Investigation of Miter Corner Joint Strength of Case Furniture from Particleboard

Valdas NORVYDAS [*], Antanas BALTRUŠAITIS, Inga JUODEIKIENĖ

Department of Wood Technology, Faculty of Design and Thechnologies, Kaunas University of Technology, Studentų St. 56, LT-514241 Kaunas, Lithuania

crossref http://dx.doi.org/10.5755/j01.ms.18.4.3095

Received 14 May 2011; accepted 21 March 2012

Most pieces of case furniture (kitchen and bathroom furniture, cabinets, wardrobes, tables and etc.) are made of 18 mm thick wood particle boards finished with various coatings. This three-layered constructional material is obtained by bonding wood particles of different fractions with synthetic resins using heating. The exploitation duration and quality of case furniture is determined by the mechanical properties of wood particle boards and the construction of joints of wood-based panels. On a frequent basis, pieces of case furniture with non-dismantable and dismantable construction are joined by using multidowel glued joints and cam connecting fittings intended for furniture, respectively. Wood-based panels can be joined with mitre joints whose mechanical properties have not undergone testing and comparison with regular joints when applying insertable wooden dowels or furniture connecting fittings. During the testing of particle board properties it was established that joining wood-based panels in this way ensures most efficient use of mechanical characteristics of the particleboard. In addition to the properties of the mitre joint, the tests also allowed determining the bending strength, tensile strength and bonding strength of the constructional material, and providing an original method for testing board properties, which can be successfully applied to the prediction of properties of the mitre joint. Tests were performed by using a universal tensile testing machine P-0.5. Joints were bonded by applying PVA dispersion. The surface of boards was veneered by using mahogany veneer and urea formaldehyde resin. It was found that mitre joints of wood particle boards can withstand loads that are higher from 2 to 4 times, in comparison to glued doweled joints or joints constructed with cam connecting fittings.

Keywords: particleboard, PVA dispersion, veneering, mitre joint, cam connecting fittings, dowel, bonding of wood based panels, bending strength.

INTRODUCTION

Most parts of case furniture are panel elements basically made of particleboard. The properties of this material are regulated and described by the standard LST EN 312: 2004 “Particle panels. Technical requirements” [1]. However, having covered particleboard by different synthetic coatings (enamels, foils, laminates) or natural wood veneers its main mechanical properties (modulus of elasticity E and bending strength f_m) essentially improve as compared to the untreated particleboard [2].

A panel is manufactured from wood particles or combinations of wood particles and fibers, bonded together with synthetic resins under heat and pressure. Particleboard is more dimensionally stable and machineable than many other cellulosic substrates and offers a smooth surface that bonds readily with nearly all laminating adhesives. While particleboard is available in many different grades and densities, industrial grades are typically specified for laminating applications. Particleboard is available up to 50 mm thick and nearly any panel size transportable.

Particleboard is a three-layered board, with fine particles on the top and bottom surfaces, and larger wood flakes in the middle. The wood particles are pressed and bonded together with resin creating a tight compact panel that can be machined cleanly.

Typically, particleboard consists of a lower density core of coarse particles and outer, higher density layers of finer particles. This distribution of density and particle size is important with respect to the board performance. Many applications involve bending loads, where a high-density upper layer and a low-density core are advantageous. The particleboard panel functions as a sandwich structure and the ratio of bending stiffness to weight becomes high. Particleboard is mainly used for furniture, for paneling and cladding [3]. According to Maloney, the Modulus of Elasticity and Modulus of Rupture (MOE and MOR) are strongly influenced by the particleboard’s compaction rate, particle geometry, percentage of adhesives and density [4].

This study also cantains research of particleboard density distribution between layers in the thickness direction. The vertical density distribution in the mattress also contributes substantially to the board’s final properties [4]. When wood-based panels undergo the veneering process by using wood veneer, the bending strength can additionally increase by 2.2 times [2].

