

INVESTIGATION OF THE INFLUENCE OF SOME FACTORS ON THE STRENGTH AND STIFFNESS OF JOINTS WITH STAPLES AND GUSSET PLATES

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ABSTRACT

Joints made with staples and gusset plates are widely used in the wood frame construction of various types of furniture, due to the quick and easy production and the availability of simple technology. In this regard, their good knowledge of bending loads would help furniture designers in the design process. The investigation aims to summarize the data from the specialized literature on the values of parameters characterizing the behavior of joints with staples and gusset plates of details in wood frame, as well as to establish the influence of some key factors such as the detailed thickness, the angle between wood details of the joints, thickness and type of material of the gusset plates on their strength and stiffness under bending load.

Key words: joints with staples and gusset plates, strength and stiffness, wood frames, bending load.

INTRODUCTION

In recent years, the information from the development of the wood-processing and furniture industry shows that the joints by means of staples and reinforcing members in a frames are still successfully applied in the structure of upholstered furniture, which makes them an interesting object of study by a number of authors also to this day. Way back in the distant year of 1971, Eckelman determined the strength under bending load and stiffness of middle corner joints in a frame of Douglas fir (*Pseudotsuga*) plywood structural members. As a result of his study, the author concluded that the strength under bending load is satisfactory with one-sided reinforcement of the joint, it could also be improved by increasing the size of the reinforcing member, and directly depends not so much on the number and density of the connecting elements, but on the shear strength of the adhesive joint of the individual veneer sheets making up the plywood structure (Eckelman, 1971). Erdil et. Al (2003) determined the maximum bending moment under

bending load of middle corner joints in a frame by means of staples on OSB structural elements and HDF reinforcing members, with and without the presence of adhesive. The results indicate that the application of adhesive results in a nearly two-fold increase in strength, with maximum bending moment values ranging from 1183 to 2728 lb.inch for non-adhesive joints and from 3763 to 4500 lb.inch for adhesive joints, depending on the number of staples, used in the joint, varying from 6 to 12 over the course of the study. Wang et al. investigated the behavior of middle corner joints by means of staples of 23/32 inch thick OSB structural elements, with reinforcing members, with and without application of adhesive. The structural elements are 6 inches wide and 16 inches long, and the reinforcing members are double-sided OSB, with a thickness of 7/16 inch, a width of 6 inches and different lengths – 4, 6, 8, 10, 12 inches. 16 and 17 gauge staples were used. The obtained results indicate: upon application of adhesive the reinforcing members, the strength of the joint increases by 27%; the reinforcing member with a

length of 102 mm is insufficient, and with a length of 305 mm it is oversized for such type of joints; with an increase in the width of the reinforcing member in the range from 102 mm to 203 mm, the presence of adhesive does not lead to a significant increase in the strength of the joint. The established values for the maximum loading force under bending load are in the range of 0.67 to 1.27 Kip. The authors found that changing the position of the staple does not affect the strength of the joint (Wang et al., 2007^a). In the second part of their study, the authors examined the behavior of the same type of joints under dynamic load. The observed characteristic damages are pulling out of the staple, shearing along the thickness of the board, breaking of the member of the joint. In conclusion of their study, the authors conclude that such type of joints should not be subjected to load with more than 48% of the breaking force obtained under a static load (Wang et. al., 2007^b). Taking into account the information from the specialized literature, we could conclude that no data were found on the strength and stiffness of joints by means of staples and reinforcing members at an angle other than 90°. In this regard, the present first part of a series of studies includes data on the maximum bending moments and stiffness coefficients of middle and end corner joints at an angle other than 90°, in a standard frame, similar to the inclination of the backrest to the seat of furniture for sitting and sleeping (BDS 17198:1990), of white pine (*Pinus sylvestris* L.) wood members with reinforcing beech plywood members, by means of staples and adhesive, subjected to static bending load.

