

STUDY ON STIFFNESS COEFFICIENTS UNDER BENDING TEST OF END CORNER DETACHABLE JOINTS OF STRUCTURAL ELEMENTS MADE OF PLYWOOD

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ABSTRACT

In this study are given the results from investigation into stiffness of end corner detachable joints of structural elements made of beech veneer plywood. The stiffness coefficients under compression bending test have been determined. The highest stiffness is characteristic of joints with universal connector and screw for wood $\varnothing 6 \times 90$ and $\varnothing 6 \times 80$ mm while the lowest stiffness is typical of joints with *Minifix* with bolt, mounting in metal sleeve and direct mounting. The parameters of the screw joints have considerable impact on the stiffness characteristics of the joints.

It is recommended that the comparative data of bending strength be taken into consideration when selecting the type of joints in the construction of furniture made of plywood.

Key words: furniture construction, plywood, joints, stiffness.

INTRODUCTION

Plywood is preferred material in furniture production. The advantages it has in terms of form complexity, line and uniqueness have stirred the interest of both designers and architects from all over the world for many years. The choice made by modern consumers is based on two key factors – product design and quality. Undoubtedly, both factors play a very important role. Design as such is a very dynamic factor and experimenting with design is compulsory if the aim is to create interesting and attractive furniture. Quality, on the other hand, is a factor which has to be constantly improved. Therefore, trying to achieve the optimum construction and reliable strength and deformation sizing are compulsory.

Determining the strength and deformation characteristics of the most common end corner detachable joints of structural elements made of plywood in furniture construction poses a question of both practical and theoretical importance.

The studies, carried out in Bulgaria do not present data concerning the experimental data of strength and deformation characteristic features of end corner joints made of plywood. There are considerably more data concerning the strength and deformation characteristics of joints of structural elements made of solid beech and chestnut wood which can be used in comparative analysis (Jivkov et al., 2000; Kyuchukov, G., et al, 2009; Kyuchukov, G., et al, 2011; Kyuchukov, G., et al, 2012; Kyuchukov, G., et al, 2013).

The foreign scientific literature provides data concerning the study on stiffness and deformation characteristics of end corner joints of structural elements made of plywood. It presents data about bending strength and some of it contain data about the stiffness of joints. There are data about strength under tensile, shear and torsion loading.

A number of these publications focus on studies of joints connected with dowels (Zhang et.al. 2001; Erdil and Eckelman 2001; Eckelman et.al. 2002; Jensen and Kozumi 2002).

Since plywood is widely used in the construction of upholstered furniture, there are studies focusing on joints with metal staples and metal plates in framework constructions of upholstered furniture made of plywood and other wood materials. A number of publications present comprehensive experimental studies of the strength characteristics of the corner joints under tensile, shear, static and cyclic loading (Zhang et.al. 2002; Zhang et.al. 2002; Erdil et.al. 2003; Zhang et.al. 2005). With the exception of Erdil, Zhand and Eckelman's publication (2003), which contains results from a study on tensile strength and bending strength of structural elements made of plywood, joint through connector with cross dowel, there is almost no information about studies on the stiffness and deformation behaviour of the detachable joints of structural elements made of plywood.

On the basis of the study we can draw the conclusion that the data about the deformation behaviour of joints made of beech veneer plywood are insufficient. That is why it is advisable to set specific and exact values of the strength and deformation characteristics of joints made of plywood which would facilitate both the scientific research into this relatively new in furniture production material and the manufacturers from the furniture industry.

MATERIALS AND WORKING METHOD

For the purpose of the study test samples were made of plywood from rotary cut beech veneer, manufactured by "Nikrom-Veneer" Ltd, Petkovo. For the needs of the study it is made entirely from 'A' quality veneer. The thickness of the plywood was 20 mm and 21mm, respectively. Veneer panels were produced in size of 920 by 500 mm. Two-component urea formaldehyde adhesive manufactured by "DINEA" – Hungary, with a

quantity of 150 g/m² was used. Plywood manufacturing was carried out on "Vecciato VALTER" multi-storey pressing machine. Pressing temperature was 110 °C, while the continuity was 15 min, and pressure was 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. BDS EN 636, Plywood: specifications' have been met.

The physical and mechanical characteristics of the panels 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.

