2019; Réh et al., 2019; Branowski et al., 2020). Furniture boards usually have a thickness of 16-22 mm, however, the aim is to reduce their thickness, e.g. to 12 mm (Máchová et al., 2019). Decreasing the thickness of the furniture boards will advantageously decrease the material consumption, reduce the weight of the furniture and increase their useful internal volume (Eckelman, 1978; Smardzewski, 2015; Joščák and Langova, 2018). On the other hand, it will be unfavorable to a proper design of furniture joints (there are several hundred types of fasteners for a board with a thickness of 16-22 mm on the market, and only a few for 12 mm boards). The aim of our study was to experimentally compare the load capacity and stiffness of furniture joints made of thick furniture boards with different material properties and using three different types of furniture fasteners.

MATERIALS

Furniture joint samples made of 12 mm thick boards were tested: particleboard (Swiss Krono, Żary, Poland), MDF (Swiss Krono, Żary, Poland), raw plywood for internal application (birch-alder, 9 layers, Biaform, Białystok, Poland), glued pine wood (Richd. Anders, Kańczuga, Poland), glued oak wood (PHDiP "Siekierki", Warsaw, Poland), HPL (Swiss Krono, Żary, Poland). The boards for the joint samples were cut into pieces (200 × 200 mm), and then their relative humidity was stabilized to 12 ±2% by seasoning in the laboratory for 6 months. The most important properties of the boards for the joint samples are summarized in Table 1.

Table 1. Mean density and bending strength of the boards for the joint samples

Material	Mean density		Bending strength	
	Value (kg/m^3)	SD	Value (MPa)	(SD)
Particleboard	717.4	10.8	11.0	1.1
MDF	747.8	7.3	21.9	1.0
Plywood	695.1	10.0	60.1	1.8
Pine (glued)	572.1	13.9	38.1	6.9
Oak (glued)	690.0	11.1	91.8	4.2
HPL	1421.7	2.9	116.7	3.2

Three different furniture fasteners were used to build the joint samples: Rastex 15 cam and DU 320 twisterrod (Hettich, Kirchlengern, Germany, Fig. 1a), Blu 8 (Car srl, Padova, Italia, Fig. 1b), Frend (Digitouch, Suchy Las, Poland, Fig. 1c). Rastex is a thread-shape fastener which:is fixingin the wide surface of the board by a thread (is screwing in) and is fixing in the wide surface of the board by its shape (the body of the fastener is anchored in the socket). Blu 8 is anexpansion-expansion fastener. Its two ends expand into the holes of the joined elements. Frend is thread-expansion fastener. The tested fasteners are shown in Fig 1.

