COMPARATIVE RESEARCH ON THE DESTRUCTIVE BENDING MOMENTS OF SOME CORNER JOINTS OF FRAME STRUCTURAL ELEMENTS MADE OF SOLID SPRUCE WOOD WITH A CROSS SECTION OF 50 X 30 MM PART III: END CORNER MORTISE AND TENON JOINTS

Georgi Kyuchukov[1], Borislav Kyuchukov[1], Vassil Jivkov[1], Assia Marinova[1], G. Gruevski[2], Z. Kalapotliev[1]
[1]University of Forestry, Sofia, Bulgaria
[2]Faculty of design and technology of furniture and interior – Skopje

ABSTRACT

The results from the research on the destructive bending moments of the end corner mortise and tenon joints of structural elements made of solid spruce wood with a cross section of 50 x 30 mm are given whereas these joints are used mainly in the construction of sitting furniture, tables and beds.

It was established that the type of joints has significant influence on the destructive bending moment. This is defined by the type and size of joint elements and the area of the contact surfaces of the joints.

The following joints are destroyed at a considerably big bending moment:

- Haunched blind mortise and tenon joint;
- Blind twin mortise and tenon joint;
- Blind mortise and tenon joint
- Haunched through twin mortise and tenon joint;
- Haunched through mortise and tenon joint;
- Haunched blind twin mortise and tenon joint;
- Twin through mortise and tenon joint;
- Through mortise and tenon joint.

It is recommended that the research results are taken into consideration in strength design of furniture.

Key words: corner joints, frame structural elements, destructive bending moments, solid spruce wood.

INTRODUCTION

Corner mortise and tenon joints are among the most commonly used joints in the furniture with frame structure. In the series of articles (Gruevski 2007, Jivkov 2001, Karalivanos 1992, Kyuchukov 2010, Kyuchukov et al 2004, Kyuchukov et al 2008 a, 2008 b, Kyuchukov et al 2009, Kyuchukov et al 2012 a, 2012 b, Kyuchukov et al 2013 and etc.) made of researchers at the University of Forestry – Sofia are given data for the strength and stiffness characteristics of some of the most often used corner joints of frame structural elements made of solid wood from deciduous tree species - mainly beech (Fagus sylvatica L.) and sweet chestnut (Castanea sativa Mill.). Publications for the strength characteristic of joints of structural elements made of solid wood from conifer tree species are almost lacking (Kyuchukov et al 2014 a, Kyuchukov et al 2014 b).

In the present part III, which is part of the series of articles, data are given for the destructive bending moments of some of the most often used corner joints of frame structural elements made of solid common spruce wood (Picea abies Karst.) which is one of the most commonly used conifer wood in Bulgaria. The data refer to the destructive beginning moments of 10 types of end corner mortise and tenon joints of structural elements with a cross section 50 x 30 mm, as stated in the Bulgarian State Standard 5527–73.

MATERIAL AND METHODS

The test samples of the joints are made of solid spruce wood, supplied from the Educational Experimental Forestry Enterprise of the University of Forestry at "Yundola". They are manufactured from the same sample tree as the tested in the parts I and II samples (Kyuchukov et al 2014 a, Kyuchukov et al 2014 b) i.e. from the solid wood with the same physical and mechanical properties: density – 387 kg/m^3; bending strength – 56 N/mm^2; compressive strength parallel to grain – 34 N/mm^2; longitudinal modulus of elasticity – 9 500 N/mm^2.

The following types of end corner mortise and tenon joints are tested:

Mortise and tenon joints (Figure 1):

- blind mortise and tenon joint;
- blind twin mortise and tenon joint;
- through mortise and tenon joint;
- twin through mortise and tenon joint.

2. Haunched mortise and tenon joints (Figure 2):

- Haunched blind mortise and tenon joint;
- Haunched blind twin mortise and tenon joint;
- Haunched through mortise and tenon joint;
- Haunched through twin mortise and tenon joint.

3. Miter mortise and tenonjoints (Figure 3):

- Miter mortise and tenon joint;
- Miter twin mortise and tenon joint.