Eight series of test samples with cross section 50 x 20 mm were made. For the purposes of the study have been selected some of the most common detachable joints, made with hardware produced by „Häfele” – Germany. The following types of detachable end corner joints have been tested:

- 1 – screw M6 with cross metal dowel;
- 2 – wood screw \varnothing 6x90 mm;
- 3 – wood screw \varnothing 6x80 mm;
- 4 – bolt and nut with external and internal thread;
- 5 – one-piece connector *Confirmat* \varnothing 7x70 mm;
- 6 – one-piece connector *Confirmat* \varnothing 7x50 mm;
- 7 – *Minifix* with M6 metal sleeve \varnothing 8x15 mm;
- 8 – *Minifix* for direct mounting in \varnothing 5 mm hole.

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

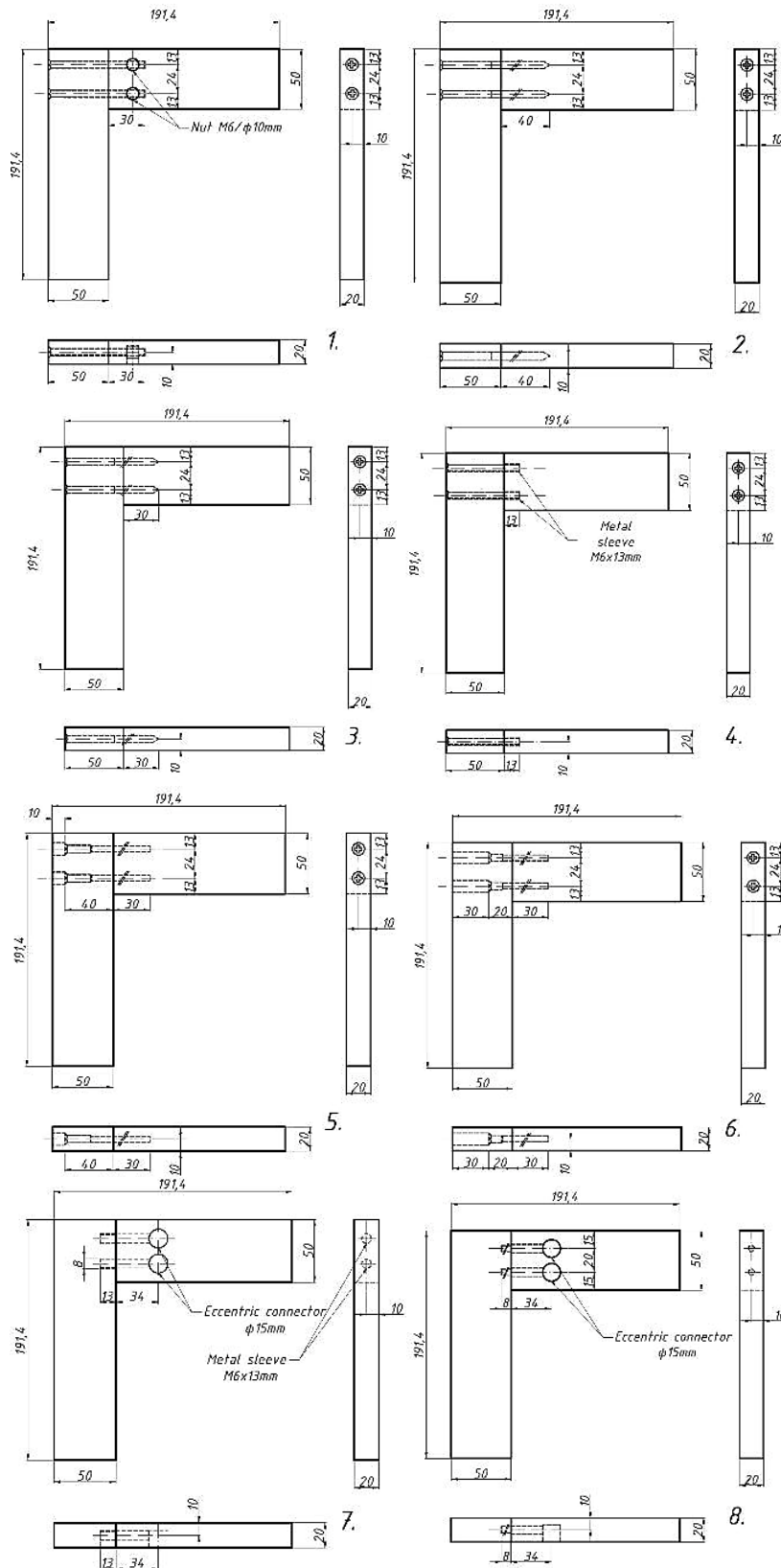


Figure 1: Type and sizes of the test samples

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

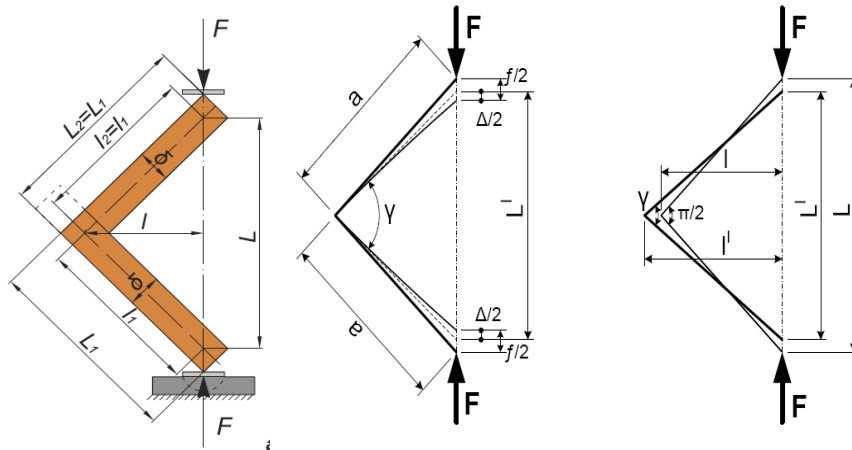


Figure 2: Type, sizes and scheme of loading and deformation of test samples

Testing was carried out in the scientific and research laboratory at the Institute of Mechanics and Biomechanics, BAS, Sofia on a TIRA test 2000 testing machine.

The load speed was selected so that the destruction of the test samples occurs between 30 s and 120 s after the start of loading.

To measure the force a sensor with range up to 10 kN with 1 % accuracy, appropriate for over 100N force was used. The testing was carried out at temperature of 22 ± 1 °C, humidity: 63 ± 5 %.

For 10 and 40 % of the maximum loading forces the change in the distance between the application points was recorded and the changed arms of bending and the changed angle between the arms of the joints were determined. Previous studies have found that this area of loading corresponds to the linear section from the “loading – deformation” correlation.

More data were recorded – the maximum force, the deformation under the maximum force, the force and deformation at the destruction of each test sample.

The theoretical and experimental studies on the strength and deformation characteristics of the corner joints illustrate that the key criteria for their evaluation are the maximum bending moment and the coefficient of stiffness.