a

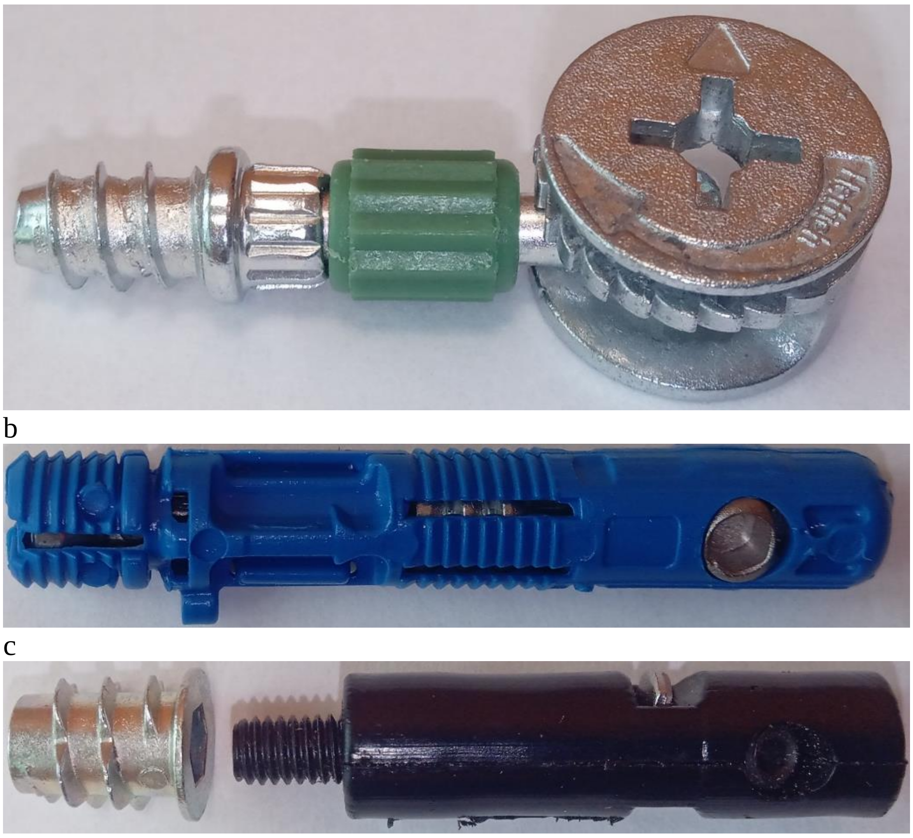

Figure 1. Furniture fasteners used in the test joint samples: a – cam Rastex 15 + twister DU 320 (Hettich, Germany), b – Blu 8 (Car, Italia), c – Frend (Digitouch, Poland)

18 series of samples were prepared (a combination of six board materials and three types of fasteners), there were 3 samples in each series (54 samples in total). Each sample was built of two panels and two fasteners. The test sample is shown in Fig. 2.

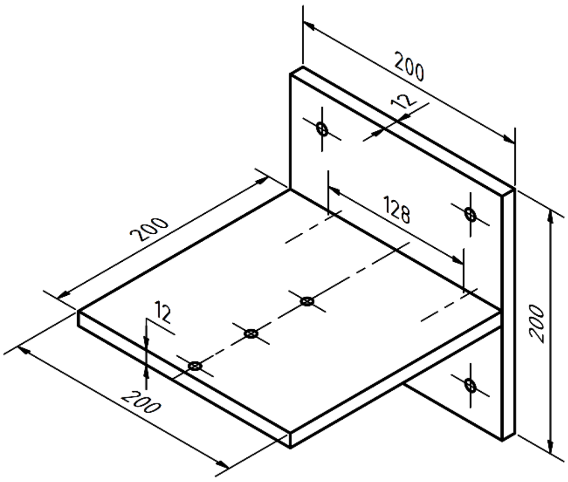

Figure 2. Research sample with two fasteners ("128" is the spacing of fasteners)

In the tests, displacement and force were measured, and then the strength of the sample and its stiffness were calculated. The laboratory testing machine (Fig. 3) was used.

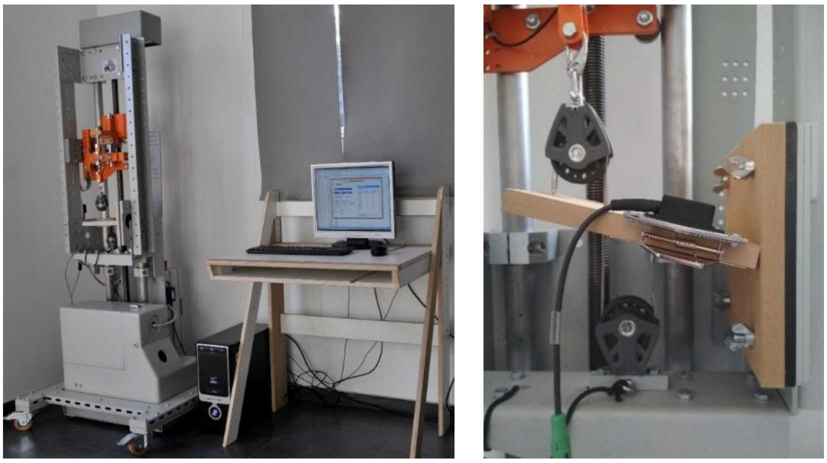

Figure 3. Test stand (source: Sydor and Pohl, 2019)