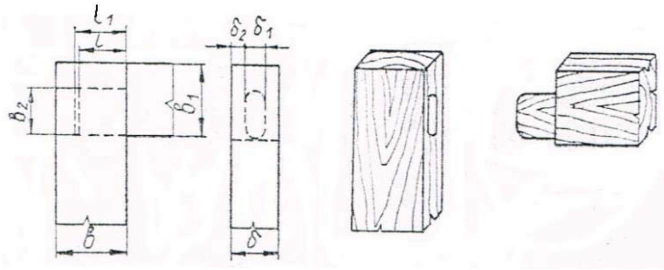
The parameters of the joints correspond to the Bulgarian State Standard 5527–73 and are given at figures 1 to 3.

The joints of the structural elements are made by gluing with polyvinyl acetate adhesive with the following characteristics: outer appearance – cream homogeneous viscose mass; viscosity – 3 500 cP (middle viscosity, suitable for brush coating); open time at 20 ^{o}C – not longer than 10 min.

The type and schemes of loading of the samples in their testing (Figure 4) correspond to the standardized methodology (BSS 9165–90), worked out at the Laboratory of Furniture Construction at the University of Forestry. The distance between the inner edges of the arms of the joint is L= 200 mm.

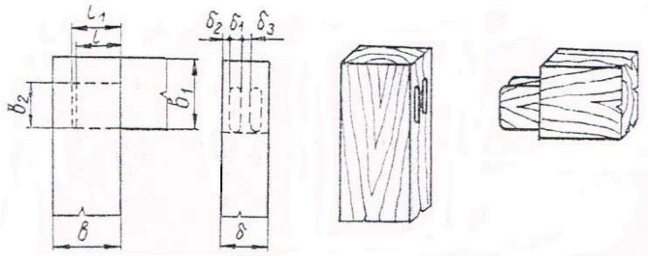
For each type of joint are manufactured 30 pieces of test samples – 15 pieces for arm opening testing load (Figure 4, a) and 15 pieces for arm compression testing load (Figure 4, b).

Before testing the samples are conditioned 5 days and nights at temperature (21 ± 3) ^{o}C and relative air humidity (55 ± 10) %.



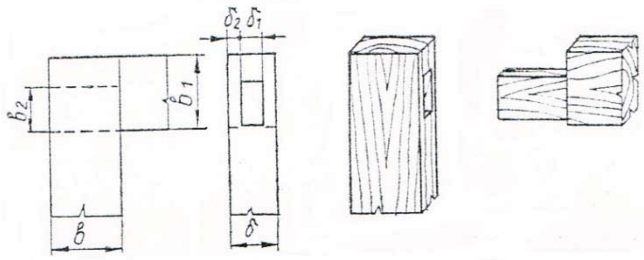
$b = b_1 = 50$ mm
$b_2 = (0.6 \div 0.8)\ b_1 = 30$ mm
$\delta = 30$ mm
$\delta_1 = 0.4\ \delta = 12$ mm
$\delta_2 = 0.3\ \delta = 9$ mm
$L = (0.5 \div 0.8)\ b = 40$ mm
$L_1 = L + 1 \div 2$ mm $= 42$ mm

1



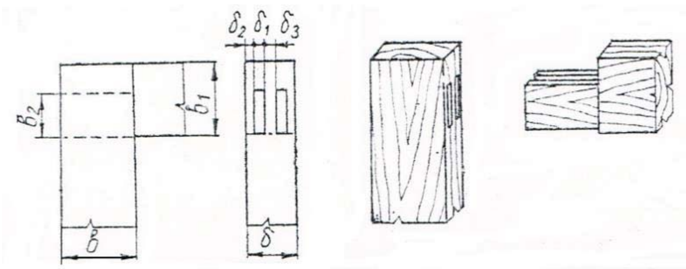
$b = b_1 = 50$ mm
$b_2 = (0.6 \div 0.8)\ b_1 = 30$ mm
$\delta = 30$ mm
$\delta_1 = \delta_3 = 0.22\ \delta \approx 7$ mm
$\delta_2 = 0.16\ \delta \approx 4.5$ mm
$L = (0.5 \div 0.8)\ b = 40$ mm
$L_1 = L + 1 \div 2$ mm $= 42$ mm

2



$b = b_1 = 50$ mm
$b_2 = (0.6 \div 0.8)\ b_1 = 30$ mm
$\delta = 30$ mm
$\delta_1 = 0.4\ \delta = 12$ mm
$\delta_2 = 0.3\ \delta = 9$ mm

