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Load-bearing capacity and characteristic forms of destruction of furniture joints made with rastex 15 and P-10 clamex fasteners

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Abstract: *Load-bearing capacity and characteristic forms of destruction of furniture joints made with rastex 15 and P-10 clamex fasteners*. The study tested the relationship between the load and angular deflection in furniture joints. The tests were carried out for two types of fasteners and five types of materials: chipboard, MDF, hardwood plywood, glued pine boards and glued oak boards. The furniture joint samples contained two fasteners preloaded only with a bending moment (without application of shear forces). The results were converted per single fastener specifying: its maximal load capacity, 50 mrad (2.9°) limit deflection and rigidity coefficient. It was found that rigidity is a better structural property of the tested joint types than their load capacity. As far as rigidity is concerned, the most durable is the combination of oak glued board – rastex 15 fastener (13.2 Nm bending moment per fastener), while the least durable combination is chipboard – clamex P-10 fastener (4.8 Nm bending moment per fastener). Photographic documentation of damaged furniture joint samples was prepared and analysed. In case of chipboard and MDF combinations (where the load is determined by the combined material), the combined boards suffer a disastrous damage, while in combinations of plywood boards and pine or oak glued boards, (where the capacity is determined by the fastener), both clamex P10 and rastex 15 fasteners are damaged.

Keywords: furniture, joint, fastener

INTRODUCTION

Case furniture is made of various types of wood composites. Typically, these are chipboards and fibreboards, plywood, glued wood and other materials also used. Furniture fasteners are commonly used for connections of furniture elements, universal, typical products made in large series of metal alloys and plastics by specialized companies (Podskarbi, Smardzewski, Moliński, & Molińska-Glura, 2016). An important structural feature of all furniture joints is their ability to carry the load. Connections of this type are semi-rigid, i.e. when loaded with forces, they undergo a slight deformation, which disappears after the load release (Branowski & Pohl, 2004). For example, the relationship between the bending moment *M* (load) and the internal coupling rotation angle of the connection sample Θ (deformation) is shown in Figure 1.

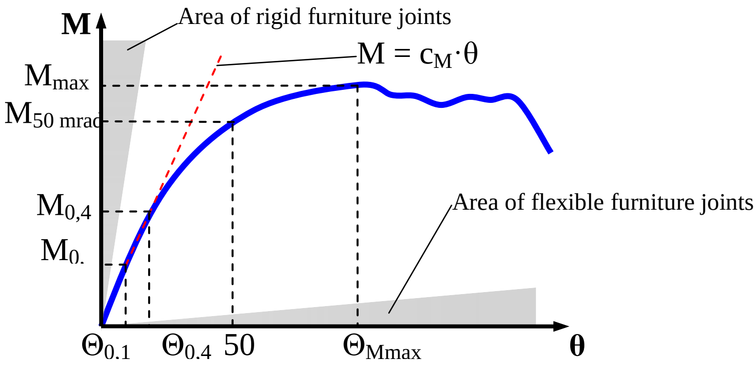


Figure 1. Adopted *M* – Θ relationship for semi-rigid joint (prepared basing on: (Sydor, 2005)) Notations: *M* – bending moment (load), *Θ* – rotation angle (deformation) of connected elements, M_{max} – maximum bending moment corresponding to the joint load carrying capacity of the joint, $M_{50\ mrad}$ – bending moment corresponding to an acceptable deflection value of 50 mrad (about 2.9°), c_M – coefficient of connection rigidity, determined on the basis of deflections for 10% and 40% of the maximum bending moment ($M_{0.1}$ and $M_{0.4}$ and $Θ_{0.1}$ and $Θ_{0.4}$).

The most important values for the *M* – *Θ* dependency shown in Figure 1 are: the maximum bending moment (M_{max}), the bending moment corresponding to the angular deformation of the connected boards of 50 mrad ($M_{50\ mrad}$) and the rigidity coefficient (c_M). M_{max} – corresponds to the maximum capacity, $M_{50\ mrad}$ – useful capacity, c_M – describes the rigidity of the connection. Based on the literature, it is assumed that the permissible angular displacement of joined board elements is 50 mrad, i.e. approx. 2.9° (Joščák, 2000), and the load causing such deformation is a carrying load.