The deformation of the joints under the compression bending test gives as a result changes in both, the right angle between the joint arms and the bending arms l of the forces. The linear displacement f_i of the application points of the forces F_i is recorder for each test sample at each loading level. It represents a sum of displacement resulting from turning the joint arms and additional displacement Δ_i resulting from bending of the arms. To find out the displacement Δ_i we use the following formula:

$$\Delta_i = \frac{F_i a^3}{3EI}, \quad (1)$$

where: F_i is the value of the loading force, N ;

a – axial length of the joint arms, m ;

E – modulus of elasticity of the plywood parallel to the layers, N/mm^2 ;

I – axial moment of inertia of the cross section of the joint arms, m^4 ,

which is worked out with the formula:

$$I = \frac{\delta b^3}{12}, \quad (2)$$

where: b is the width of the arms, m ;

δ – thickness of the arms, m .

The distance between the force application points at each level of loading is determined with the formula:

$$L_1 = L - f_i + \Delta_i, \quad (3)$$

The angle γ_i [rad] changed under loading between the joint arms is worked out with the formula:

$$\gamma_i = 2 \arcsin \frac{L_1}{2a} = 2 \arcsin \frac{L - f_i + \Delta_i}{2a}. \quad (4)$$

The changed bending arm l_i is determined with the formula:

$$l_i = a \cos \frac{\gamma_i}{2}. \quad (5)$$

The result from the deformation under compression bending test is the semi rigid rotation of the joint arms in [rad]:

$$\alpha_i = \frac{\pi}{2} - \gamma_i. \quad (6)$$

For certain values of the loading force F_i the bending moment [N.m] is determined with the formula:

$$M_i = F_i l_i. \quad (7)$$

Stiffness coefficient c_i [N.m/rad] under compression bending test is determined with the formula:

$$c_i = \frac{\Delta M_i}{\Delta \alpha_i}, \quad (8)$$

In (8) the following designations are used:

$$\Delta M_i = M_i - M_0,$$

$$\Delta \alpha_i = \alpha_i - \alpha_0,$$

where: M_i and α_i are determined under (7) и (6) for the value of force F_i , equal to 40% of F_{\max} , while M_0 and α_0 – under (7) and (6) for the value of force F_0 , equal to 10 % of F_{\max} .