3



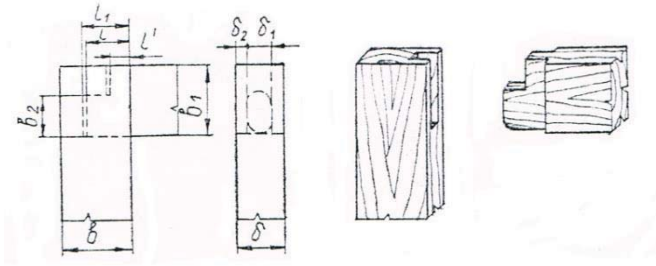
$b = b_1 = 50$ mm
$b_2 = (0.6 \div 0.8)\ b_1 = 30$ mm
$\delta = 30$ mm
$\delta_1 = \delta_3 = 0.22\ \delta \approx 7$mm
$\delta_2 = 0.16\ \delta \approx 4.5$ mm

4

Figure 1: End corner mortise and tenon joints: 1 – blind mortise and tenon joint; 2 – blind twin mortise and tenon joint; 3 – through mortise and tenon joint; 4 – twin through mortise and tenon joint.

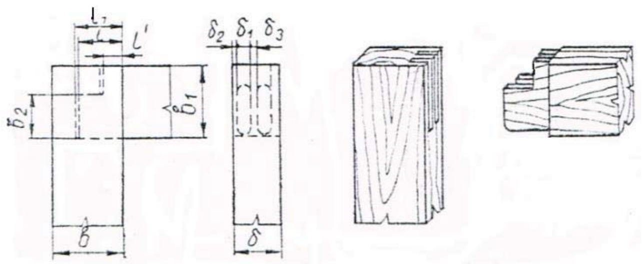
The test is carried out at a universal testing machine at an equal speed of loading in the length of (60 ± 30) s from the beginning of the loading and accuracy of reading of the results 1 % of the failure force of loading.

The destructive bending moments M_1 under arm opening bending test and M_2 under compression bending test have been calculated correspondingly by formulas (1) and (2).



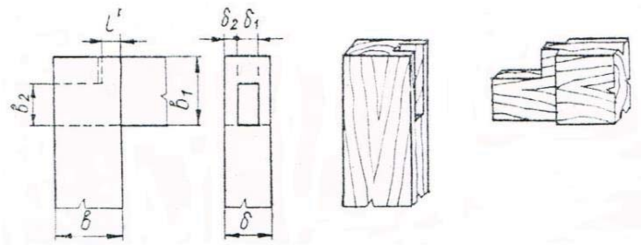
5

$b = b_1 = 50$ mm
$b_2 = (0.6 \div 0.8)\ b_1 \approx 30$ mm
$\delta = 30$ mm
$\delta_1 = 0.4\ \delta = 12$ mm
$\delta_2 = 0.3\ \delta = 9$ mm
$L = (0.5 \div 0.8)\ b = 40$ mm
$L_1 = L + 1 \div 2$ mm $= 42$ mm
$L^i = 12$ mm



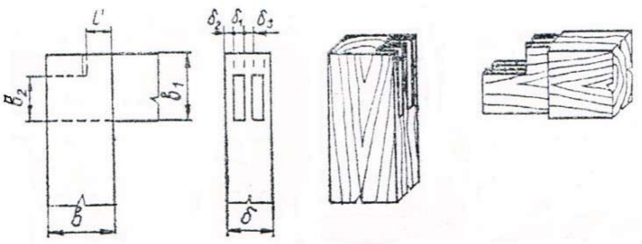
6

$b = b_1 = 50$ mm
$b_2 = (0.6 \div 0.8)\ b_1 \approx 30$ mm
$\delta = 30$ mm
$\delta_1 = \delta_3 = 0.22\ \delta \approx 7$ mm
$\delta_2 = 0.16\ \delta \approx 4.5$ mm
$L = (0.5 \div 0.8)\ b = 40$ mm
$L_1 = L + 1 \div 2$ mm $= 42$ mm
$L^I = 12$ mm



7

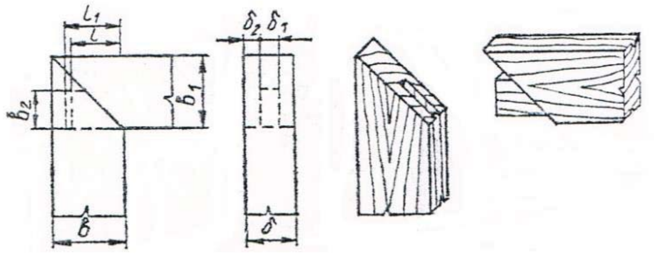
$b = b_1 = 50$ mm
$\delta = 30$ mm
$\delta_1 = 0.4\ \delta = 12$ mm
$\delta_2 = 0.3\ \delta = 9$ mm