Majority of case furniture from particleboard joints are constructed with cam connecting fittings and glued multidowel joints or tongued and grooved. Constructional elements of these joints are affected by loads of tension perpendicular to the plane. When dealing with wood particle boards, resistance to tension perpendicular to the plane is lower from 30 to 35 times in comparison to bending, as a result of which there is no maximal exploitation of all strength properties of this constructional material.

[*]Corresponding author. Tel.: +370-37-300235; fax.: +370-37-353989.
E-mail address: *valdas.norvydas@ktu.lt* (V. Norvydas)

The majority of tests involved joints on the basis of tenons, tongues and various types of connecting fittings. The strength of the entire product (furniture) construction depends on strength properties of joints. Applying adhesive joints ensures longer exploitation duration and allows holding higher loads in comparison to dismantable joints (connecting fittings) [5, 6].

Scientific literature provides a great deal of data regarding the testing of joints of wood particle boards when joining with cam connecting fittings, TZ type connecting fittings, biscuit joints, tongue and groove joint, screw joints and multidowel joints. In order to be able to compare these data to the results obtained during this test, outcomes were translated into the bending moment.

The testing revealed that when panels are joined at a 45° angle, it is possible achieve maximal strength jointing. The mitre joint of wood-based panel parts is most advantageous in comparison with other joints. Therefore it is possible to avoid loads that occur due to the tension perpendicular to the plane during the exploitation of products. This method of joining enables to obtain an enclosed joint more economic as using cam connecting fittings.

In order to establish to what extent it is possible to strengthen the joint, the mitre joint of wood particle boards was also tested while facing the board with wood veneer.

The aim of this study was investigate strength of miter corner adhesive joints of case furniture constructed of particleboard. Tensile strength of bonded joints and bending strength were also investigated for prediction of miter corner joint strength properties.

MATERIALS AND METHODOLOGY

The wood particle board (WPB) used for all the specimens was manufactured by SC "Girių Bizonas" (Lithuania): it was part of the same batch, had 18 mm in thickness, was three-layered, of planar pressing, uncoated and sanded (Table 1).

Table 1. Properties of particleboard 18 mm of thickness according LST EN 312:2004 and experimental

Value	Modulus of elasticity, MPa	Density, kg/m^3	Resistance to perpendicular tensile stress, [10],MPa	Bending strength, MPa
Relevant characteristics [LST EN 312:2004]	1600	from 570 to 680	0.35	13
WPB	3431	639	0.39	19.71
Veneered WBP	5561	640	0.39	39.91

Part of the specimens were coated with a sliced 0.6 mm thick mahogany veneer. Moisture content of the veneer comprised 6 %, density 512 kg/m³ [7]. UF resin "Prefere 4114" and hardener "Prefere 5219" by "DYNEA" (Finland) were used. The ratio of the resin and the hardener was 5 : 1. The adhesion process was carried out in the press "PL100" according to the following curing method: gluing temperature was 100 °C, working pressure 1 MPa, hot pressing duration 2 min.

The least number of specimens pointed out in the LST EN 326-1:1999 standard [8] is 6 units. To ascertain the dependence of modulus of elasticity and bending strength of panel details on the type of coating, a collection of 8 specimens was accepted. The speciemens were prepared according to the requirements of the LST EN 310:1999 standard [9]: the length of specimen was 410 mm, width – 50 mm. The specimens before testing were conditioned in 20 °C ±2 °C temperature and relative air humidity at 65 % ±5 %.

Miter corner joints constructed of particleboard were bonded with polyvinyl acetate dispersion (PVAc). PVAc dispersion generally is used for natural wood bonding, as well as leather, fabric and paper. It is even used for products such as armoured doors, when steel sheet is pasted with natural wood. One of the requirements for glued materials is to absorb humidity with one of glued surfaces at least [11]. Poly (vinyl acetate) PVAc emulsion plasticised with 10 % of dibutylphthalate (DF 51/10). This type adhesive is used as D2 water resistance class adhesive for gluing wood [12]. Adhesion strength is 800 N/m.

