

STUDY ON BENDING STRENGTH OF END CORNER DETACHABLE JOINTS OF STRUCTURAL ELEMENTS MADE OF PLYWOOD

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ABSTRACT

The study presents the results from the research carried out on bending strength of end corner detachable joints of structural elements made of beech veneer plywood. The bending moment under compression bending test has been established. The highest bending strength was achieved with Universal connector and Confirmat 7 x 50 and 7 x 70 mm and the lowest bending strength is typical of joints with bolt and nut and two types of eccentric connectors. It has been established that joints made of beech veneer plywood have higher strength compared to the same type of joints made of beech solid wood.

It is recommended that the comparative data of bending strength are taken into consideration when choosing the type of joints in furniture constructions.

Key words: furniture construction, plywood, joints, bending strength, bending moment

INTRODUCTION

Plywood is a widely used material in furniture construction. It meets the requirements of designers and engineers in terms of the opportunities it provides to achieve both a traditional and unconventional form in furniture construction made of plywood. Furthermore, the manufacture method and process allow for the utilisation of wood resource of lower quality which results in product economy. This is a prerequisite for its even wider utilisation.

In Bulgaria there is data about studies on the physical and mechanical characteristics of plywood. (Shishkov et al 1989, Kyuchukov et al 1991) but research into studies on strength and deformation characteristics of joints of structural elements made of plywood have not turned any results. Most studies in Bulgaria focus on establishing strength and deformation characteristics of structural elements made of solid wood (Jivkov et al. 2000; Kyuchukov, B. et al. 2012; Kyuchukov B, et al. 2013, Kyuchukov, G. et al. 2013), which can be used to carry out a

comparative analysis of the strength of joints made of plywood.

In the world there are publications in the field of joints made from plywood and the greater part refer to joints made with dowels (Zhang *et.al.* 2001; Erdil and Eckelman 2001; Eckelman *et.al.* 2002; Jensen and Kozumi 2002).

Zhang, Quin, Tackett (2001) published data about the bending strength and stiffness of T-shape joints with cross dowel of structural elements made of several types of solid wood, plywood, fiberboard and other wood materials. It was concluded that the joints made of red oak and plywood are characterized with the highest bending strength with oak performing by 4.4 % better, while joints from plywood have the lowest one. Another experimental study provides data about the stiffness and bending strength of T-shape joints of structural elements made of plywood and OSB (Eckelman *et.al.* 2002). These are of interest to engineers of frames, primarily for sitting furniture.

Other publications include the tension strength of glued joints with dowels of test

samples made of plywood (Erdil and Eckelman, 2001; Zhang *et.al.* 2002).

A considerable number of publications are related to the characteristics of the joints made of plywood when cyclically loaded (Zhang *et.al.* 2001; Zhang *et.al.* 2003; Zhang *et.al.* 2004; Zhang *et.al.* 2005; Zhang *et.al.* 2006).

The only data about tension and bending strength of detachable joints of structural elements made of plywood are about the joint with cross dowel of structural elements made of plywood in the publication by Erdil, Zhang and Eckelman (2003). In the literature were not found other information concerning the study on strength characteristics of detachable joints of structural elements made of plywood.

All this gives reasons to conclude that due to insufficient information about the strength behaviour of detachable joints of structural elements made of plywood it is necessary to conduct research in order to establish those.

MATERIALS AND METHODS

The study was carried out with test samples made of beech veneer plywood from rotary cut veneer, manufactured by “Nikrom-Veneer”Ltd, Petkovo. For the needs of the study in particular it is made entirely from veneer layers, quality A. The plywood panels are 20 mm thick with the size 920 x 500 mm. Two-component urea formaldehyde resin by “DYNEA”, Hungary has been used. Resin consumption is 150g/m². The plywood pressing is carried out on a “Vecciato VALTER”

multi-storey pressing machine. Pressing temperature is 110 °C, the continuity is 15 min and the pressure – 1,3 N/mm².