Wood composites are difficult for theoretical modelling. For this reason, the construction features of connections are usually determined experimentally. The purpose of this study was to determine the load-bearing capacity and the rigidity of furniture joints, in five commonly used wood materials and two popular couplings used. An additional goal was to present a catastrophic destruction of such connections, to indicate their weak points.

MATERIALS AND METHODS

Boards intended for the construction of samples were cut into pieces, and then their humidity was stabilized at 12 ±2%, next, they were seasoned in the workshop for 2 months. Before the assembly of samples, their density was measured to obtain the following results:

- chipboard of 637 kg/m^3 density,
- MDF of 745 kg/m^3 density,
- hardwood plywood of 727 kg/m^3 density,
- glued pine wood board of 521 kg/m^3 density,
- glued oak wood board of 698 kg/m^3 density.

The connection types selected for the assembly of the two samples differed significantly from each other, however they played the same roles in the connections, namely being the couplings for Ready to Assemble (RTA) case furniture:

- cam clamex P-10 coupling (hereinafter referred to as "clamex") (Fig. 2a).
- an eccentric coupling was made of the rastex eccentric 15 and a twister DU 320 coupling (hereinafter referred to as "rastex") (Fig. 2b).

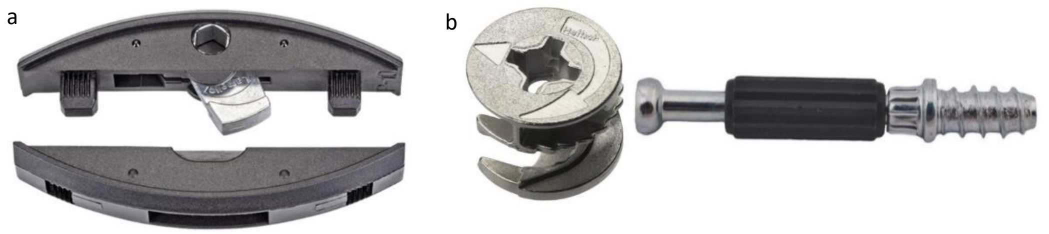


Figure2. Furniture fasteners used in experiment: a – clamex P-10, b – rastex 15+twister DU 320.

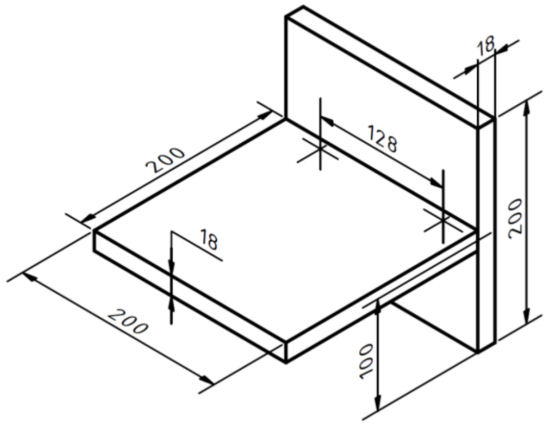


Figure 3. The structure of tested samples.

A total of 100 connection samples were made. Each sample contained two 128 mm fasteners apart from each other. The sizes and main dimensions of a single sample are shown in Figure 3. The samples were so loaded that the fasteners used were loaded only with a bending moment ($M = F\ d$, Fig. 4). This was to facilitate the interpretation of the obtained results, especially in the subsequent analyses of the damage mechanisms, in individually designed variants of the samples.