MATERIALS AND METHODS

For the purposes of the study, Scots pine (*Pinus sylvestris* L.) wood was used for the members of the test specimens, with a cross

section of 50x25 mm and 5-layer beech plywood, class B/BB, with a thickness of 8 mm for the reinforcing members. The materials have the following physical and mechanical properties: Scots pine with density – $\rho_{12} = 430 \text{ kg.m}^{-3}$, modulus of elasticity – $E_{L12\%} = 9000.10^6 \text{ N.m}^{-2}$ and bending strength $\sigma_{\text{bend.12}} = 64,84.10^6 \text{ N.m}^{-2}$; plywood – $\rho = 760 \text{ kg/m}^3$, $E_{\parallel} = 3500.10^6 \text{ N.m}^{-2}$, $E_{\perp} = 7100.10^6 \text{ N.m}^{-2}$, $\sigma_{\text{bend.}\parallel} = 75.10^6 \text{ N.m}^{-2}$, $\sigma_{\text{bend.}\perp} = 68.10^6 \text{ N.m}^{-2}$. The structural members of the laboratory-tested joints were assembled by connecting elements – staples and adhesion. Staples series 100, type M₁ (gauge 17) of the OMER company, with a wire cross-section of 1.24/1.46 mm and a body length of 30 mm, were used. The application of adhesive with polyvinyl acetate adhesive (PVA) – Moment Wood Standard of the company HENKEL, class D2 was carried out at a controlled consumption per unit area of 180 g.m⁻², by means of the weight method. The assembly was carried out by means of a device that ensures the angle between the wood members and a pneumatic stapler of the company FASCO – model F44C. An operating pressure of 5.10^5 N.mm^{-2} was used.

The study was carried out on the series of test specimens shown in table 1 with the appearance, shape and dimensions presented in Fig. 1.

The specimens are loaded in arm compression bending load, according to the scheme presented in Fig. 2, until reaching the maximum loading force F_{max} , in a time interval of $60 \pm 30 \text{ s}$, for each test specimen.

The maximum bending moment under bending stress by collecting arms was determined according to formula (1) in N.m (Kyuchukov, 2016).

$$M_{\text{max}} = F_{\text{max}} \cdot l \quad , \quad (1)$$

where F_{max} is a bending moment under bending stress by collecting arms, N;

l – bending arm, m.

Table 1: Butt joints by gusset plates and staples M_{1/30} with glue used for laboratory tests depending on the angle between the details

Type of corner joint	135° (45°)	120° (30°)	105° (15°)
T-shape butt joints at an angle other than 90° by staples with gusset plates and glue	A _{1M1/30PVA} 1*	A _{2M1/30PVA} 2	A _{3M1/30PVA} 3
End corner butt joints at an angle other than 90° by staples with gusset plates and glue	A _{4M1/30PVA} 4	A _{5M1/30PVA} 5	A _{6M1/40ΔPVA} 6