The joints in the tested samples were loaded with a bending moment only, without any transverse loading (Fig. 4). This was to facilitate the interpretation of the obtained results. The loading of the bending moment only makes it possible to compare the results with the results in other publications. The test results are independent of the dimensions of the tested samples by different authors.

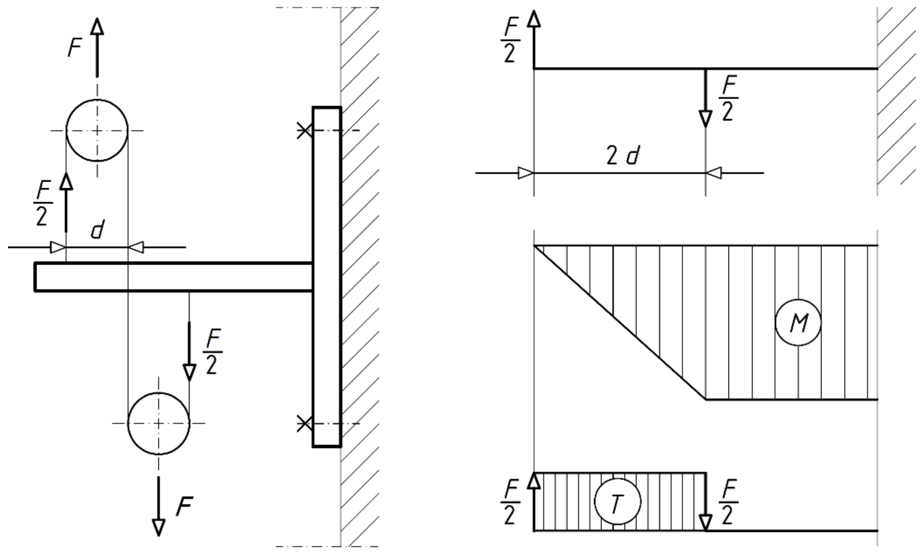

Figure 1. Method of loading the joint samples

Force (F) was exerted with a speed 1.6 mm/s, the measurement of the force was made using a dynamometer with a measuring range up to 5000 N and with an accuracy of ±0.5%. The force for all samples was applied in one direction (up) and converted to the bending moment M. The angular deformation of the sample (deflection) was measured with an inclinometer with an accuracy of ±0.1° (±0.002 rad). The research was performed to the angle Θ = 12° (0.209 rad). The applied research methodology was the same as the methodology of the our research described in the previous publication (Sydor and Pohl, 2019).

RESULTS AND ANALYSIS

The results of the tests are the M–Θ characteristics for every tested joint sample. As mentioned earlier, 18 series of joints were tested with three samples in each series. One exemplary characteristic for one series is shown in Figure 5 (the measured bending moment was converted to one fastener–in other words the calculated bending moment value for the sample was divided by two).