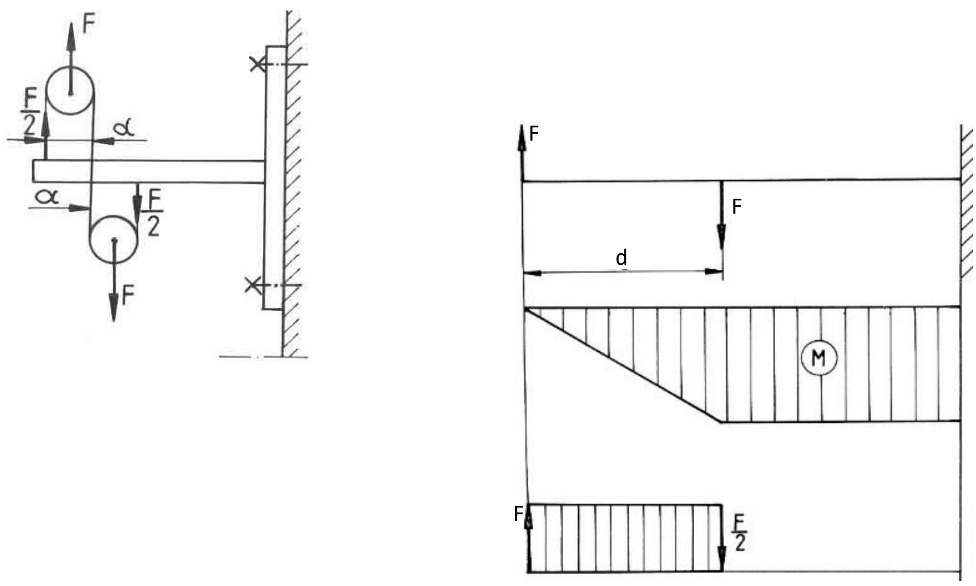


Figure 4. The method of loading the connection, with diagrams of bending moments and shear forces in the tested sample.

The tests were carried out with use of a special strength machine (Fig. 5) allowing the load to be applied only with a bending moment (without shear forces).

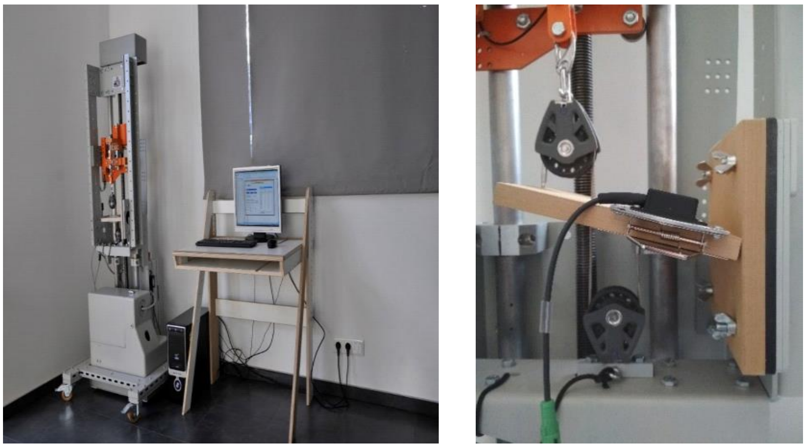


Figure5. The testing machine used for testing, with connection sample during the tests.

The speed of the force *F* load was 1.6 mm/s, the force was measured using a force meter with a measuring range of up to 5,000 N and ± 25 N accuracy. The force for all samples was exerted only in one direction (up). The measured force was converted to the bending moment *M*. The angular deflection was recorded using an inclinometer with an accuracy of 1.7 mrad (0.1°). The testing was carried out until an angle of 230 mrad (13.2°) was reached. The results of the testing are presented in from of $M – \Theta$ relations for all 100 samples. After the tests, the connection samples were dismantled and photographed to document the nature of damage.

The plan of performed tests is presented in the table 1.

Table 1. Test plan for connection samples.

Item	Fastener type	Type of board material	Number of repetitions
1	"Clamex" cam fastener	MDF	10
2		Particleboard	10
3		Hardwoodplywood	10
4		Oak LVL	10
5		Pine LVL	10
6	"Rastex" eccentric fastener	MDF	10
7		Particleboard	10
8		Hardwoodplywood	10
9		Oak LVL	10
10		Pine LVL	10

RESULTS AND ANALYSIS

By creating the $M – \Theta$ graphs, the bending moment values were calculated per single fastener (the bending moment value was divided by 2, as each sample contained two fasteners). The research of each structure variant resulted in 10 aggregate characteristics, one of which is shown in Figure 6.