* 1, 2, 3, 4, 5, 6 – number series

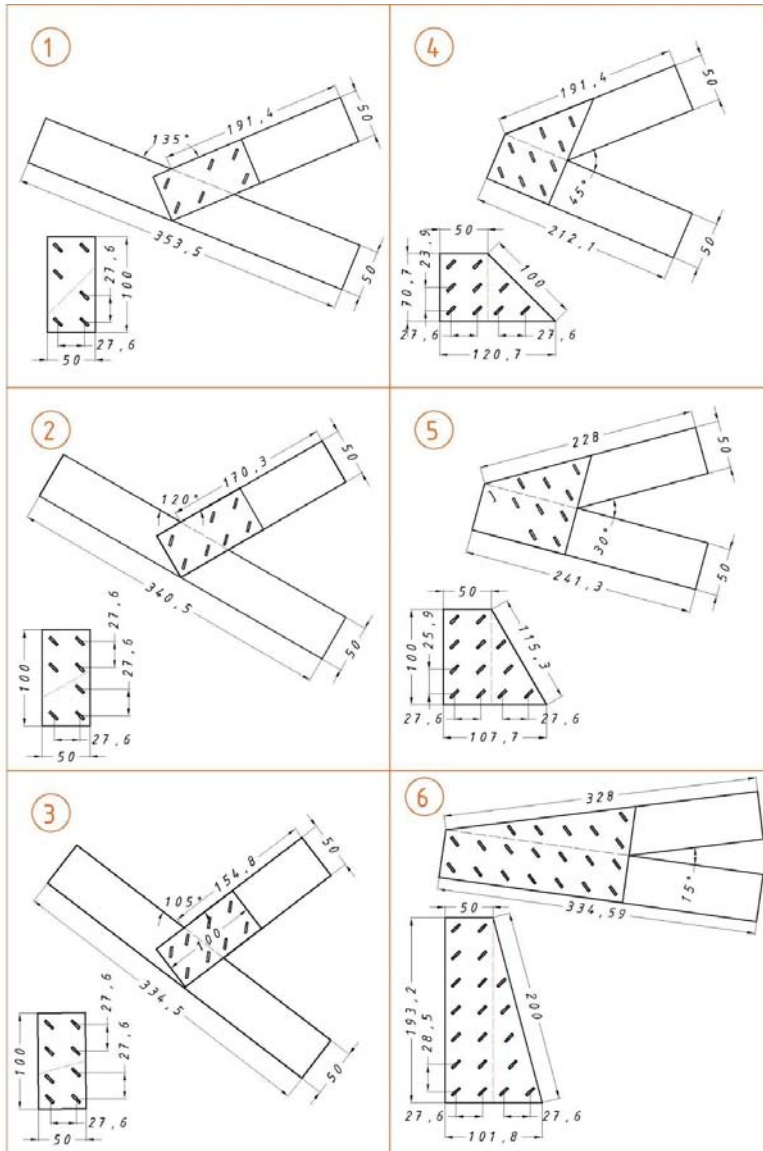


Figure 1: Type and dimension of the tested samples

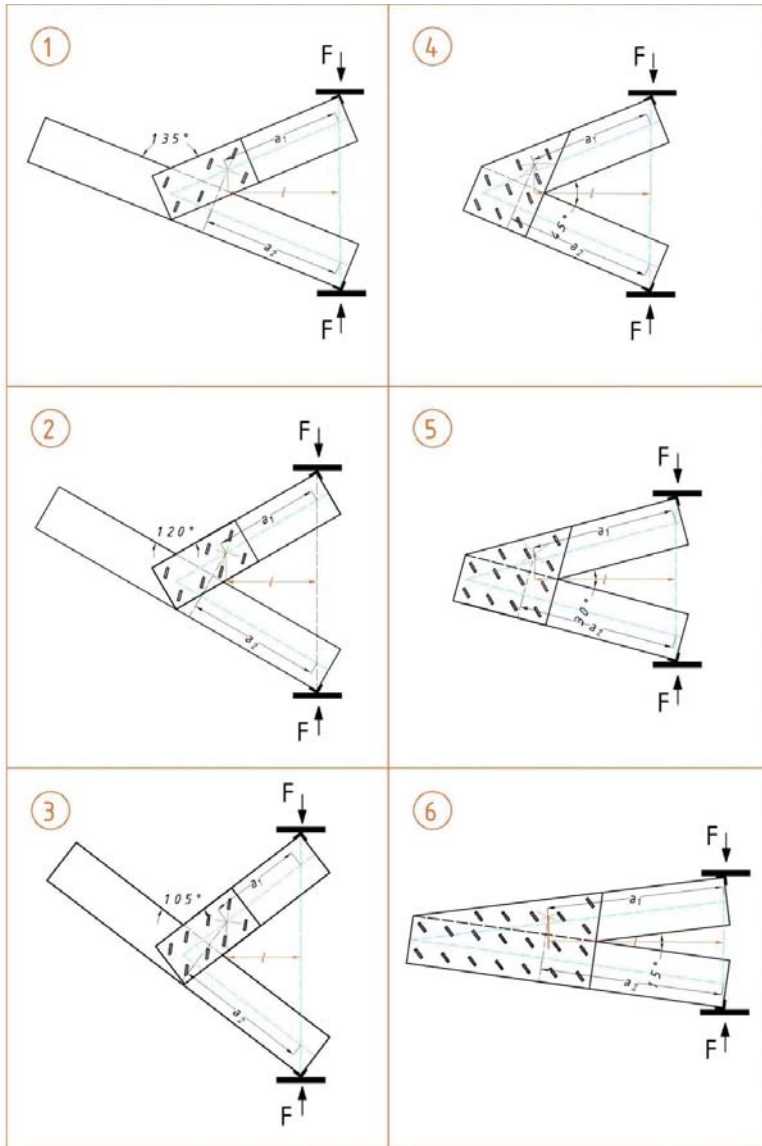


Figure 2: Scheme for testing of test simple and method of determining the bending arm l depending on the types of joint

The stiffness coefficient c_i under bending stress by collecting arms was determined according to formulas (2), (3) and (4) in N.m.rad^{-1} .

$$c_i = \frac{\Delta M_i}{\Delta \alpha_i}, \quad (2)$$

$$\Delta M_i = M_i - M_0 \quad (3)$$

$$\Delta \alpha_i = \alpha_i - \alpha_0 \quad (4)$$

Where c_i is rotational stiffness, N.m.rad^{-1} ;
 M_i, M_0 – bending moment for F_{40} and F_{10} ,
 N.m ;
 α_i, α_0 – angle of semi-rigid rotation of the arms of the joint at F_{40} and F_{10} , rad.