The stiffness coefficient c as a deformation characteristic of the corner joint under compression bending test is defined as

the arithmetic mean of the result of (8) numbers for each test sample when loaded in the section which corresponds to the linear section on the curve of the correlation between the bending moment and the corner deformation of the joint.

The testing of each test sample lasts until the maximum loading is reached and then – until complete destruction. The maximum bending moment is determined with formula (7) for the maximum strength of the loading. In this way, by testing the test samples under one and the same pattern of loading, we determine both the stiffness and strength characteristics of the joint.

RESULTS AND ANALYSIS

The objects of the study are eight types of detachable end corner joints at right angle under compression bending test. Table 1 and Figure 3 present the data related to the mean values of the stiffness coefficients of the studied detachable end corner joints.

The data in table 1 and figure 3 show that the results related to the stiffness of the studied end corner joints of the components made of beech plywood can provisionally be divided into three groups. The highest stiffness is typical of the joints with a connector with cross metal dowel (5167 Nm/rad) and screw $\varnothing 6 \times 90$ mm (4931 Nm/rad), average stiffness is typical of the joints with screw $\varnothing 6 \times 80$ mm (4565 Nm/rad), bolt and nut (4310 Nm/rad) and *Confirmat* $\varnothing 7 \times 70$ mm (4124 Nm/rad), and the lowest stiffness is typical of joints with connectors *Confirmat* $\varnothing 7 \times 50$ mm (3392 Nm/rad), *Minifix* with metal sleeve (2596 Nm/rad) and bolt for direct mounting (2398 Nm/rad).

Table 1: Stiffness coefficient

Type of the corner joints	No of the series	No of the test samples	Average, N.m.rad ⁻¹	Minimum, N.m.rad ⁻¹	Median, N.m.rad ⁻¹	Maximum, N.m.rad ⁻¹	Standard deviation, N.m.rad ⁻¹	Coefficient of variation, %
Screw M6 with cross metal dowel	1.	10	5167	4593	5295	5473	336	6,5
Countersunk screw for wood $\varnothing 6 \times 90$ mm	2.	13	4931	4453	4916	5559	273	5,5
Countersunk screw for wood $\varnothing 6 \times 80$ mm	3.	15	4565	3875	4508	5431	406	8,9
Screw with metal sleeve	4.	12	4310	3619	4525	5122	745	11,7
Confirmat $\varnothing 7 \times 70$	5.	15	4124	2190	4251	5149	847	20,5
Confirmat $\varnothing 7 \times 50$	6.	13	3392	2226	3232	5122	752	22,2
Minifix for metal sleeve	7.	15	2596	1768	2661	3172	486	18,7
Minifix for hole $\varnothing 5$	8.	12	2398	1437	2442	3313	571	23,8

The difference between the highest (with cross metal dowel) and the lowest (*Minifix* for bolt with direct mounting) value is more than two times. The difference between the stiffness coefficient of the two

types of screw connectors is 8,0 %; between the two types *Confirmat* – 21,6 %; between the two *Minifix* types – 8,3 %. The difference between the screw with cross dowel and the screw $\varnothing 6 \times 90$ mm is 4,8 %.