In the most experiments, the samples were tested in tension using an universal tensile machine "P5", using reverse clutches. Loading speed was 5 mm/min, the highest loading was achieved over 60 s ±30 s. Modulus of elasticity in bending is determined (calculated) by using the slope of the linear region of the load-deflection curve (at 10 % and 40 % of the maximal load).

The deflection was measured in the centre of the specimen with 0.1 mm accuracy, and the dependence of this value on corresponding loadings, measured with 1 % value accuracy, was drawn. Standard deviation of strength values comprised from 1.48 to 3.89.

In order to determine density distribution according to thickness, specimens with measurements of (110×41×18) mm were cut out in compliance with the above-mentioned standards.

Density distribution in terms of the WPB thickness was obtained (Fig. 1) through the weighing process, by slicing 9 layers of 1mm thick and weighing the rest part of the specimen with 0.001 gram accuracy.

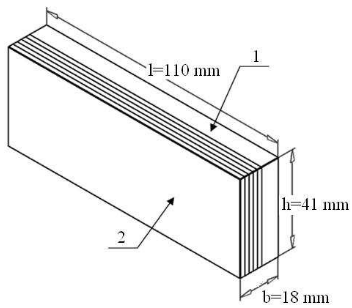
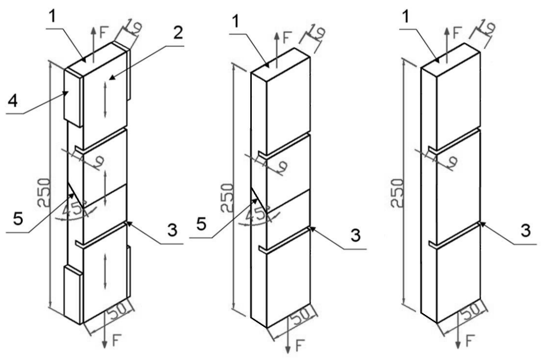


Fig. 1. Slicing scheme for density distribution of particleboard in the thickness direction: *l, h, b* – length 110 mm, height 41 mm ant thickness 18 mm of specimen in mm; 1 – particleboard; 2 – 9 cut off layers

Specimens of three different models were used for testing the bonding and the tensile strength of the wood particle board (Fig. 2).

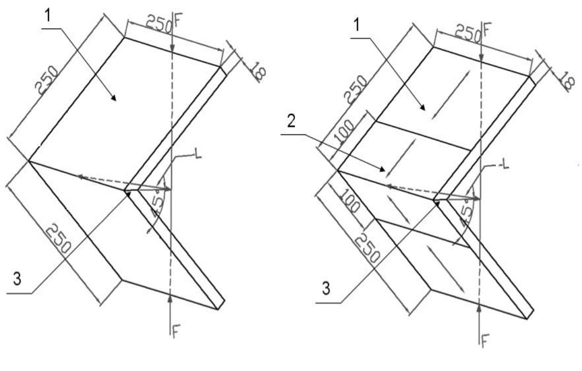
Taking into consideration that only one outer layer of the three layered board tends to function and it contains tensile stresses in specimens, when the construction undergoes bending or the mitre joint is under compression (Fig. 2), cuts with thickness of half the board are introduced. In order to establish the bonding strength, specimens in Figure 2, a, additionally was veneered with wood veneer, since under tension all the specimens in Figure 2, b, shows failure passed not through the adhesive layer but particleboard fibre failure.

The following two models of specimens were used for testing properties of the mitre joint of wood particle boards: non-veneered and veneered. Only the area of the highest tensile stresses, i. e. the joint disintegration zone, undergoes the veneering process. The veneered zone is 100 mm in length and veneering is carried out in the longitudinal direction. After cutting the connecting side at a 45° angle, wood-based panel parts of the joint are bonded by applying PVA adhesive (Fig. 3).



a b c

Fig. 2. Tensile specimen and loading scheme: a – veneered specimen (miter bond), b – uncoated specimen (miter bond), c – uncoated specimen (solid): 1 – particleboard, 2 – wood veneer, 3 – cuts (half of specimen thickness), 4 – plywood, 5 – PVA glue line, *F* – load direction



a b

Fig. 3. Specimen scheme of uncoated (a) and veneered (b) miter joints: 1 – panel (particleboard); 2 – wood veneer; 3 – glue line (PVA); *F* – load direction