The results of the conducted laboratory experiments were processed variationally and statistically by the least-squares method using Microsoft Excel.

RESULTS AND DISCUSSION

As a result of the study, the arithmetic mean values of the maximum bending mo-

ments and stiffness coefficients of butt joints, at an angle other than 90° , by gusset plates and staples $M_{1/30}$ with glue, in a wood frame, were determined, the values are presented in table 2 and table 3.

Table 2: Variation statistics parameters from maximum bending moments $M_{\max.\text{bend.}}$ of butt joints at an angle other than 90° by gusset plates and staples $M_{1/30}$ with glue in a wood frame

№ series	Type of joints	$\bar{\chi}$, N.m	M_{\max} , N.m	M_{\min} , N.m	med., N.m	s, N.m	v, %	p, %	n, бр.
1	A _{1M1/30PVA}	185,36	229,99	150,23	188,64	22,85	12,33	3,90	10
2	A _{2M1/30PVA}	143,78	165,99	115,35	144,52	17,67	12,29	3,89	10
3	A _{3M1/30PVA}	142,74	164,56	106,74	147,93	17,10	11,98	3,79	10
4	A _{4M1/30PVA}	182,05	203,82	130,36	186,87	22,43	12,32	3,90	10
5	A _{5M1/30PVA}	322,95	352,88	284,71	327,09	21,63	6,70	2,12	10
6	A _{6M1/30PVA}	668,42	900,50	544,68	587,62	130,88	20,42	6,46	10

Table 3: Variation statistics parameters from stiffness coefficients c_i of butt joints at an angle other than 90° by gusset plates and staples $M_{1/30}$ with glue in a wood frame

№ серия	Вид серия	$\bar{\chi}$, N.m.rad ⁻¹	c_{\max} , N.m.rad ⁻¹	c_{\min} , N.m.rad ⁻¹	med., N.m.rad ⁻¹	s, N.m.rad ⁻¹	v, %	p, %	n, бр.
1	A _{1M1/30PVA}	2492,43	2809,18	1898,40	2625,58	298,07	11,96	3,78	10
2	A _{2M1/30PVA}	1618,64	2041,53	1346,27	1686,54	220,32	13,61	4,30	10
3	A _{3M1/30PVA}	1430,00	1712,46	1205,04	1450,74	171,15	11,97	3,78	10
4	A _{4M1/30PVA}	3589,97	4294,86	2829,13	3498,70	492,63	13,72	4,34	10
5	A _{5M1/30PVA}	4792,46	5957,43	4206,89	4575,41	602,85	12,58	3,98	10
6	A _{6M1/30PVA}	11417,57	14815,47	9358,68	10764,49	2249,75	19,70	6,23	10

The results of table 2 show that with a decrease in the angle between the arms of the joint, the values of the maximum bending moments $M_{\max.\text{bend.}}$ for T-shape butt joints, series No. 1, 2, 3, respectively, decrease in the range of 185.36 to 142.74 Nm, with between 135° and 120° the percentage difference being 28,92%, and between 120° and 105° being insignificant, due to the fairly close values between series No. 2 and No. 3, 143.78 Nm and 142.74 Nm, respectively. These close values are probably the result of the larger number of connecting elements – staples connecting the reinforcing member of the joint with the lower structural element, in series No. 3 compared to series No. 2.

The opposite trend is observed in end corner joints, series No. 4, 5, 6, with values of $M_{\max.\text{bend.}}$ from 182,05 to 558,42 Nm. This large percentage increase is due to the larger adhesive area between the structural elements, as well as between them and the reinforcing member. The strength of the end corner joints increases by 43.63% when the angle decreases from 45° to 30° and by 51.68% in the range from 30° to 15° .