The plywood panels are cut out to make test samples for testing strength and deformation characteristics of various types of corner joints. The BDS EN 636, Plywood: specifications’ have been met. The physical and mechanical characteristics of the manufactured plywood are as follows (Jivkov et al):

- Density – 760,1 kg/m³;
- Bending strength under loading perpendicular to panel layers – 55,58 N/mm²;
- Bending strength under loading parallel to panel layers – 63,16 N/mm²;
- Modulus of elasticity in bending under loading perpendicular to the veneer layers – 5286 N/mm²;
- Modulus of elasticity in bending under loading parallel to the veneer layers – 6650 N/mm².

The test samples are made of elements with cross section 50 x20 mm. All joints are made with hardware produced by „Häfele“-Germany. The following types of detachable end corner joints have been tested: 1 – with connector with cross dowel; 2 – one-piece connector *Confirmat* ø7x70 mm; 3 – one-piece connector *Confirmat* ø7x50 mm; 4 – Countersunk screw for wood ø6x90 mm; 5 – Countersunk screw for wood ø6x80 mm; 6 – bolt and nut with external and internal thread; 7 – *Minifix* with *M6* metal sleeve ø8x15; 8 – *Minifix* for direct mounting in ø5 mm hole.

The type and sizes of the test samples are shown in figure 1.