It is necessary to emphasize that before cutting out specimens, the direction was set for the manufacture of (2440×1830×18) mm wood particle boards (in the press line) and all the specimens and bonded joints were oriented towards this direction. Prior to being cut out, edges of mitre joints bonded with PVAc adhesive, were oriented in the same board and the same direction close to each other. Gluing temperature was 20 °C, assembling pressure 0.2 MPa, cold pressing duration 120 min.

RESULTS AND DISCUSSIONS

The test of density distribution in terms of board thickness showed the distribution of layer thickness and density of the three-layered wood particle board. Processed results allowed drawing a curve, which shows density distribution in terms of board thickness.

It was determined that the wood-based panel of the WPB has the following ratios of density and layer thickness distribution: 2 : 1 : 2 and 1 : 4 : 1, respectively. The central layer t_2 = 12 mm has the lowest density – 430 kg/m^3, whereas, the density of outer layers t_1 = 3 mm reaches 885 kg/m^3. The average density value of the wood particle board used in this test was 639 kg/m^3. Figure 5 illustrates the structure of the wood particle board crossection and provides the size of fractions of wood particles in relation to the outer (a) and central (b) layers of the particle board. Obtained images illustrate the main difference between the outer and inner layers, namely the size of fractions of wood particles. The outer layer has small particles without any space in between, meanwhile, the central layer consists of large particles with empty space in between.

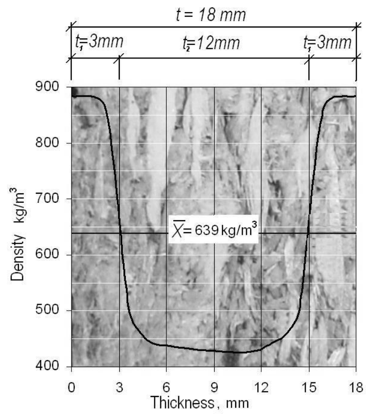
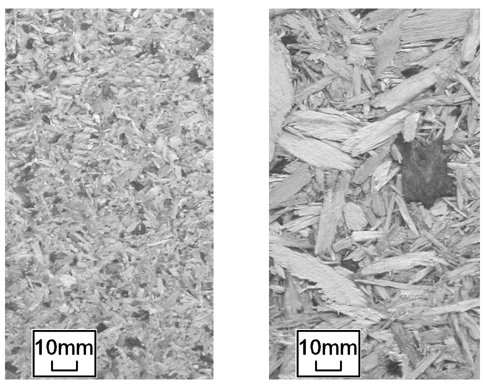


Fig. 4. Density distribution of particleboard in the thickness direction: thickness of particleboard t = 18 mm, thickness od outer layers t_1 = 18 mm; thickness of inner layer t_2 = 12 mm



a b

Fig. 5. Optical views of wood particle in the outer (a) and inner (b) layers of the particleboard

Thus, the heterogeneity of the wood particle board in terms of thickness leads to uneven distribution of internal stresses, when the construction undergoes bending and is exposed to loads in Fig. 6.

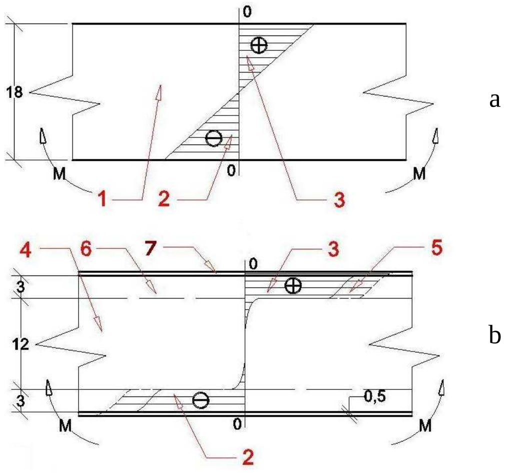


Fig. 6. Bending stress distribution for particleboard (a) and solid material (b): 1 – solid material; 2 – tensile stress, 3 – compression stress; 4 – inner layer of low density, 5 – strengthened due to veneering, 6 – outer layer of high density, 7 – wood veneer

Tension testing of specimens Fig. 2, b, and Fig. 2, c, enabled to determine that the tensile strength of the uncoated wood particle board is 5.29 MPa.