From the determined values for the stiffness coefficients /table 3/ it was found that as the angle between the arms of the joint decreases, the compliance of the connection between the structural elements decreases in the

T-shape butt joints, series No. 1, 2, 3 and increases in the end corner joints, series No. 4, 5, 6 with the following percent differences: series No. 1, 2 – 53.98%; series No. 2, 3 – 17.95%; series No. 4, 5 – 33.5%; series No. 5, 6 – 138.24%.

As a result of the conducted study, two types of destruction were found in series No. 1, 2 and 3. The first type is expressed in the destruction of the adhesive joint between the two wood members, and the second type in the delamination of the plywood. Higher values of the maximum bending moment were found in the second type of destruction. In the case of series No. 4, destruction of the plywood reinforcing member was observed, in the part with the wood member with a smaller adhesive area. Delamination of the reinforcing member is also observed in series No. 5,

in the part before the adhesive joint. Series No. 6 is characterized by two types of destruction, which is also due to the slightly increased values of the accuracy index for $M_{\max.\text{bend.}}$ and c^i . The first type is expressed in the destruction of one of the arms of the wood joint, and the second in the delamination of the plywood. Determining for the type of destruction in this series is the direction and density of the annual rings in the wood members.

Fig. 3 and Fig. 4 show the dependences between the values of the maximum bending moments and stiffness coefficients and the angle between the members, the object of the study. Second-order equations are derived, which would help in predicting the strength and stiffness of joints of the studied species.

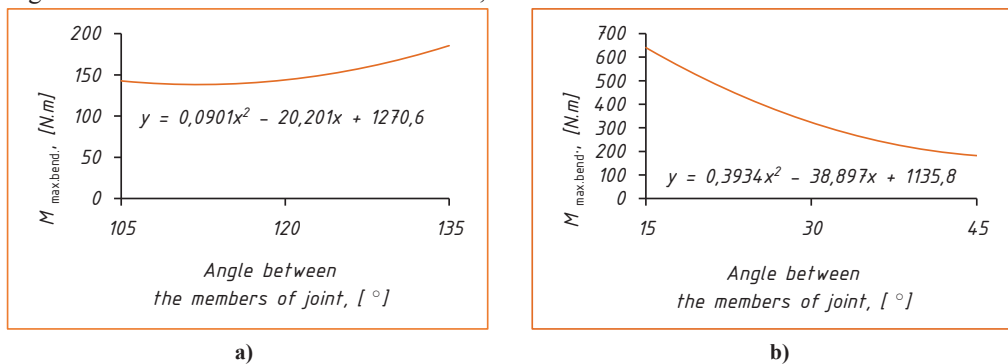


Figure 3: Relation of the angle between the arms of the joint and the maximum bending moment $M_{\max.\text{or.}}$ of the investigated T-shape a) and end corner b) butt joints

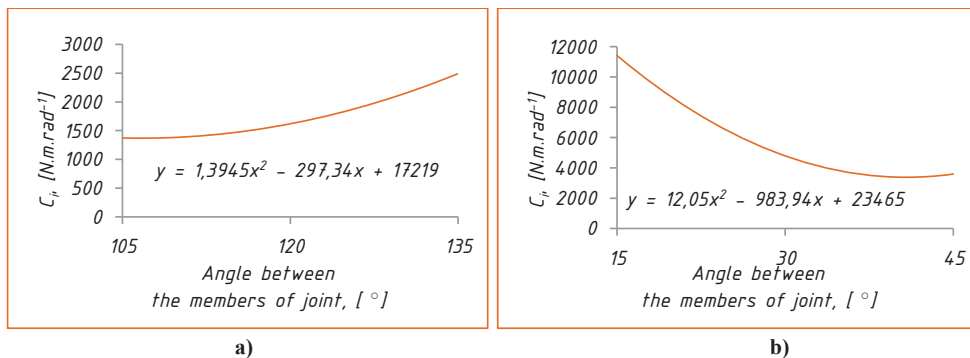


Figure 4: Relation of the angle between the arms of the joint and the stiffness of coefficients c_i of the investigated T-shape a) and end corner b) butt joints

CONCLUSIONS

From the laboratory study thus carried out, the values for the maximum bending moments and stiffness coefficients under bending load of butt joints, at an angle other than 90° , by gusset plates and staples $M_{1/30}$ with glue in a wood frame, were established, as a result of which several recommendations could be made:

- It is recommended in the T-shape butt joints by staples with glue and 8 mm thick plywood reinforcing members and an angle between the members of 135° and 120° , to check the strength and stiffness of the joints under bending load and four numbers of staples in the joining part on the plywood reinforcing member and the lower wood member;
- In the butt end corner joints by staples with 8 mm thick plywood reinforcing members and an angle between the members of 45° , the strength and stiffness of the joint under a bending load should be checked and a larger size of the plywood reinforcing member;

- In the butt end corner joints by staples with 8 mm thick plywood reinforcing members and an angle between the members of 15° , it is recommended to check the strength and stiffness of the joint under bending load with a reduced number of connecting elements.

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UNIVERSITY OF FORESTRY

FACULTY OF FOREST INDUSTRY



INNOVATION IN WOODWORKING INDUSTRY AND ENGINEERING DESIGN

1/2023

INNO vol. XII Sofia

ISSN 1314-6149
e-ISSN 2367-6663

Indexed with and included in CABI

INNOVATION IN WOODWORKING INDUSTRY AND ENGINEERING DESIGN

Science Journal
Vol. 12/ p. 1–80
Sofia 1/2023

ISSN 1314-6149
e-ISSN 2367-6663

Edition of
FACULTY OF FOREST INDUSTRY – UNIVERSITY OF FORESTRY – SOFIA

The Scientific Journal is indexed with and included in CABI.

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Cover Design: **DESI SLAVA ANGELOVA**

Printed by: **INTEL ENTRANCE**

Publisher address: **UNIVERSITY OF FORESTRY – FACULTY OF FOREST INDUSTRY**
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CONTENTS

DESIGNING AN ICONOSTASIS OF AN ORTHODOX CHURCH.....	5
Asparuh Atanasov, Aleksandrina Bankova	
DATA ENVELOPMENT ANALYSIS OF FACTORS FOR FOREST INDUSTRY WAGES AND SALARIES LEVELS IN NUTS 2 REGIONS OF BULGARIA.....	12
Nikolay Neykov, Radostina Popova-Terziyska, Emil Kitchoukov	
INVESTIGATION OF THE INFLUENCE OF SOME FACTORS ON THE STRENGTH AND STIFFNESS OF JOINTS WITH STAPLES AND GUSSET PLATES.....	18
Desislava Hristodorova, Nelly Staneva	
DEPENDENCE ON SHRINKAGE AND SWELLING IN CHEMICAL COMPOSITION AND ANATOMICAL STRUCTURE – AN OVERVIEW	25
Martina Todorova, Nikolai Bardarov	
REDUCTION OF FORMALDEHYDE EMISSION FROM WOOD-BASED PANELS BY MODIFICATION OF UF ADHESIVES WITH NATURAL BIOPOLYMERS.....	31
Ján Matyašovský, Ján Sedliačik, Peter Jurkovič, Peter Duchovič, Igor Novák	
MODERN ENGINEERING TECHNIQUES FOR THE PRODUCTION OF MODIFIED POLYSACCHARIDES WITH BIOLOGICAL ACTIVITY.....	41
Dragomir Vassilev, Nadezhda Petkova, Milka Atanasova, Panteley Denev	
SUNFLOWER STALKS AND LIGNOSULFONATE – ALTERNATIVE RAW MATERIALS FOR THE PRODUCTION OF ECO-FRIENDLY MEDIUM DENSITY FIBREBOARDS	47
Julia Mihajlova, Viktor Savov	
BEECH WOOD MODIFIED BY RADIO-FREQUENCY DISCHARGE PLASMA.....	58
Peter Jurkovič, Ján Sedliačik, Igor Novák, Ivan Chodák, Angela Kleinová, Ján Matyašovský	
MODIFICATION OF VARIOUS WOOD SPECIES BY BARRIER DISCHARGE PLASMA	62
Ján Sedliačik, Igor Novák, Ivan Chodák, Angela Kleinová, Ján Matyašovský, Peter Jurkovič	
APPLICATION OF ONLINE PLATFORMS IN TRAINING FOR THE DEVELOPMENT OF PROFESSIONAL DIGITAL COMPETENCES.....	66
Adelina Ivanova, Melina Neykova	
SCIENTIFIC JOURNAL „INNOVATIONS IN WOODWORKING INDUSTRY AND ENGINEERING DESIGN“	78