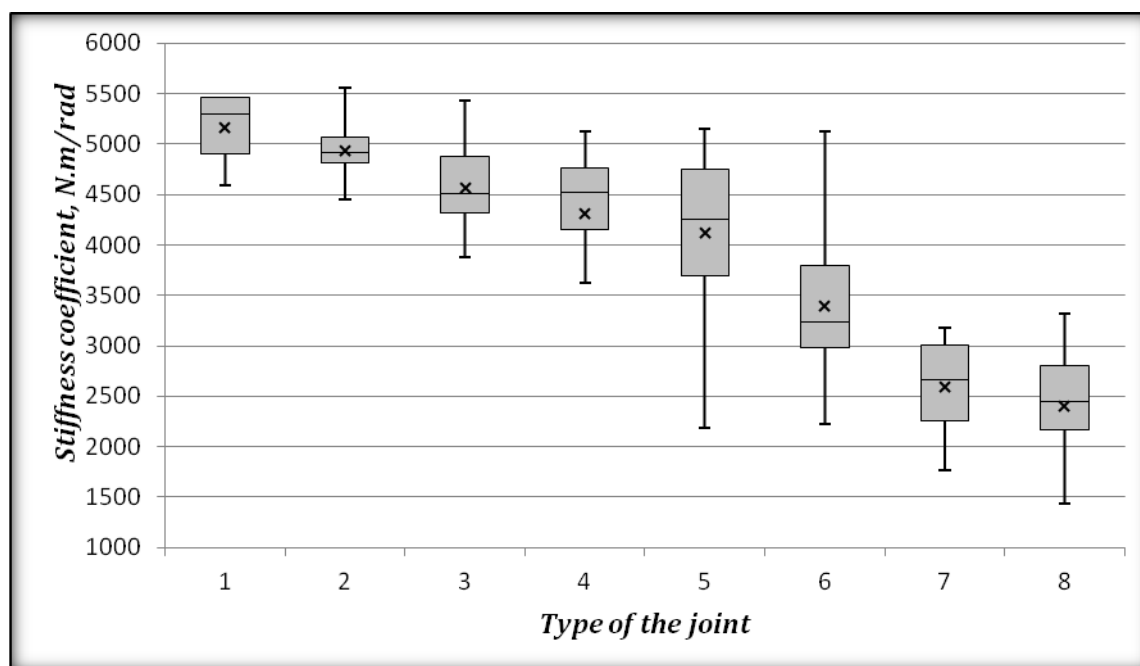


Figure 3: Stiffness coefficients of the studied detachable end corner joints under compression bending test: 1 – with connector with cross metal dowel; 2 – screw for wood $\varnothing 6 \times 90$ mm; 3 – screw for wood $\varnothing 6 \times 80$ mm; 4 – bolt and nut with external and internal thread; 5 – one-piece connector *Confirmat* $\varnothing 7 \times 70$ mm; 6 – one-piece connector *Confirmat* $\varnothing 7 \times 50$ mm; 7 – *Minifix* for bolt mounting in metal sleeve M6 $\varnothing 8 \times 15$; 8 – *Minifix* with bolt for direct mounting in $\varnothing 5$ mm hole.

The difference between the stiffness coefficients of the connector with cross dowel

and $\varnothing 6 \times 90$ screw is insignificant and statistically negligible. The choice between the two connectors which are characterised with

identical stiffness has to be made on the basis of their technological manufacture and/or its aesthetic characteristics.

All values of the stiffness coefficient of the joints with the same type of connector (screw, *Confirmat* and *Minifix*) are grouped in pairs within a relatively narrow range. The only exception is the one-piece connector *Confirmat*.

The mounting of all types of connectors and screws comply with the recommended diameters and sizes which are intended mostly for materials such as Particleboard and *MDF*, which have different structure and physical and mechanical properties. When they have to be fitted in a material with considerably higher stiffness and density, such as plywood, certain internal stress occurs in the connector itself when tightening up, which affects its own stiffness indicators and the labour-intensity of the screwing process. The results clearly show that the parameters of the individual types of joints play a key role for their stiffness. For example, the bolt in the connector with cross metal dowel passes through one of the components and is screwed vertically in a metal nut in the other component, thus providing considerable stiffness of the joint. In the case with screw joints the bigger length of the part of the screw which enters along the axis of the component results in higher stiffness. For the one-piece connector “*Confirmat*” the greater depth of the hole where the head of the screw enters leads to considerably reduce of the stiffness (more than 25 %). Eccentric connectors exhibit relatively low stiffness since their construction and material are mostly designed for softer materials such as Particleboard and *MDF*.

The results about the stiffness of the end corner joints of elements made of solid beech and chestnut wood in other studies (Jivkov et al., 2000; Kyuchukov, G., et al, 2009;

Kyuchukov, G., et al, 2011; Kyuchukov, G., et al, 2012; Kyuchukov, G., et al, 2013) show that the joints of elements made of beech veneer plywood are almost equally stiff.

CONCLUSION

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

1. Of the studied end corner detachable joints the ones with the highest stiffness are the joints with connectors with cross dowel and screw $\varnothing 6 \times 90$ and $\varnothing 6 \times 80$ mm.
2. The lowest stiffness is observed into joints with *Minifix* with bolt for mounting in sleeves and *Minifix* with bolt for direct mounting.
3. The parameters of the screw connectors play an important role for the stiffness of the joint.
4. The stiffness of the joints of components made of beech plywood is comparable with the stiffness of the same type of joints made of solid beech wood and chestnut wood.
5. 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 stiffness of the selected joints.

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