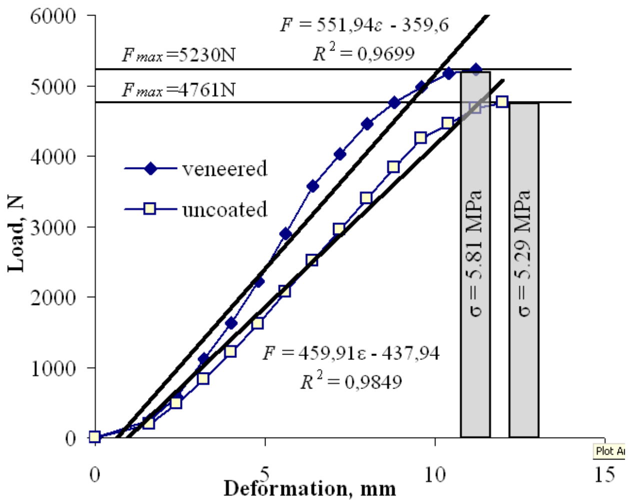


Fig. 7. Effect of veneering on tensile strength of specimen

Tests showed that the bonding strength exceeds the material strength, since none of the tested specimens disintegrated at the bonding area. This can be explained by the fact that within the bonding area PVA adhesive fills up gaps existing inside the board and also bonds wood particles, especially the central layer with lower density. In this way the wood particle board receives additional strengthening at the bonding area and failure occurs in the nearby area (Fig. 8).

After enhancing the board surface through the veneering process by using wood veneer with 0.6 mm in thickness Fig. 2, a, the wood tensile strength reaches even 80 MPa –120 MPa [13], the determined bonding strength of the wood particle board was 5.81 MPa, which exceeds the material strength by even 10 %.

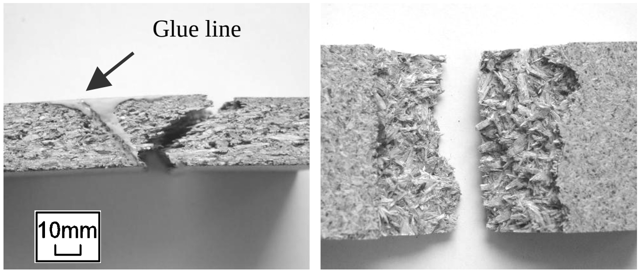


Fig. 8. View of uncoated specimen after tensile tests (edge and face views)

In the case of all the joints that underwent testing, partial disintegration through the adhesive line was observed (Fig. 9).

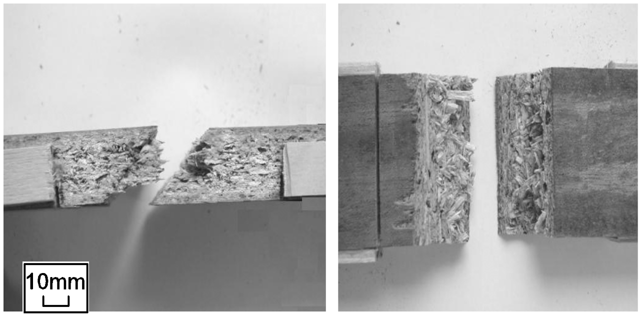


Fig. 9. View of veneered specimen after tensile tests (edge and face views)

Based on the experimental it was obtained effect of veneering (Fig. 10) on the bending strength of miter corner joint.