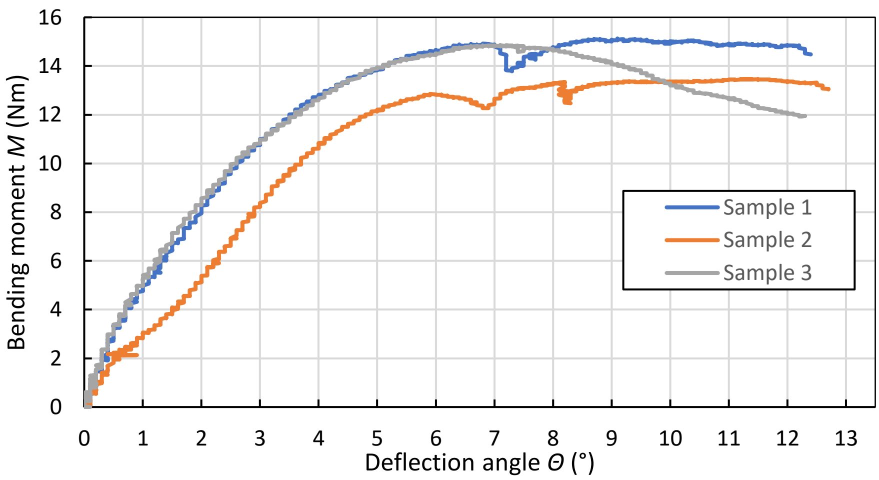

Figure 5. Raw test results for the series of three HPL samples

The experiments results were statistical analysed. The median value was taken as a estimator of the expected value, the upper deviation is the maximum value, and the lower deviation is the minimum value in each series. An exemplary result of the statistical calculations is shown in Figure 6.

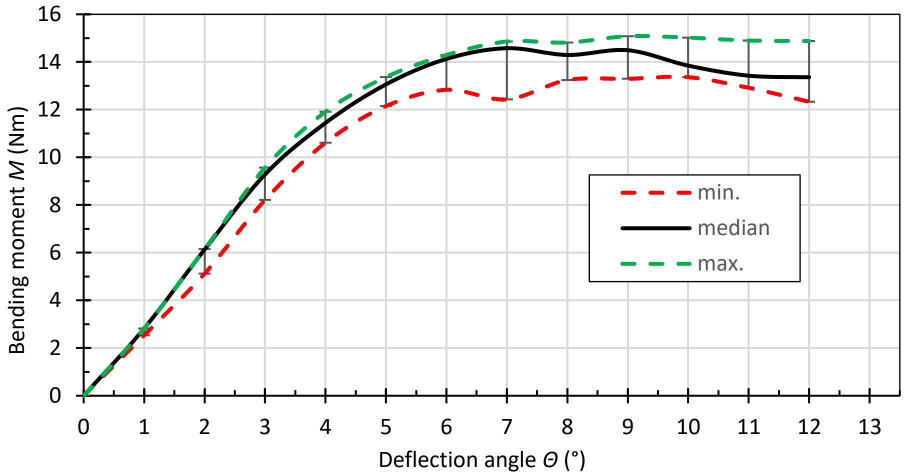

Figure 6. Cumulative test results for a series of three samples (HPL board, Rastex fastener)

The Cumulative test results of all samples are presented in Figures 7-9.

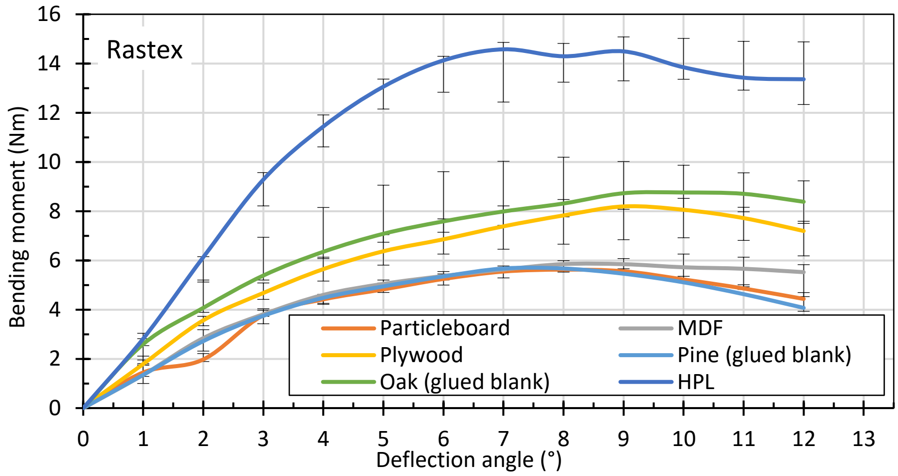

Figure 7. Cumulative test results of samples with Rastex fasteners (median values)