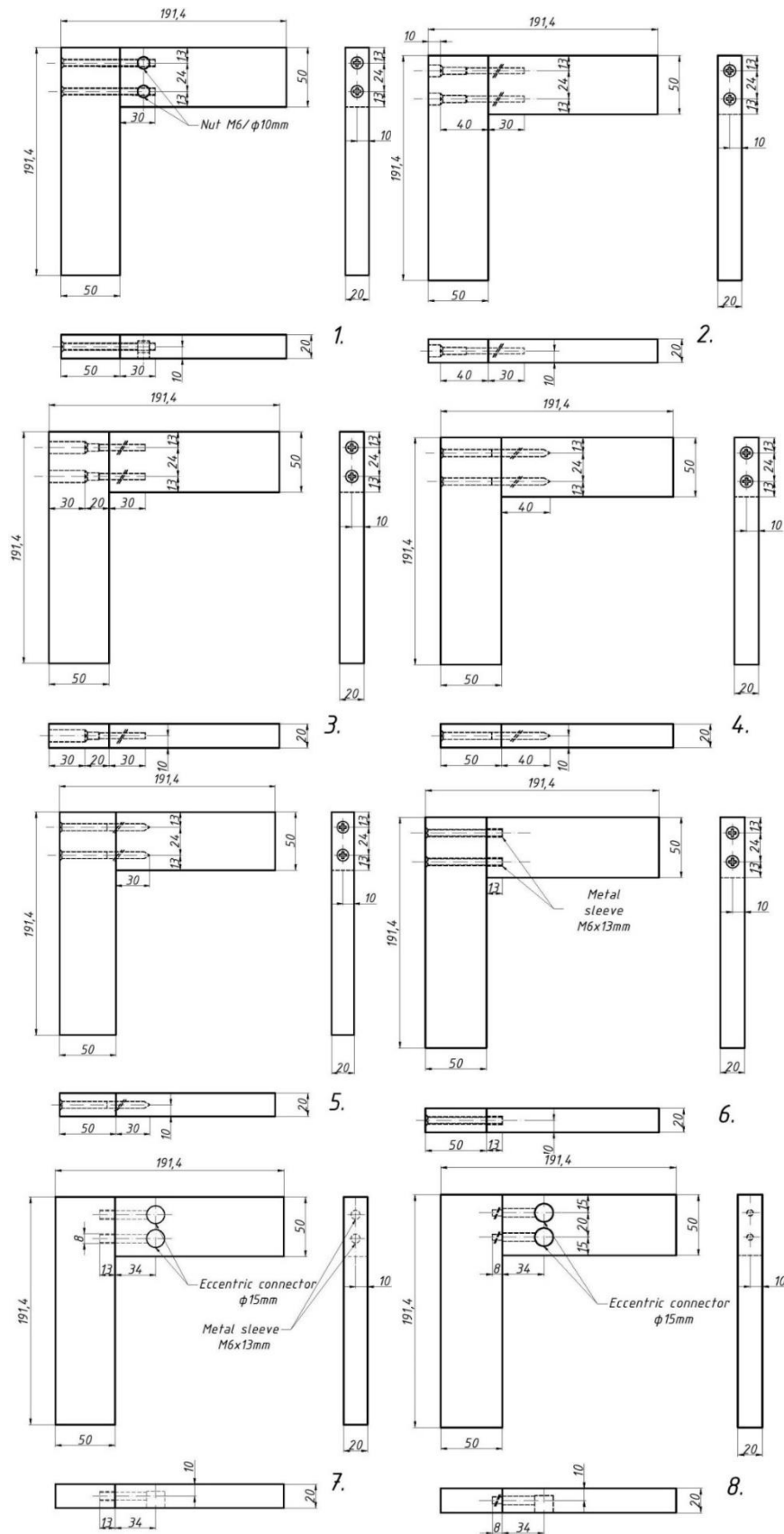


Figure 1: Type and sizes of the test samples : 1 – with connector with cross dowel; 2 – one-piece connector *Confirmat* $\phi 7 \times 70$ mm; 3 – one-piece connector *Confirmat* $\phi 7 \times 50$ mm; 4 – screw for wood $\phi 6 \times 90$ mm; 5 – screw for wood $\phi 6 \times 80$ mm; 6 – bolt and nut with external and internal thread; 7 – *Minifix* with M6 metal sleeve $\phi 8 \times 15$; 8 – *Minifix* for direct mounting in $\phi 5$ mm hole.

The test samples were loaded under compression bending as shown in Fig. 2.

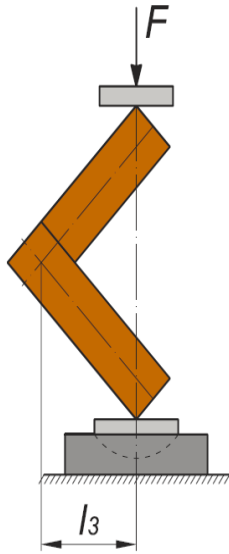


Figure 2: Scheme of loading the test samples

The testing was carried out in the scientific and research laboratory at the Institute of Mechanics and Biomechanics, BAS, Sofia on a *TIRA test 2300* testing machine.

The maximum strength, deformation under maximum strength, strength and deformation at a point, determined to be the destruction point, were recorded.

A criterion used to determine the strength of the detachable end corner joints under compression loading is the maximum bending moment M_{\max} , given by the formula:

$$M_{\max} = F \cdot l, \text{ Nm}$$

where F is the maximum strength under compression loading, N;



Figure 3: Testing machine and test installation

l – bending shoulder, m.

Data were processed following the method of variational statistics

Temperature of the environment during testing: 22 ± 1 °C, humidity: 63 ± 5 %.

RESULTS AND ANALYSIS

Figure 4 and table 1 show data about the bending strength of the studied detachable end corner joints when loaded in compression.