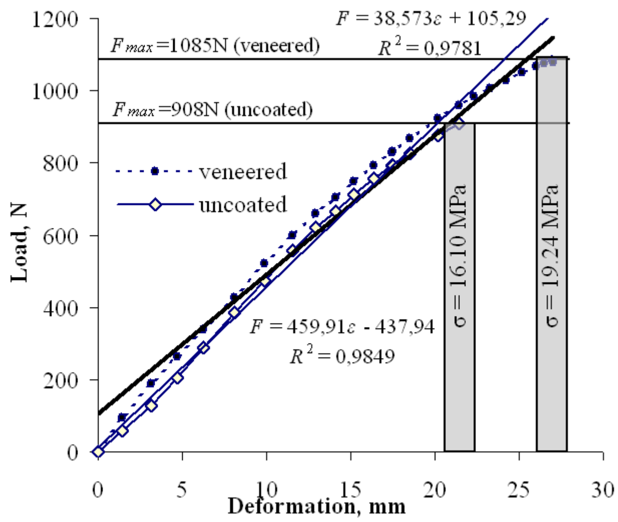
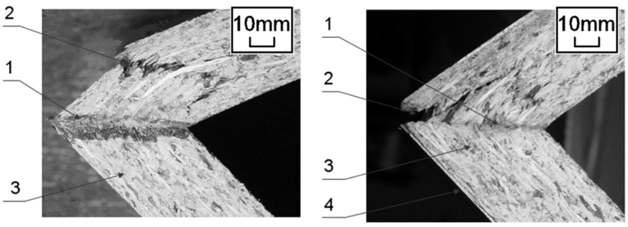


Fig. 10. Effect of veneering on bending strength of miter corner joint

Mitre joints of the uncoated wood particle board withstood the load of 908 N, whereas, the veneered ones endured 1085 N load. When the outer layer of the wood particle board was strengthened due to veneering, the capacity to carry loads of the joint had increased by 19.5 %.

Two different fracture patterns can be observed in the case of non-veneered and veneered mitre joints of wood particle boards (Fig. 11). The non-veneered mitre joints, the same as when the board undergoes tensile testing, does not tend to fracture through the adhesive line (Fig. 11, a); its fracture occurs, when the outer layer of the wood particle board develops a longitudinal crack, after reaching the maximal joint load.

The veneered mitre joint, the same as when the veneered board undergoes tensile testing, tends to partially failure through the adhesive line (Fig. 11, b); its fracture occurs, when the outer edge of the joint/the outer part of the adhesive line appears a crack, after reaching the maximal joint load.



a b

Fig. 11. Failure scheme of uncoadet (a) and veneered (b) mitre joint: 1 – glue line; 2 – fracture crack; 3 – particleboard; 4 – wood veneer

Due to the different stress distribution in the case of joint tension and oblique compression, the veneering of the corner mitre joint increases the joint strength twice: as much as in tensile loading (Fig. 2, a).

Results obtained in connection with the mitre joint testing were compared to data acquired by other researchers (Fig. 12).

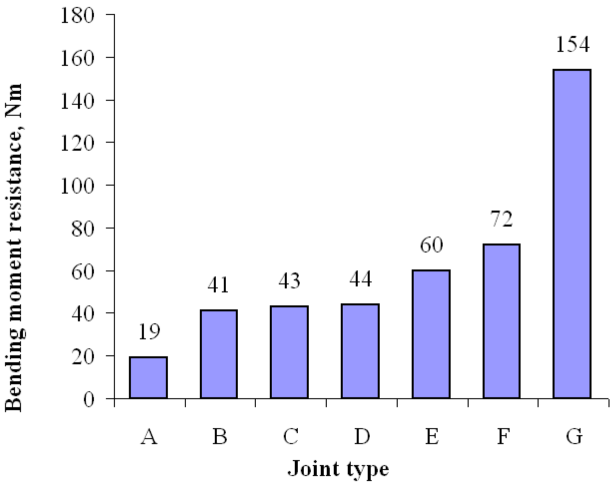


Fig. 12. Joint strength dependence on joint type: A – cam connecting fittings [14]; B – TZ connecting fittings [15]; C – bisquit joint [16, 17]; D – tongue and groove joint [18]; E – screw joint [19 – 21]; F – multidowel joint [22]; G – mitre joint