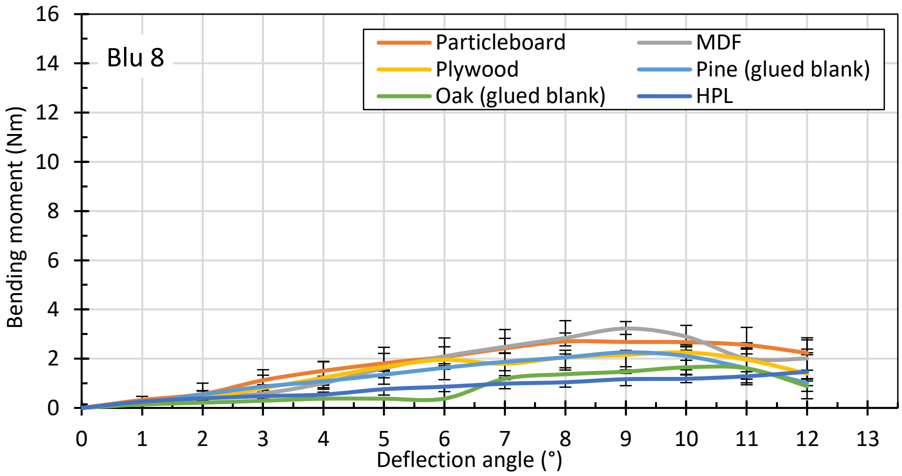

Figure 8. Cumulative test results of samples with Blu 8 fasteners (median values)

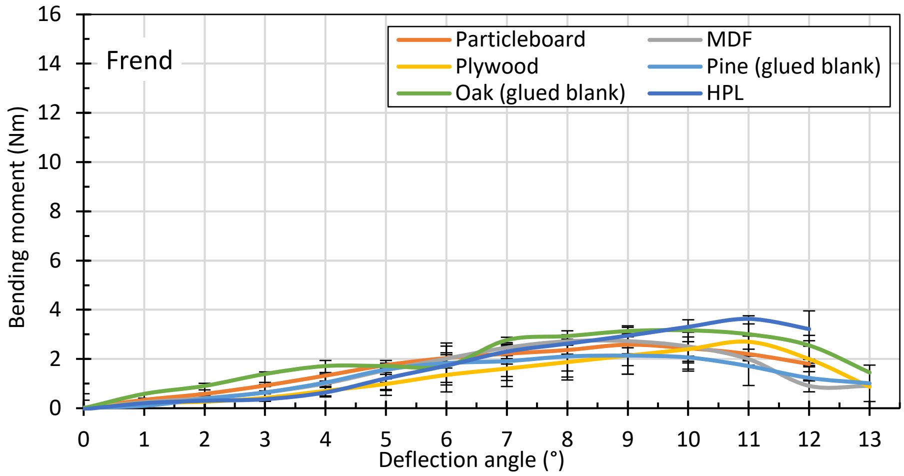

Figure 9. Cumulative test results of samples with Frend fasteners (median values)

Using the characteristics *M–Θ*, the stiffness coefficient *c* was calculated for every fastener. This coefficient was determined for two points of each *M–Θ* characteristic. The measured bending moment for angles 3 and 0° was determined according the formula: $c = \frac{M_{3°}}{\theta_{3°}}$ (in $\frac{\text{Nm}}{°}$); where: M_3 is the value of the bending moment corresponding to a joint rotation of 3° (the 3° of rotation as, a permissible deformation value was based on the literature (e.g. Branowski and Phol, 2004; Sydor, 2005). The obtained results for the tested joints are presented in Table 2.