8

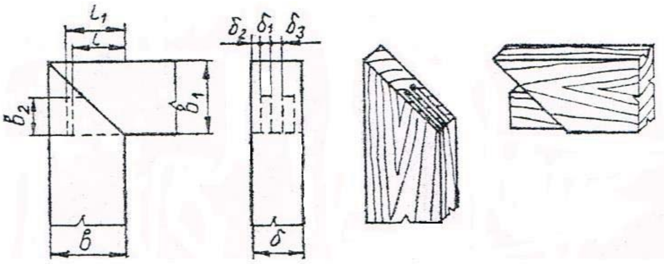
$b = b_1 = 50$ mm
$\delta = 30$ mm
$\delta_1 = \delta_2 = \delta_3 = 0.25\delta = 7.5$ mm

Figure 2: End corner haunched mortise and tenon joints: 5 – haunched blind mortise and tenon joint; 6 – haunched blind twin mortise and tenon joint; 7 – haunched through mortise and tenon joint; 8 – haunched through twin mortise and tenon joint.



$b = b_1 = 50$ mm
$\delta = 30$ mm
$\delta_1=\delta_3=0{,}16\ \delta\approx 5$ mm
$\delta_2 =0{,}10\ \delta\approx 2{,}5$ mm
L= (0,5÷0,8) b=40 mm
L_1=L+1÷2mm=42 mm

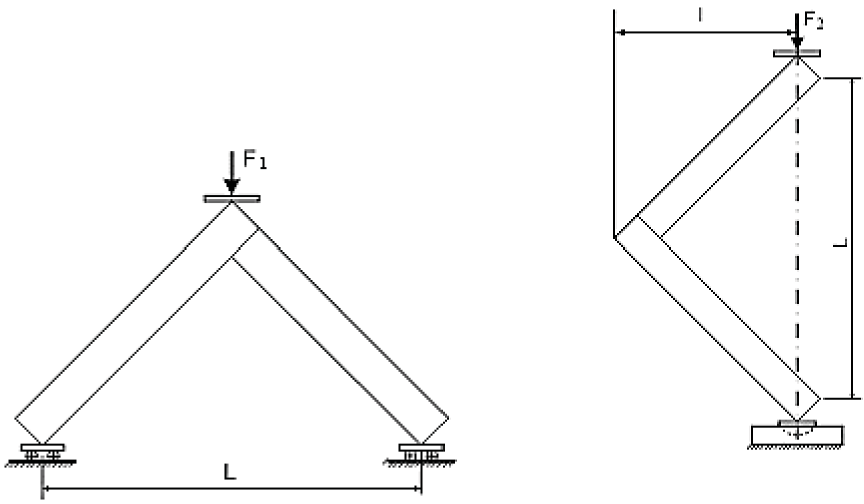
9



$b = b_1 = 50$ mm
$\delta = 30$ mm
$\delta_1= \delta_3 = 0{,}22\ \delta \approx 7$ mm
$\delta_2 = 0{,}16\ \delta \approx 4{,}5$ mm
L= (0,5÷0,8) b=30 mm
L_1=L+1÷2mm= 42 mm

10

Figure 3: End corner miter mortise and tenon joints: 9 – miter mortise and tenon joint; 10 – miter twin mortise and tenon joint.



a b

Figure 4: Scheme for testing of end corner joints:
a – in arm opening testing load; b – in arm compression testing load.

$$M_1 = \frac{F_1.L}{4} \quad (1)$$

$$M_2 = F_2.l \quad (2)$$

F_1 – failure force in arm opening bending test in N

F_2 – failure force in compression bending test in N;

L – span distance of arm opening bending test in m

l – arm of bending in compression bending test in m

The results from the experiments are processed by the variation statistics methods.

COMPARATIVE ANALYSIS OF THE EXPERIMENTAL RESULTS

The results from the research are given in Table 1and Table 2, and the correlation between the destructive bending moments of the tested corner joints is presented graphically in the same order on Figure 5.