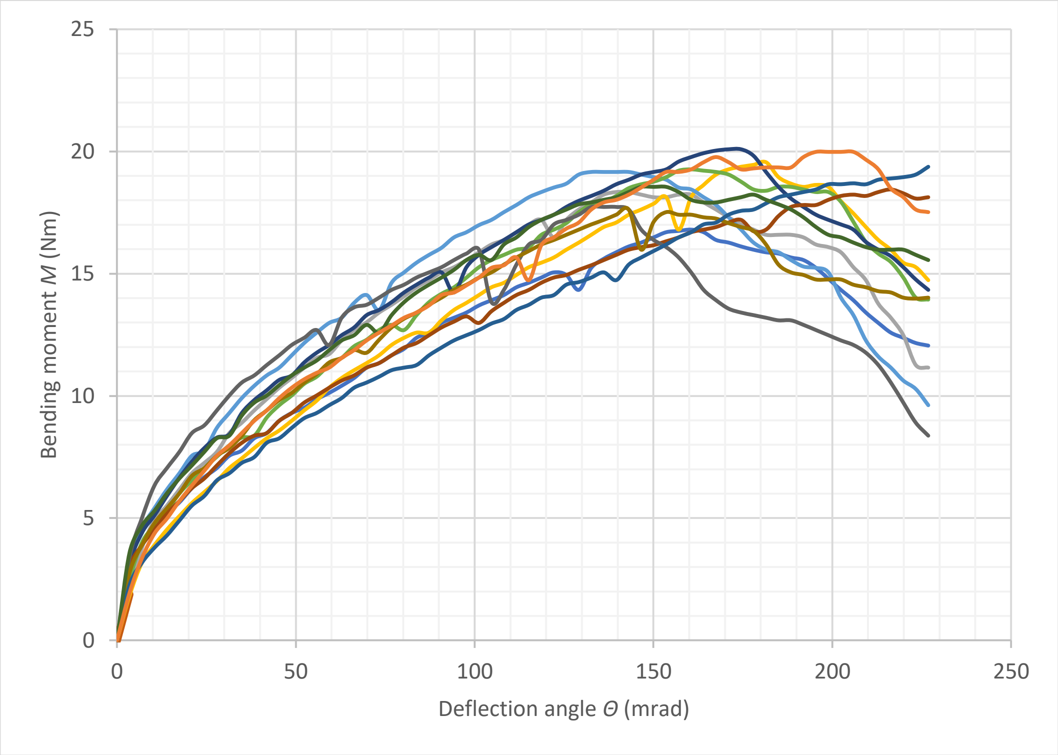


Figure 6. Example results of measurements for 10 samples of each variant of oak glued boards with clamex fasteners.

The obtained results had been statistically analysed to determine the expected value and deviations for each measurement point. The estimator of the expected value was the median, the deviations were defined as ±1.5 · σ (σ – standard deviation). The example of statistical calculations is shown in Figure 7. It shows 10 repetition average line of the angle changes depending on the load bending moment, including error columns. The maximum value of the bending moment and the trend line used to determine the rigidity coefficient c_M of connection, are also visible.

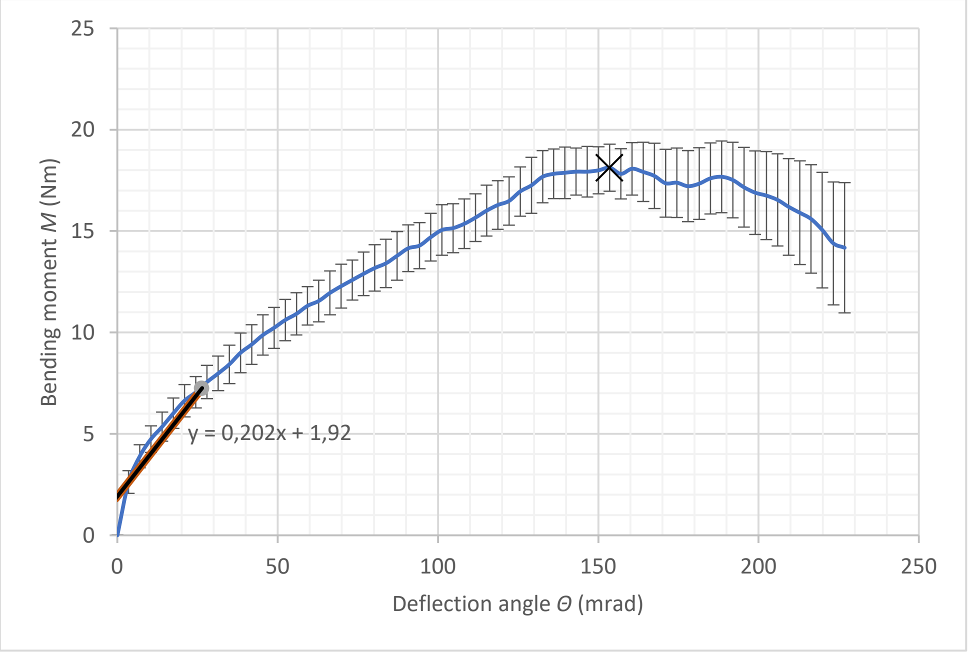


Figure 7. Example results of measurements for 10 connection samples made of oak glued boards with clamex fasteners after statistical analysis.