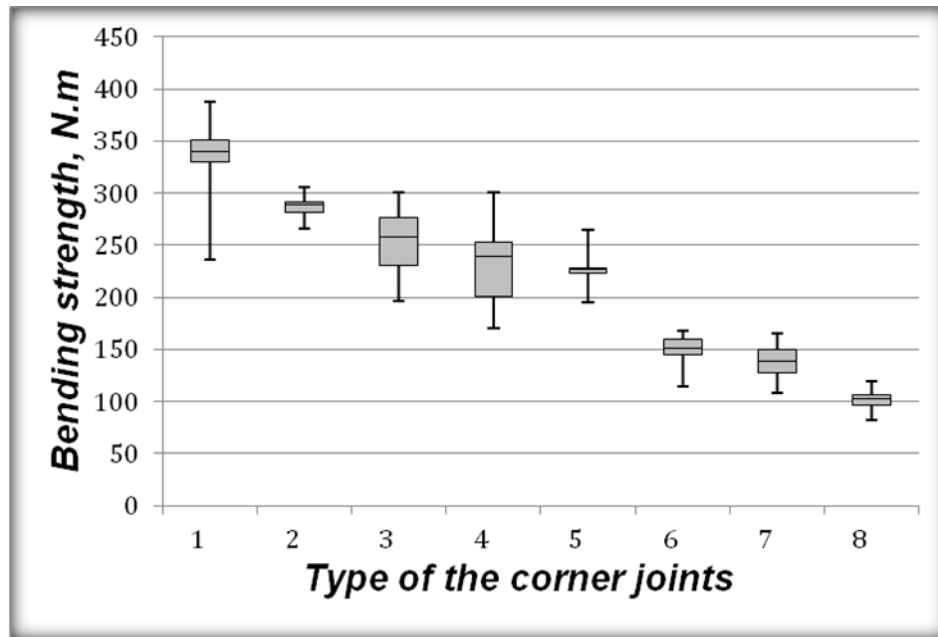


Figure 4: Bending strength of the studied detachable end corner joints under right angle when loaded with converging shoulders: 1 – with connector with cross dowel; 2 – one-piece connector Confirmat $\phi 7 \times 70$ mm; 3 – one-piece connector Confirmat $\phi 7 \times 50$ mm; 4 – screw for wood $\phi 6 \times 90$ mm; 5 – screw for wood $\phi 6 \times 80$ mm; 6 – bolt and nut with external and internal thread; 7 – “Minifix” with M6 metal sleeve $\phi 8 \times 15$; 8 – “Minifix” for direct mounting in $\phi 5$ mm hole.

Table 1: Bending strength

Type of the corner joints	$N_{\text{of the series}}$	Number of the test samples	Average, N.m	Minimum, N.m	Median, N.m	Maximum, N.m	Standard deviation, N.m	Coefficient of variation, %
Screw with cross dowel M6	1.	10	334	236	340	388	41,8	12,5
Confirmat $\phi 7 \times 70$	2.	15	286	266	289	306	12,0	4,2
Confirmat $\phi 7 \times 50$	3.	13	255	196	259	301	31,7	12,4
Countersunk screw for wood $\phi 6 \times 90$ mm	4.	13	235	170	240	301	31,7	16,4
Countersunk screw for wood $\phi 6 \times 80$ mm	5.	15	227	195	227	265	18,8	8,1
Screw with metal sleeve	6.	12	150	115	151	168	14,3	9,6
Minifix for metal sleeve	7.	15	138	108	139	166	16,4	11,8
Minifix for hole $\phi 5$	8.	12	102	82	103	120	11,3	11,1

The results from the study show that the joints with connector with cross dowel (334,4 Nm); *Confirmat* $\phi 7 \times 70$ mm (286,4 Nm) and *Confirmat* $\phi 7 \times 50$ mm (255,3 Nm) have maximum bending moment values. Next in the line are $\phi 6 \times 90$ mm screw (234,7 Nm); $\phi 6 \times 80$ mm screw and the lowest strength have bolt and nut connectors (150,2 Nm), *Minifix* for bolt M6 for metal

sleeve for hole $\phi 8 \times 15$ (138,8 Nm) and *Minifix* for direct mounting in $\phi 5$ mm hole (101,7Nm). The difference between the joints with highest and the lowest value is more than 3 times. The difference between the bending moments of the two types screw joints is 3.5 %; of two type *Confirmat* – 12.2 % and two type of *Minifix* – 35.3 %. The difference between the bending moments of the connector with bolt and screw and the

connector with *Minifix* for bolt with *M6* metal sleeve for hole $\varnothing 8 \times 15$ mm is 8.7 %.

The most common ways for destroying the joints are withdrawing the external, farther connector and considerable deformation of the internal. In all test samples were observed crushing the lower edge of the shorter arm. With some connectors like *Confirmat* $\varnothing 7 \times 50$ mm and $\varnothing 6 \times 90$ mm wood screw we observe splitting of the plywood in some of

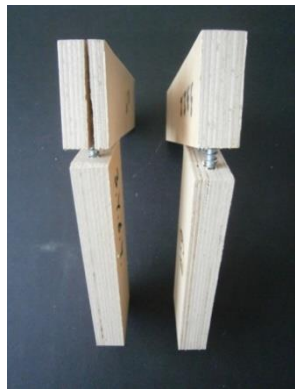
the test samples, while with others - $\varnothing 6 \times 80$ mm wood screw all test samples split. The connector with cross dowel is destroyed through splitting the plywood with three of the test samples breaking in the area of the internal connector in the long arm. Similarly, two of the test samples joint with one-piece connector *Confirmat* $\varnothing 7 \times 70$ are destroyed in the same way (fig. 5).