Table 1: Destructive bending moments of end corner mortise and tenon joints of frame structural elements from solid spruce wood with a cross section 50 x 30 mm.

Type of joints	Variation statistics parameters of destructive bending moment $M_{b,d}$					
	$\bar{x}$, Nm	s, Nm	s_r, Nm	v, %	p, %	N, pc.
A. Arm opening bending load, M_1						
1. Blind mortise and tenon joint	141	21	5,5	15	3,9	15
2. Blind twin mortise and tenon joint	178	18	4,6	10	2,6	15
3. Through mortise and tenon joint	163	19	4,9	12	3,0	15
4. Twin through mortise and tenon joint	180	24	6,3	14	3,5	15
5. Haunched blind mortise and tenon joint	211	21	5,4	10	2,5	15
6. Haunched blind twin mortise and tenon joint	193	18	4,8	10	2,5	15
7. Haunched through mortise and tenon joint	140	13	3,4	9	2,4	15
8. Haunched through twin mortise and tenon joint	154	16	4,1	10	2,7	15
9. Miter mortise and tenon joint	125	17	4,3	13	3,5	15
10. Miter twin mortise and tenon joint	105	13	3,5	13	3,3	15
B. Arm compression bending load, M_2						
1. Blind mortise and tenon joint	258	20	5,3	8	2,1	15
2. Blind twin mortise and tenon joint	280	18	4,8	7	1,7	15
3. Through mortise and tenon joint	223	20	5,1	9	2,3	15
4. Twin through mortise and tenon joint	238	29	7,5	12	3,1	15
5. Haunched blind mortise and tenon joint	376	30	7,7	8	2,1	15
6. Haunched blind twin mortise and tenon joint	238	31	8,0	13	3,3	15
7. Haunched through mortise and tenon joint	242	25	6,6	10	2,7	15
8. Haunched through twin mortise and tenon joint	251	28	7,3	11	2,9	15
9. Miter mortise and tenon joint	231	29	7,6	13	3,3	15
10. Miter twin mortise and tenon joint	210	23	7,3	14	3,5	15

Where:

$\bar{x}$ - mean value, Nm;

s – mean error, Nm;

s_r – mean square error, Nm;

v – coefficient of variation, %;

p – index of accuracy, %;

n – number of test samples.

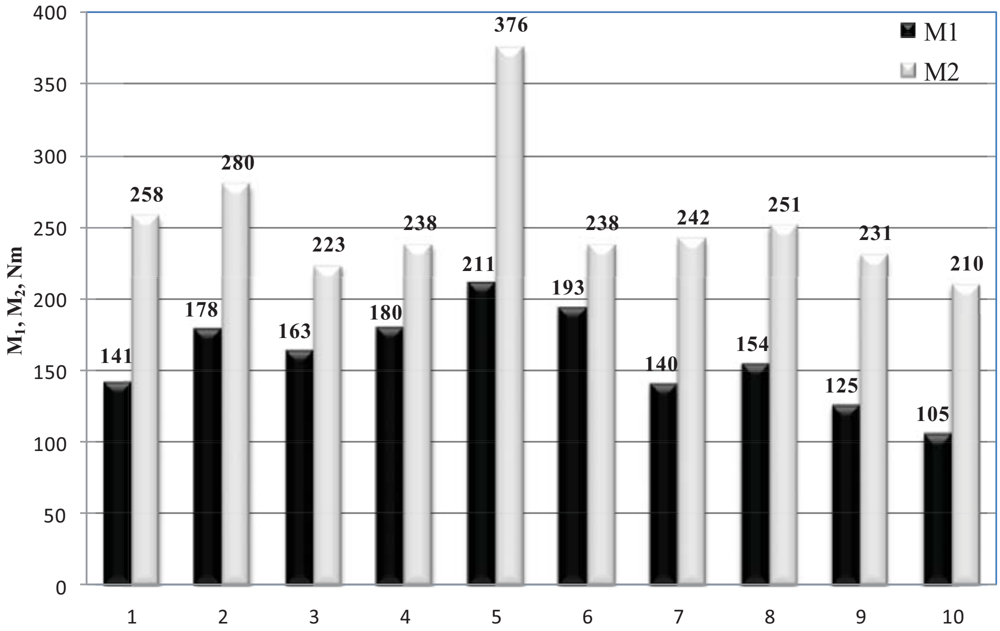


Figure 5: Comparative data for the destructive bending moments of the tested end corner mortise and tenon joints of frame structural elements made of solid spruce wood with a cross section 50 x 30 mm (1 to 10 as in Table 1).