The results of all measurements are presented in two subsequent graphs. Fig. 8a shows the results for 50 samples of connections with clamex fastenerss, and Fig. 8b – 50 samples with rastex fasteners. Each line in the graph shows the average values for 10 samples tested. For better readability of the presented results, the error columns are not shown.

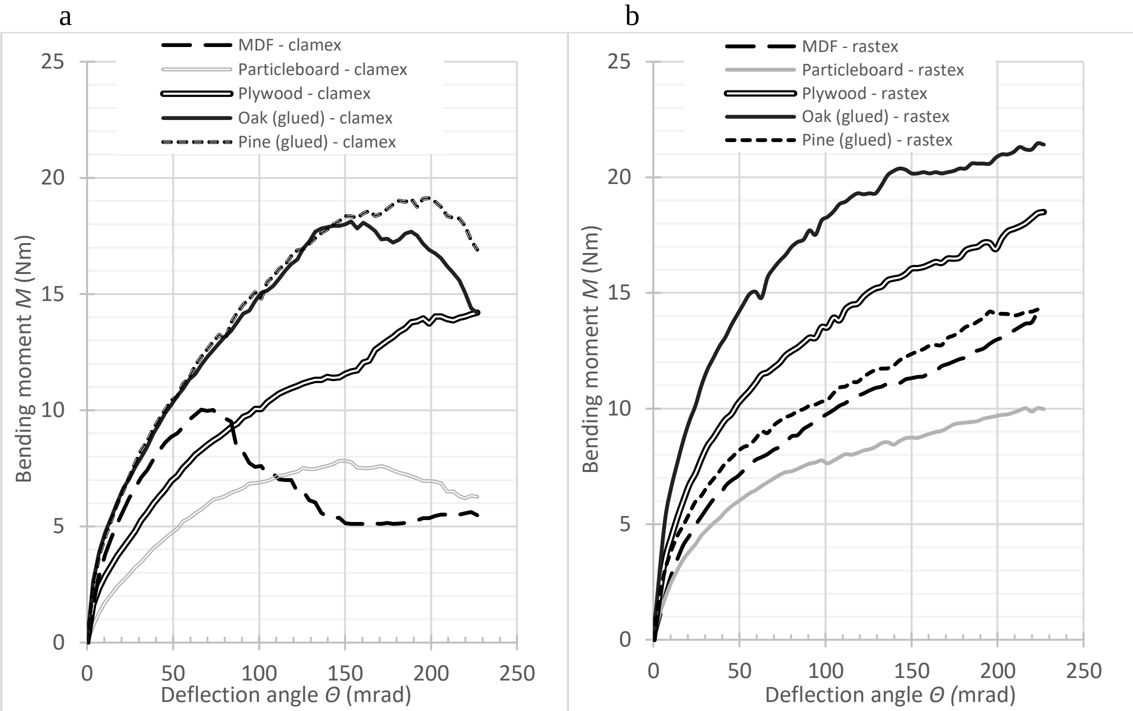


Figure 8. Collective graphs of M (Θ) dependence in angular connections of the boards in samples: a – boards with clamex fasteners, b – boards with rastex fasteners.

As it is seen in Figure 8a, in the case of the clamex fasteners, the most durable connections are those made of pine and glued oak board (destruction only after 18 and 19 Nm load). The smallest maximum load capacity was registered for chipboard samples (destruction at 7.8 Nm). In case of four out of five material variants tested, in the examined angular range (230 mrad), a clear exhaustion of the load (curve bending and the maximum load capacity clearly shown in the graph) were observed. Only samples made of plywood showed no serious reduction in the load capacity of the studied ranges. For all Figure 8a presented cases, the rigidity (extensive deformation), instead capacity shown in bending moment units, is the designed limitation. All samples shown in Figure 8a represent the situation where the maximal measured capacity is obtained beyond the acceptable 50 mrad (2.9°) limit of deformation.