Based on the test results, it was found that when joining wood particle boards with the mitre joint, it is possible to reach the maximal joint strength, which exceeds the one obtained with commonly used cam connecting fittings and screw joints by even 8.1 and 2.6 times, respectively. When joining wood-based panels with multidowel joints and adhesive, the joint can be strengtened by 1.2 – 3.8 times in comparison when cam connecting fittings, TZ connecting fittings, biscuit joints, tongue and groove joint and screw joints were used. However, even this method produces results that are weaker by 2.1 times in comparison to the mitre joint.

When joining wood particle boards with the mitre joint, it is possible to achieve maximal load baring capacity at bending. It can be explained by the inner structure of the wood particle board of this type, as outer, thicker and therefore stronger board layers carry the highest loads.

Applying the mitre joint to the board allows to reach a significant increase exploitation loads, which can range even between 3.8 and 8.1 times, in comparison to conventional methods used for joining wood-based panels with connecting fittings and multidowel joints.

When the surface of the wood-based panel applies enhancement by using various coatings, i. e. it is laminated, veneered or faced with layered plastic, it becomes possible to additionally increase the strength of the mitre joint by up to 20 %. Then after reaching the maximal strength the wood particle board and adhesive layer, it is impossible to achieve better results.

Based on the obtained test results, it is possible to conclude that the adhesively bonded mitre joint appears to be the most proper method for joining panels of wood particle boards. It allows to achieve maximal strength of construction from this type material. However, even taking into account that the strength of this joint exceeds the one of a regular joint with cam connecting fittings by 8 times, the mitre joint is not in wide use due to the more complex manufacturing process and greater amount of work required for product assembly. In addition, this method cannot be applied to products with large overall dimensions and complex construction.

The mitre joint provides the following advantages: the wood-based panel needs no edge finishing; since the oblique surface is adhesively bonded, it is possible to use wood-based panels whose thickness is twice smaller; the case furniture stiffness is higher than the one of other joints by 2 – 4 times; the connection area is enclosed and panel edges in the joint is invisible, the product looks more solid from an aesthetic perspective. This technique of panel joining would be especially suitable for creating modular furniture systems with small overall dimensions.

The testing revealed all the positive advantages of the mitre joint of wood particle boards. Moving towards a wider use of such joint in the constructions of case furniture seems to be a promising tendency for the emergence of a new production technology of such products.

CONCLUSIONS

1. It was established that the wood-based panel of the WPB has the following ratios of density and layer thickness distribution: 2 : 1 : 2 and 1 : 4 : 1, respectively. The central layer $t_2 = 12$ mm has the lowest density – 430 kg/m^3, whereas, the density of outer layers $t_1 = 3$ mm

reaches 885 kg/m^3. The average density value of the wood particle board used in this test was 639 kg/m^3.

2. The test showed that the bonding strength exceeds the material strength, since none of the tested specimens disintegrated at the bonding area. Within the bonding area PVA adhesive fills up gaps existing inside the board and also bonds wood particles, especially the central layer with lower density, since it contains more empty space.

3. The established bonding strength of the mitre joint of the wood particle board exceeds the material strength by even 10 %.

4. When the outer layer of the wood particle board is strengthened through the veneering process by using wood veneer, it is possible to reach a 20 % increase of the mitre joint strength.

5. The strength of the mitre joint is higher than the one of a regular joint with cam connecting fittings and screw joints by 8.1 and 2.6 times, respectively.

6. When applying the mitre joint from wood particle board, it is possible to achieve maximal load baring capacity of construction.