From the data in Table 1 and Figure 5 is seen that the destructive bending moment depends upon the scheme at which the joint is loaded as well as the type of the joint. The destructive bending moments of joints under compression bending test have about 60 % bigger values compared to the joints loaded under arm opening bending test.

Under arm opening test the following 5 types of joints are destroyed at comparatively big bending moment (over 160 Nm):

- Haunched blind mortise and tenon joint;
- Haunched blind twin mortise and tenon joint;
- Twin through mortise and tenon joint;
- Blind twin mortise and tenon joint;
- Through mortise and tenon joint.

Under arm compression test the following 5 types of joints are destroyed at comparatively big bending moment (over 230 Nm):

- Haunched blind mortise and tenon joint;
- Blind twin mortise and tenon joint
- Blind mortise and tenon joint;
- Haunched through twin mortise and tenon joint;
- Haunched through mortise and tenon joint

It is seen that in both types of loading the same corner joints are destroyed in a comparatively big bending moment.

From the data in Table 1 and Figure 5 it is seen again that the type of joints, dimensions of the joint elements and the area of the adhesive line have a considerable influence on the destructive bending moment. This is confirmed by the mode of destroying of the samples (Table 2) as well. The corner joints having greater strength characteristic are destroyed mainly because of a fracture or withdraw of the tenon or splitting the mortise, i.e. outside the glue line.

Table 2: Mode of destroying of the samples of the tested corner joints at an average for the both types of loading.

Type of joints	Mode of destroying of the samples			
	In the glue line, %	Fracture of the tenon, %	Withdraw of the tenon, %	Splitting of mortise, %
1. Blind mortise and tenon joint	0	0	60	40
2. Blind twin mortise and tenon joint	0	100	0	0
3. Through mortise and tenon joint	0	60	15	25
4. Twin through mortise and tenon joint	0	100	0	0
5. Haunched blind mortise and tenon joint	0	56	0	44
6. Haunched blind twin mortise and tenon joint	0	80	20	0
7. Haunched through mortise and tenon joint	0	10	35	55
8. Haunched through twin mortise and tenon joint	0	37	30	33
9. Miter mortise and tenon joint	100	0	0	0
10. Miter twin mortise and tenon joint	100	0	0	0

CONCLUSION

The results from the carried out research give reason to make the following more common conclusions:

1. The type of joint is a determining factor for its strength characteristics. It is defined by the type and dimensions of the joining elements and the area of the gluing of the contact surfaces of the joints.

2. The following joints are destroyed at a considerably big bending moment in arm opening bending test:

- Haunched blind mortise and tenon joint;
- Haunched blind twin mortise and tenon joint;
- Twin through mortise and tenon joint;
- Blind twin mortise and tenon joint;
- Through mortise and tenon joint.

3. The following joints are destroyed at a considerably big bending moment in compression bending test:

- Haunched blind twin mortise and tenon joint;
- Blind twin mortise and tenon joint;
- Blind mortise and tenon joint;
- Haunched through twin mortise and tenon joint;
- Haunched blind twin mortise and tenon joint.

4. Ties recommended that the results from the research should be taken into account in the strength design of the sitting furniture, tables and beds.

REFERENCES

1. Gruevski, G. (2007). *Izstrajuvanja na sostavite vo konstruktsiite na stolovi, izraboteni od kostenovo drwo*. Doktorska disertatsia, Faculty of forestry, Skopje.
2. Jivkov, V. (2001). *Influence of the tolerances on the strength characteristics of the main glued joints of furniture*. PhD thesis, University of Forestry, Sofia.
3. Karalivanos, A. (1992). *Comparative studies on strength characteristics of joints in chair constructions made from beech wood*. PhD. thesis, Aristotle University of Thessaloniki.
4. 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*. Zagreb University, 23rd International scientific conference, Proceedings, 103–110.
5. KyuchukovG., Marinova, A., Gruevski, G., Kyuchukov, B., Jivkov, V. (2012). *Stiffness coefficients under bending test of T-shape corner joints of frame structural elements with a cross section 50 x 30 mm made of sweet chestnut wood*. Zagreb university, 23rd International scientific conference, Proceedings, 97–102.