In the case of the rastex fastener (Fig. 8b), the highest limit load capacity in the tested range was obtained for the samples made of glued oak board (almost 21.5 Nm), and the smallest – for chipboard samples (about 10 Nm). In none of the examined cases, a clear exhaustion of the connection capacity was observed (each time, the bending moment increased up to the end of the examined range of 230 mrad). Similar to the previously described samples with clamex fasteners, the rastex fasteners show the maximum measured load capacity after exceeding the adopted limit of acceptable deformation (50 mrad) and occurs towards the end of the measurement range (230 mrad).

Basing on the determined $M – \Theta$ dependencies, the rigidity factor for each connection was determined. This coefficient was determined in two points of each M - Θ characteristics corresponding with 0.1 and 0.4 values of the limit load capacity of the joint (in this case the maximum bending moment) along the following formula (Joščák, 2000; Branowski & Pohl, 2004):

$$c_M = \frac{dM}{d\theta} \approx \frac{M_{0,4} - M_{0,1}}{\theta_{0,2} - \theta_{0,1}}$$

where: $M_{0.1}$ and $M_{0.4}$ represent 0.1 and 0.4 of total load capacity, $\Theta_{0.1}$ and $\Theta_{0.4}$ represent the angular deflection in $M_{0.1}$ and $M_{0.4}$ panels. Table 2 show the results of calculated rigidity of the tested joints.

Table 2. Rigidity coefficients, limit load capacities and carrying load capacities of the tested joint samples.

Material kind and fastener kind combination		The c_M rigidity coefficient within M_{max} 0.1 to 0.4 range		The maximum bending moment (M_{max})		Bending moment for 50 mrad ($M_{50\ mrad}$) bending angle	
		(Nm/mrad) value	Reference to the most rigid series of the samples	(Nm) value	Standard deviation	(Nm) value	Reference to the most endurable sample series
Clamex	MDF	0.270	65%	10.03	0.98	8.90	63%
	Particleboard	0.092	22%	7.82	1.38	4.77	34%
	Plywood	0.124	30%	14.20	2.14	7.03	49%
	Oak (glued)	0.202	49%	18.13	1.16	10.36	73%
	Pine (glued)	0.219	53%	19.13	1.85	10.56	74%
Rastex	MDF	0.147	36%	14.39	0.61	7.14	50%
	Particleboard	0.146	35%	10.02	1.22	6.023	42%
	Plywood –	0.241	58%	18.50	2.29	10.29	72%
	Oak (glued)	0.414	100%	21.47	2.37	14.22	100%
	Pine (glued)	0.196	47%	14.34	1.96	8.22	58%

As can be seen from table 2, the most rigid sample of the combinations is a combination of oak glued boards – rastex fasteners, and the least rigid combination is the chipboards – clamex fasteners. Rigidity coefficients are shown in Fig. 9.