REFERENCES

1. LST EN 312:2005 Particleboards – Specifications.
2. **Norvydas, V., Minelga, D.** Strength and Stiffness Properties of Furniture Panels Covered with Different Coatings *Materials Science* (*Medžiagotyra*) 12 (4) 2006: pp. 328 – 332.
3. **Nethercot, D.** Handbook of Wood Chemistry and Wood Composites. Taylor & Francis, 2005: 293 p.
4. **Wei Xu**. Horizontal Density Distribution of Particleboard: Origin and Implications. The University of British Columbia, 1993: pp. 5 – 164.
5. **Vassiliou, V., Barboutis, I.** Bending Strength of Furniture Corner Joints Constructed with Insert Fittings *Forestry and Wood Technology* 67 2009: pp. 268 – 274.
6. **Norvydas, V., Juodeikienė, I., Minelga, D.** The Influence of Glued Dowel Joints Construction on the Bending Moment Resistance *Materials Science* (*Medžiagotyra*) 11 (1) 2005: pp. 36 – 39.
7. **Wagenfuhr, R.** Holz Atlas (Wood Atlas). Fachbuchverlag Leipzig im Carl Hanser Verlag, 2000 (in German).
8. LST EN 326-1:1999 Wood-based Panels. Sampling, Cutting and Inspection. Part 1: Sampling and Cutting of Test Pieces and Expression of Test Results.
9. LST EN 310:1999. Wood-based Panels. Determination of Modulus of Elasticity in Bending and of Bending Strength.
10. LST EN 319:1999. Particleboards and Fibreboards - Determination of Tensile Strength Perpendicular to the Plane of the Board.
11. **Frihart, Ch. R.** Handbook of Wood Chemistry and Wood Composites. Wood Adhesion and Adhesives. Boca Raton, Fla.: CRC Press, 2005: p. 215 – 278.
12. **Šipailaitė-Ramoškienė, V., Fataraitė, E., Mickus, K. V., Mažeika, R.** The Adhesion, Mechanical Properties and Water Resistance of Vinyl Acetate Copolymer Based Blends *Materials Science* (*Medžiagotyra*) 9 (3) 2003: pp. 271 – 274.
13. Wood Handbook – Wood as an Engineering Material. Gen. Tech. Rep. FPL-GTR-190. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 2010: 463 p.
14. **Vassiliou, V., Barboutis, I.** Bending Strength of Furniture Corner Joints Constructed with Insert Fittings *International Conference: Wood Science and Engineering in the Third Millennium* ICWSE 2009: pp. 627 – 632.
15. **Smardzewski, J., Prekrad, S.** Stress Distribution in Disconnected Furniture Joints *Electronic Journal of Polish Agricultural Universities* (*EJPAU*) 5 (2) 2002: #04.
16. **Kociszewski, M.** Stiffness and Load Capacity of Biscuit Corner Joints *Folia Forestalia Polonica* Seria B (36). 2005: pp. 39 – 47.
17. **Tankut, A. N., Tankut, N.** Effect of Some Factors on the Strength of Furniture Corner Joints Constructed with Wood Biscuits *Turkish Journal of Agriculture and Forestry* 28 2004: pp. 301 – 309.
18. **Altinok, M., Hüseyin, H. T., Sancak, E.** Load Carrying Capacity of Spline Joints as Affected by Board and Adhesives Type *Scientific Research and Essay* 4 (5) 2009: pp. 479 – 483.
19. **Liu, Wan-Qian, Eckelman, C. A.** Effect of Number of Fasteners on the Strenght of Corner Joints of Cases *Forest Products Journal* 48 (1) 1997: pp. 93 – 95.
20. **Lin, Far-Ching, Eckelman, C. A.** Bending Strength of Corner Joints Constructed with Injection-molded Splines *Forest Products Journal* 47 (4) 1997: pp. 89 – 92.
21. **Kasal, A., Sener, S., Belgin, C. M., Efe, H.** Bending Strength of Screwed Corner Joints with Different Materials *G.U. Journal of Science* 19 (3) 2006: pp. 155 – 161.
22. **Zhang, Ji-Lei, Eckelman, C. A.** Rational Design of Multi-dowel Corner Joints in Case Construction *Forest Products Journal* 43 (11/12) 1993: pp. 52 – 58.