Table 2. Stiffness coefficient, allowable load and limit load for the tested joint samples (calculated for one fastener)

Material		Stiffness *c*		Median bending moment at 3° deflection angle (M_3, Nm)	Bending moment (*M* in Nm)		
		Value (Nm/°)	Reference to HPL samples (%)		min.	median	max.
Rastex 15 + twister DU 320, Hettich	Particleboard	1.27	41%	3.81	5.68	5.85	6.26
	MDF	1.26	41%	3.77	5.53	5.63	5.81
	Plywood	1.56	50%	4.68	6.92	8.19	8.73
	Pine	1.25	40%	3.75	4.64	5.67	5.90
	Oak	1.80	58%	5.39	8.08	8.76	10.20
	HPL	3.09	100%	9.28	13.36	14.58	15.08
Blu 8, Car	Particleboard	0.38	235%	1.13	2.68	2.70	3.04
	MDF	0.20	123%	0.59	2.73	3.23	3.55
	Plywood	0.27	167%	0.80	1.67	2.26	2.44
	Pine	0.29	181%	0.87	1.54	2.26	2.76
	Oak	0.10	61%	0.29	1.40	1.65	2.20
	HPL	0.16	100%	0.48	1.19	1.47	1.53
Frend, Digitouch	Particleboard	0.31	252%	0.92	2.58	2.58	3.03
	MDF	0.21	175%	0.64	2.56	2.73	2.98
	Plywood	0.14	115%	0.42	1.93	2.70	3.13
	Pine	0.21	175%	0.64	1.71	2.14	2.21
	Oak	0.46	380%	1.39	3.09	3.16	3.43
	HPL	0.12	100%	0.37	2.52	3.63	3.95

As can be seen in Table 2, the stiffest joint sample is HPL with Rastex fasteners, and the least stiff is the oak glued blank with Blu 8 fasteners. The stiffness coefficients *c* for all material-fastener combinations are summarized in Figure 10.

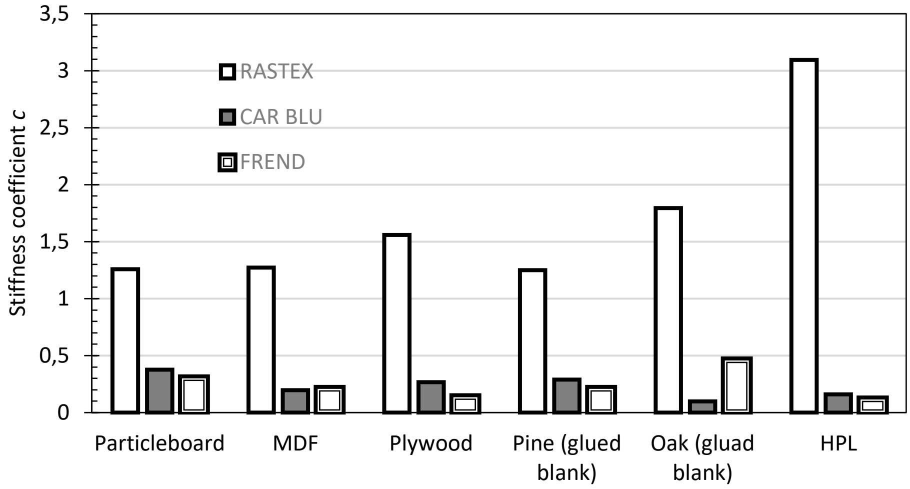

Figure 10. Stiffness coefficient *c*

Based on the calculated stiffness, it can be concluded that for a thread-shape anchoring fasteners (Rastex), the stiffness is directly proportional to the strength of the material (samples of joints made of stronger materials are stiffer – as in the publication from 2007 presenting the results of tests carried out with the same materials, but made for 18 mm thick boards and with other fasteners (Branowski et al., 2007)). There is no such relationship for expansion fasteners. The stiffnesses of the connection samples do not vary.