1.



2.



3.



4.



5.



6.

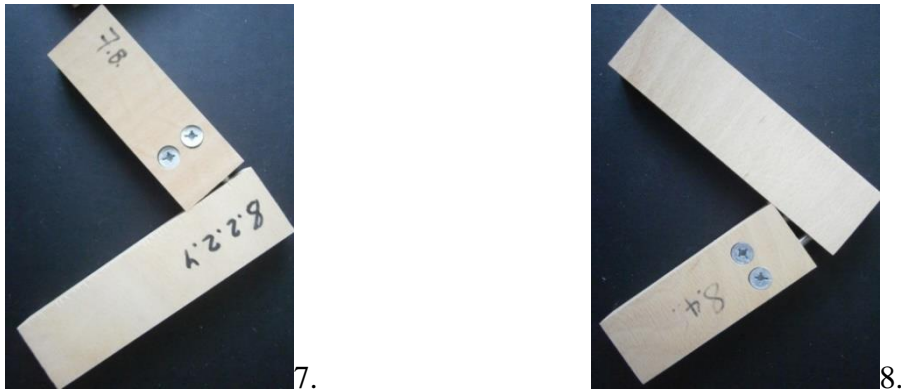


Figure 5: Ways how test samples are destroyed: 1 – with connector with cross dowel; 2 – one-piece connector *Confirmat* $\varnothing 7 \times 70$ mm; 3 – one-piece connector *Confirmat* $\varnothing 7 \times 50$ mm; 4 – screw $\varnothing 6 \times 90$ mm; 5 – screw $\varnothing 6 \times 80$ mm; 6 – bolt and nut with external and internal thread; 7 – *Minifix* with *M6* metal sleeve $\varnothing 8 \times 15$; 8 – *Minifix* for direct mounting in $\varnothing 5$ mm hole.

In eccentric connectors were observed withdrawing of the eccentric bolts from the eccentric and thus causing considerable deformation in the housing. In some of the test samples connected with *Minifix* for bolt *M6* with metal sleeve for hole $\varnothing 8 \times 15$ mm. The connector with bolt and nut with external and internal thread is destroyed in a similar way.

The low bending strength values of joints with eccentric connectors are most probably due to the physical and mechanical characteristics of the alloy they are made from. Another indicator, which probably influences unfavourably the bending strength of joints, is the insufficient depth of the carving for the metal fitting.

The high bending moment value of the joint with connector with cross dowel is due to its construction where the bolt is going through the element. Furthermore, high bending moment values are observed in the study on various types of wood and wood materials in this type of joint.

The difference in the maximum bending moment values of joints with *Confirmat* is statistically significant and the results for the bending strength are comparatively high.

What impresses is the statistically insignificant difference between the values of the

two types of screw joints; respectively the impact of the length in the selected parameters is negligibly small.

The low bending moment values of the eccentric connectors in joints made of plywood illustrate that they should be used in furniture with lower levels of load or the number of connectors should be increased and additional some dowels should be used. The same conclusion is valid for the bolt and nut connector.

To establish the impact of the construction material on the bending strength, the results from the current study have been compared with those from the study done by Jivkov et al (2000) which contains data about the strength and deformation characteristics of some end corner detachable joints of structural elements made of solid beech wood. The analysis of similar types of joints such as those with *Confirmat* 7×50 and 7×70 mm concluded that joints of plywood show the same strength indicators and even have higher bending strength. Joints with *Minifix* for direct mounting and with bolt for metal sleeve also have higher strength when the joints are from plywood.