6. 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 50 x 25 mm*. Innovation in woodworking industry and engineering design, INNO vol II, Sofia, 1/2013, 98–104.
7. Kyuchukov, G., Gruevski, G., Kyuchukov, B. (2010). *Comparative studies on destructive bending moments of end corner joints of component of solid chestnut wood with a cross section of 50 x 25 mm*. Proceedings scientific papers, scientific technical conference "Innovation in woodworking industry and engineering design", Sofa 5–7 November 2010, pp. 206–210.
8. Kyuchukov, G., Gruevski, G., Kyuchukov, B. (2012). *Comparative studies on destructive bending moments of T-shape corner joints of frame structural elements made of sweet chestnut wood with a cross section 50 x 25 mm*. "Innovation in woodworking industry and engineering design", Sofia, 1/2012, vol. 1, pp. 79–85.
9. Kyuchukov, G., Gruevski, G., Kyuchukov, B. (2013). *Comparative analysis between the destructive bending moments of end and T-shape corner joints of frame structural elements made of solid chestnut wood with a cross section 50 x 25 mm*. Innovation in woodworking industry and engineering design, INNO vol. II, Sofia, 1/2013, pp. 93–97.
10. Kyuchukov, G., Gruevski, G., Marinova, A., Kyuchukov, B., Jivkov, V. (2011). *Stiffness coefficients under bending test of end corner joints of structural elements made of sweet chestnut wood*. Zagreb university, International scientific conference, Proceedings, pp. 89–97.
11. Kyuchukov, G., Gruevski, G., Marinova, A., Kyuchukov, B. (2008). *Stiffness coefficients under bending test of end corner joints of frame structural elements made of sweet chestnut wood*. 7th Symposium with International symposium "Furniture 2008", Faculty of Wood Science and Technology, Zvolen, Slovakia.
12. Kyuchukov, G., Gruevski, G., Marinova, A., Kyuchukov, B. (2008). *Stiffness coefficients under bending test of T-shape corner joints of frame structural elements made of sweet chestnut wood*. Proceedings scientific papers, scientific technical conference "Innovation in woodworking industry and engineering design", Yundola, 14–16 November 2008, pp. 265–270.
13. Kyuchukov, G., Gruevski, G., Marinova, A., Kyuchukov, B. (2009). *Comparative analysis of stiffness coefficients of end and T-shape corner joints of frame structural elements made of sweet chestnut wood*. 20th International scientific conference, University of Zagreb, Proceedings, Zagreb, October 2009, pp. 101–104.
14. Kyuchukov, G., Kyuchukov, B., Jivkov, V., Marinova, A., Gruevski, G., Kanarchev, K. (2014). *Comparative research on the destructive bending moments of some corner joints of frame structural elements made of solid spruce wood with a cross section of 50 x 30 mm. Part II: Endcorneropen mortise and tenonjoints*. 25th International scientific conference "New materials and technologies in the function of wooden products", 17th of October, Zagreb, Croatia, pp. 93–101.
15. Kyuchukov, G., Kyuchukov, B., Jivkov, V., Marinova, A., Gruevski, G., Masov, V. (2014). *Comparative research on the destructive bending moments of some corner joints of frame structural elements made of solid spruce wood with a cross section of 50 x 30 mm. Part I: End corner but joints and face splined joints*. Wood, Design & Technology, Vol. 3, No 1: 73–82.
16. Kyuchukov, G., Marinova, A., Gruevski, G., Kyuchukov, B., Jivkov, V. (2013). *Comparative analysis of stiffness coefficients under bending test of end and T-shape corner joints of frame structural elements with cross section of 50 x 30 mm*. International scientific technical conference "Wood technologies and product design", Ohrid, May, Proceedings, pp. 135–138.
17. Kyuchukov, G., Marinova, A., Kyuchukov, B., Gruevski, G. (2004). *Stiffness coefficients of corner joints of details from chestnut wood*. Proceedings, 12th Balkan conference of standardization, BSS, Sofia, pp. 98–101.

UNIVERSITY OF FORESTRY

FACULTY OF FOREST INDUSTRY

INNOVATION IN WOODWORKING INDUSTRY AND ENGINEERING DESIGN

2/2016

INNO vol. V Sofia

ISSN 1314-6149
e-ISSN 2367-6663

CONTENTS