The distribution of contact pressure in a joint of boards depends on the thickness of the boards, the thinner the board, the less favorable this distribution (Mostowski and Sydor, 2005). The obtained test results were compared with the results of analogous tests carried out for 18 mm thick panels (Sydor and Pohl, 2019). The results of this comparison are summarized in Table 3.

Table 3. Comparison of strength parameters for 12 mm and 18 mm boards joined with Rastex fasteners

Material	Stiffness *c* (Nm/°)		Ratio c_{18}/c_{12}	$M_{3°}$ in Nm (median bending moment at the deflection angle 3° (0.0524 rad))	
	c_{12} board 12 mm (own study)	c_{18} board 18 mm (source: [9])		board 12 mm (own study)	board 18 mm (source: [9])
Particleboard	1.27	2.05	1.61	3.81	6.15
MDF	1.26	2.44	1.94	3.77	7.32
Plywood	1.56	3.50	2.24	4.68	10.50
Pine	1.25	2.78	2.22	3.75	8.34
Oak	1.80	4.84	2.69	5.39	14.53
HPL	3.09	n.d.	–	9.28	n.d.

According to Euler–Bernoulli bending theory, for three-point bending the deflection of the 12 mm board will be 2.25 times bigger than the deflection of the 18 mm board. In the case of the tested joint samples, this proportion occurs for medium-hard and hard lignocellulosic materials. The joint samples made of soft board materials, such as particleboard, have only 1.61 times less strength. The results of our research suggest that in the case of particleboard the key is the force anchoring the fastener in the hole, not the strength of the board.

CONCLUSIONS

The findings of this study have several implications for furniture design:

1. Expansion fasteners offer exceptionally lowjoint rigidity. This was observed for all tested furniture materials, from soft (chipboard) to very hard (HPL). On the one hand, the more durable the board material - the more durable the joint, and on the other hand, the expansion connectors fit better in soft materials and a bit worse in hard materials. These two opposing phenomena cause that the stiffness of connections of lignocellulosic materials with different strength, connected with expansion fasteners, are similar to each other.
2. Expansion connectors work well in soft materials only. This explains the low stiffness of joints made with expansion fasteners, obtained for HPL boards (which are the most durable of the tested materials). The main advantage of expansion fasteners is the low visibility in the joint and the technological ease of assembly..

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Streszczenie: *Analiza porównawcza wytrzymałości połączeń meblowych wykonanych z różnych materiałów*. Zbadano wpływ obciążenia na odkształcenie kątowe próbek połączeń wykonanych z różnych materiałów stosowanych w meblarstwie: płyty wiórowej, MDF, sklejki liściastej, drewna sosnowego klejonego, drewna dębowego klejonego oraz HPL. W badaniach wykorzystano trzy rodzaje łączników: gwintowo-kształtowy (mimośrodowy), rozprężno-rozprężny i gwintowo-rozprężny. Próbki połączeń zostały obciążone wyłącznie momentem zginającym (bez wywoływania sił ścinających). Zmierzono nośność maksymalną oraz nośność przy odkształceniu 3° (0,052 rad), a następnie obliczono współczynniki sztywności połączeń. Stwierdzono znaczne różnice w wytrzymałości między HPL a innymi materiałami lignocelulozowymi. Łączniki rozprężne zapewniają bardzo małą sztywność połączenia. Zaobserwowano to dla wszystkich badanych materiałów meblowych, od miękkich (płyta wiórowa) po bardzo twarde (HPL). Łączniki tego typu lepiej sprawdzają się w miękkich materiałach lignocelulozowych niż w materiałach twardych. Główną zaletą łączników rozporowych, w porównaniu do łączników gwintowo-kształtowych, jest ich mała widoczność w połączeniu oraz technologiczna łatwość montażu. Z drugiej strony łączniki gwintowo-kształtowe oferują znacznie większą wytrzymałość i sztywność połączeń.

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