CONCLUSION

The analyses of the results of the current study show that the following important conclusions can be drawn:

1. The highest bending strength under compression loading of the studied end corner detachable joints made of beech veneer plywood have the joints with connectors with cross dowel and one-piece connector *Confirmat* $\varnothing 7$ x 70 and $\varnothing 7$ x 50 mm.
2. The lowest bending strength of the studied end corner detachable joints made of beech veneer plywood have the joints with bolt and nut and the two types with eccentric connectors.
3. It has been found that the detachable joints made from plywood have higher strength in comparison with those made from solid beech wood.
4. The results from the current study can be used for the strength design of furniture and to be used by constructors as a guideline with respect to the bending strength of the selected joints choosing the appropriate joints.

REFERENCES

1. Eckelman C., Erdil, Y., Zhang J. (2002). Withdrawal and Bending Strength of Dowel Joints Constructed of Plywood and Oriented Strandboard. *Forest Products Journal*. 52(9):66–74.
2. Erdil, Y., C. Eckelman. (2001). Withdrawal Strength of Dowels in Plywood and Oriented Strand Board. *Turk J Agric For*. 25. p. 319–327.
3. Erdil, Y., J. Zhang, C. Eckelman. (2003). Withdrawal and Bending Strength of Dowel-Nuts in Plywood and Oriented Strandboard. *Forest Product Journal*. 53(6): 54–57.
4. Jensen J., Koizumi T. (2002). Plywood frame corner joints with glued-in hardwood dowels. *J. Wood Sci*. 48:289–294.
5. Jivkov, V., Genchev, J., Marinova, A. (2000). Bending strength and stiffness of some detachable end corner joints from beech wood. 14th Scientific Conference of Faculty of Wood Technology “Wood – Everlasting Material”, Warsaw Agricultural University, Warsaw, 13–15 November, 127–131.
6. Jivkov, V., Simeonova, R., Marinova, A. (2013). Influence of the veneer quality and load direction on the strength properties of beech plywood as structural material for furniture. *Innovation in Woodworking Industry and Engineering Design*, 1/2013 (3): 86–92.
7. Kyuchukov, B., Kyuchukov, G., Jivkov V. (2013). Comparative study on the destructive bending moments of some end corner joints of structural elements of solid beech wood with cross section of 50 x 25 mm. *Innovation in Woodworking Industry and Engineering Design*, 1/2013 (3): 98–105.
8. Kyuchukov, B., Kyuchukov, G., Jivkov, V. (2012). Comparative study on the destructive bending moments of some T-shape corner joints from beech wood with cross section of 50 x 25 mm. 23rd International Scientific Conference “Wood is Good – with knowledge and technology to a competitive forestry and wood technology sector”, Zagreb, 12th of October, 103–110.
9. Kyuchukov, G., Gruevski, G., Marinova, A., Kyuchukov, B., Jivkov, V. (2013). Comparative analysis of stiffness coefficients of end and t-shape corner joints of frame structural elements with two types of cross sections made of sweet chestnut wood. 24th International scientific conference “Wood is Good – User oriented material technology and design”, Ambienta, Zagreb, 18 October, 87–93.
10. Kyuchukov, G., Shishkov, I., Dimova, L. (1991). Establishment of strength characteristics of plywood used in furniture construction. Study of mechanical properties of plywood panels. University study, Report, Sofia
11. Shishkov, I., Kyuchukov, G., Dimova, L., Georgieva, A. (1989). Establishment of strength characteristics of plywood used in furniture construction. Modulus of elasticity under bending. University study, Report, Sofia
12. Zhang J., Quin F., Tacket B. (2001). Bending Strength and Stiffness of Two-Pin Dowel Joints Constructed of Wood and Wood Composites. *Forest products Journal*. 51(2):29–35.
13. Zhang J., Quin F., Tacket B., Park S. (2002). Direct Withdrawal Strength of Single Staple Joints in Pine Plywood. *Forest Product Journal*. 52(2):86–91.

14. Zhang, J., F. Quin, B. Tacket. (2002). Direct Withdrawal Strength of Multi-Staple Joints in Pine Plywood. *Forest Product Journal*. 52(2):61–66.
15. Zhang, J., Y. Yoshan, F. Quin. (2005). Moment Capacity of Metal-Plate-Connected Joints in Furniture Grade Pine Plywood. *Forest Product Journal*. 55(5):45–51.
16. BDS EN 636 „Plywood: specifications”