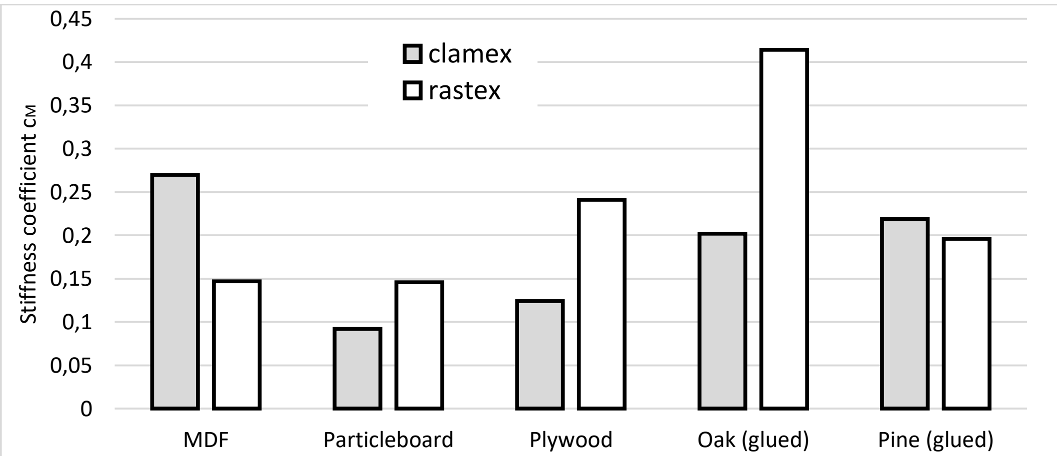
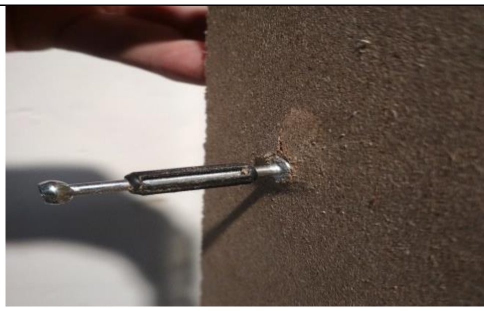
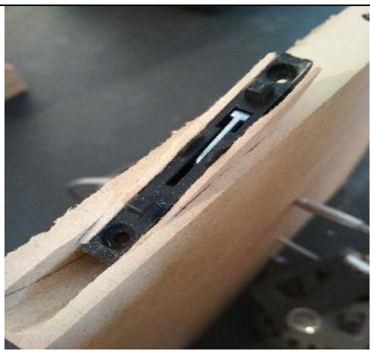
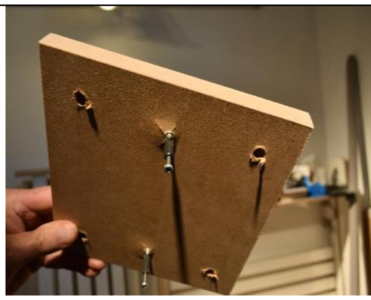


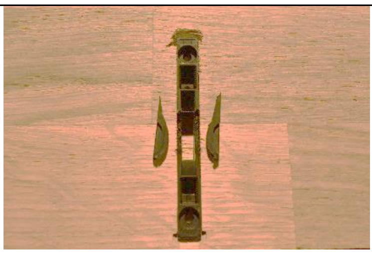
Figure9. c_M rigidity coefficients.

Based on the calculated rigidity coefficients, it can be concluded that the chipboard connection samples are in each case less rigid and less resistant than samples made of MDF boards. Similar to the publication of 2007 showing the results of tests performed for the same materials with other fasteners (Branowski et al. 2007).

Table 3 shows the typical destructions of tested samples after reaching the angular deflection limit of (230 mrad).

Table 3. Typical destructions of tested samples after (230 mrad) angular deflection limit.

Combined materials	Fastener type	
	Clamex	Rastex
Chipboard	 Cutting and breaking the board where it is glued in the narrow plane	 Partial spindle pull-out  Board separation resulting from the eccentric mandrel force
MDF	 coupling out due to chipping of the layer	 Spindle out due to the delamination of the board
Hardwood plywood	 Destruction (cracking) of the plastic latch that works with the metal eccentric latch	 Bent-up to the breaking of the eccentric latch, spindle bending

Pine wood panel	 Destruction (cracking) of the plastic latch that works with the metal eccentric latch	 Bent-up to the breaking of the eccentric latch, spindle bending
Oak wood panel	 Destruction (cracking) of the plastic latch that works with the metal eccentric latch	 Breaking off the eccentric connection, spindle bending, cracking of the plastic spindle guide

Analysed destructions shown in Table 3, imply the following observations:

- Connections of chipboard. The combined panels are always damaged irrespective of the type of fastener. The fasteners were pulled out of the narrow board surface (out of the board side). This is because these fasteners are mounted in the weakest, central part of the board. The destruction occurred at the border, in the central and outer, more durable parts of the board. The outer edge of the board also broke off. In case of couplings, what is characteristic is drop-out of the threaded rod placed in the wide surface of the board and breakage caused by the rod placed in the narrow surface of the board. Analogous results were obtained in this respect comparing to the 2005 publication (Branowski, Wieloch, & Pohl, 2005).
- MDF connections. Regardless of the type of fastener, the connected boards are always damaged. The destruction of the connection with the clamex fasteners happens when the board in the narrow surface (parallel to the panel plane) from the T-grove to the panel's narrow plane, is cut-off. The destruction of the connection between the rastex connector occurs by pull-out the threaded spindle and delamination of the board.
- Hardwood plywood connections. Regardless of the type of fastener, fasteners are always damaged. The destruction of the connection with the clamex fasteners occurs as a result of the breakage in the plastic hitch of the fixed part cooperating with the metal eccentric hook fixed in the wide surface of the panel. The destruction of the connection with the rastex coupling occurs due to the bending until breaking of the metal eccentric latch and bending of the spindle.
- Glued pine boards connections. Regardless of the type of fasteners, fasteners are always damaged. The form of destruction in connection with the clamex fastener is the same as in case of plywood panels. The destruction of the rastex fastener is the same as in case of plywood panels.

Oak glued boads connections. Regardless of the type of fastener, fasteners are always damaged. Clamex connection damage is the same, as in case of plywood panels. Rastex connection damage is very similar to plywood panels connections. What happens is bending and breaking of the eccentric latch, the spindle is bent, and sometimes even the plastic spindle guide is also cracked.

CONCLUSIONS

On the basis of the results obtained, the following conclusions and observations can be made:

- The basic design criterion for all tested combinations of connectors and lignocellulose panels, is the criterion of the acceptable distortion. This indicates that the rigidity of connections is a better measure of their performance than the load capacity.
- In respect of the acceptable deformation (rigidity criterion), the most durable combination is an oak glued board – rastex fastener combination (13.2 Nm per fastener), while the least durable combination is chipboard – clamex fastener combination (4.8 Nm per fastener). The clamex fasteners evidently weakens the cross-section of the chipboard, and this, combined with the chipboard cracking tendency, makes the coupling (embedded in the chipboard) to show only 34% strength comparing with the rastex fasteners in the oak glued boards.
- An interesting phenomenon was observed in the case of MDF – clamex combination. The limiting load capacity of MDF samples was observed at a deflection of barely 75 mrad, while in the case of the other four materials, it happened only around 150 mrad deflection (Fig. 8a). The most probable explanation of the above is the MDF delamination tendency, where the relatively large size of the coupling contributed to weakening of the panel cross-section.
- In chipboard and MDF, catastrophically damaged are the combined panels and their joints, while both clamex and rastex fasteners are not damaged.
- In the combination of plywood boards, as well as glued pine and beech wood, catastrophically damaged are fasteners, both clamex and rastex, while the glued panels are not damaged.

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AUTHOR'S PARTICIPATION

Maciej Sydor – identification and elaboration of the scientific approach, analysis of the scientific literature, experiment planning, photographic documentation, elaboration and presentation of the testing results, participation in the proposals, final version manuscript editing, correspondence.
Piotr Pohl – test performance, drafting the initial version of manuscript, participation in the proposals.

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Streszczenie: *Nośności i charakterystyczne obrazy zniszczenia połączeń meblowych z łącznikami rastex 15 i clamex P10*. Badano zależności pomiędzy obciążeniem, a odkształceniem kątowym połączeń meblowych. Badania przeprowadzono dla dwóch rodzajów łączników (krzywkowym i mimośrodowym) oraz pięciu rodzajach płyt: płytach wiórowych, MDF, sklejki liściastej, a także na płytach z litego drewna (tzw. klejonki) sosny i dębu. Połączenia obciążano wyłącznie momentem, bez sił tnących. Określano maksymalną nośność połączenia, nośność przy odkształceniu granicznym 50 mrad oraz sztywność połączenia. Sporządzono dokumentację fotograficzną zniszczonych połączeń i przeprowadzono jej analizę. Stwierdzono, że podstawowym kryterium projektowym w przypadku wszystkich badanych kombinacji łączników i płyt lignocelulozowych jest kryterium dopuszczalnej deformacji. Wskazuje to, że sztywność jest lepszą miarą właściwości konstrukcyjnych połączenia niż jego nośność. W połączeniach płyt wiórowych i MDF katastroficznemu zniszczeniu ulegają łączone płyty, natomiast w połączeniach płyt sklejki, oraz litych płyt sosnowych i dębowych katastroficznemu zniszczeniu ulegają łączniki zarówno clamex jak i rastex.

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