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INFLUENCE OF TYPE OF FIT ON STRENGTH AND DEFORMATION OF OVAL TENON-MORTISE JOINT

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ABSTRACT

Only a few studies were found in which joints are taken into consideration while analyzing spatial furniture by usage of finite element method. This paper presents results of effects of type of fit on strength of oval tenon-mortise. When calculation are to be made in solid-mechanics, specific input parameters must be defined. In most modern finite element software's Young's modulus of elasticity is one of the basic data. The type of strain, which is result of the fit with splice, has impact on the changes in the Young's modulus of elasticity, which is the basic parameter in the defining of the material of the model. Aim of this study is to define rate of deformation of oval tenon-mortise joint as a result of fitting influence. Type and size of strains which occur in a joint in case of the fit with splice were examined with templates which were set on a joint. Based on this study results, the type of fit has influence on strength of the joints. In the presence of the fit with splice, a permanent change in the dimensions of the plug and hole will occur. During joining of joints with a splice fit, most strains belong to the group of elastic strains, which by all means contributes to the joint strength.

KEYWORDS: Chair, *Fagus sylvatica*, joint, deformation, oval mortise and tenon, type of fit.

INTRODUCTION

Study of scientific papers in the field of the application of the finite element method in the construction of chairs and other types of spatial furniture creates the impression that few investigators engaged in the analysis of joints. In papers which analyse furniture as a spatial construction, combined stress-strain situation occurs within wood joints. State in joints is mainly defined as inner stress, without further analysis of the type of fit, the shape of the hole and tenon, the thickness of the layer of glue, as well as other factors which have impact on joint strength. In order to analyse wood joints by applying the finite element method it is necessary to carry out preliminary preparatory research. Its results reveal values which can enable element modelling by the finite element method using a programme package. An overview of the published scientific papers revealed neither such data nor recommendations which could serve as the base for defining a model. Beside other things, defining a model requires available data on the size and type of strain which appears as a result of the fit with splice. This type of strain has impact on the changes in the Young's modulus of elasticity which is the basic parameter in defining the material of this model.

Durability and strength of chairs are influenced by a number of correlated factors which make the stress situation of chairs highly complex. Strength and durability of different types of chairs (wooden chairs) are mostly a function of rigidity and type of joints. Based on prior research, the strength of joints was influenced by gluing surface, machining quality, type of fit, species and humidity of material, glue quality and parameters of gluing. Prior research in the field, in this country and abroad, gave an insight into the influence of certain single factors on this complex issue. In most studies which investigated this topic (Potrebić 1970, Skakić and Janićijević (2000), Džinčić (2006), Skakić and Džinčić (2006), Rüdiger et al. (1991) joints were made in a slight fit with splice or uncertain fitting.

We found that Potrebic was the first one to consider influence of type of fit on the strength of joints in spatial furniture in our country. One of the most important conclusions, given in his master thesis (Potrebic (1970)), is recommendation that wooden joints used in chairs must be produced with splice of 0.2 mm.

Rüdiger et al. (1991), suggests that there are two critical places in wooden chairs. One is joint between front leg and side rail, and the other is joint side rail and back leg.

In the article Skakić and Janićijević (2000), comparative analyses of strength of various joints was presented. Based on the study results, authors presented that the highest strength was shown by double tenon-mortise, and the lowest strength by the joint with two dowels. They concluded that machining quality and type of fit affects the strength of joints in all study constructions.

In the paper (Skakić and Džinčić 2006) authors examined influence of type of fit on the strength of oval tenon-mortise joint. In referred paper one of the conclusions was that fit with splice, where upper splice was 0.55 mm (class of fit TD25; fit K/r, according to DIN 68101, 1984), gives 25 % higher values of joint strength than the joint with uncertain fitting where splice was 0.25 mm (class of fit TD25; fit K/p).

In his master thesis (Džinčić 2006), (not published in English), the author shoved that machining quality, type of fit and gluing surface have influence on rigidity of joints which are used in chair production. Testing was performed on 20 chairs and 120 T-joints (joint of rear leg and side rail). Among other conclusions author also concluded the following:

- Fit with splice gives higher values of joint strength then joint with uncertain fitting for approximately 25 %.
- Machining quality has great influence on strength of joints. Strength of joints is increasing with increase of machining accuracy. Joints produced in machining class TD25 (according to DIN 68101, 1984) gave 20 % higher values for strength than joints produced in class TD 40.
- Critical spot in chair construction is the place (area) where side rail meats rear leg.

Based on Mackerle (2005) study and further review and analysis of studies of the investigators who analysed spatial furniture using the finite element method, we can only find a few studies which take joints into consideration. Polish investigators Smardzewski and Papuga (2004) contributed to the efforts of investigators who engaged in solving problems of introducting the finite element method into chair construction. In this study the analysis of a chair model was performed by the finite element method using the ALGOR program package. Components of a chair were joined by means of a cubical tenon and mortise and dowels. By defining the fits, both kinds of joints were made with a loose fit and a gap of 0.1 mm.

As a part of his study, Gawronski (2006) carried out a comparative analysis of different models of finite elements in the attempt of defining the model, which can be applied to the joint element, oval tenon-mortise. By defining joints geometry, type of fit was not specified, but the thickness of the layer of glue on the gluing line was and it was 0.1 mm. Accordingly, it can only be assumed that the joint was produced with a loose fit and a gap both per plug height and per diameter.

On grounds of prior research and practical experience no recommendations were found for the production of chair joints with a loose fit, as shown in the studies of the Polish researchers.

Based on the review of the results from prior research obtained by other authors, we can reach the following conclusions:

- Type of fit and work-piece accuracy of the oval tenon-mortise joint affect joints strength and consequently the strength and durability of chairs.
- The greatest strength of joints can be expected with fitting the splice slightly.

MATERIAL AND METHODS

In case of production of glued chairs, it is common to use frame construction where different parts are put together with a tenon-mortise, double tenon –mortise, a dowel and a hole and the ZABO (ZApfen-BOlzen – square tenon in hole) joint with the application of glue. Critical place from the aspect of chair load with rails is the connection rear leg - side rail (Džinčić 2006, Rüdiger et al. 1991). Joining of legs with rails is mainly performed with a tenon-mortise joint, which is most often produced with two types of fit K/p or K/n (DIN 68101, 1984), and the appropriate quality class. The aim of this research is to investigate the size of the joint strain, which appears due to the uncertain fitting K/p.

The choice of joints and choice of glue

Consonant with the aim of this study 10 pairs of tenon bearing beams and 10 pairs of mortise bearing beams were produced. Dimensions of joints are shown in Tab. 1.

Tab. 1: Display dimensions of joints with a varied factor according to DIN 68101 (1984).

Type of joint	Nominal dimensions (mm)			Accuracy class	Type of fit by joint thicknes	Type of fit by hight of joint
	length	height	thicknes			
Tenon-mortise	24	40	10	TD 15	K/p	K/p

Gluing of carpentry joints in final wood processing is almost always performed with the use of PVA-c resin based glues. Besides numerous advantages, such as great strength of the glued joint, high elasticity, long shelf storage life, spreading of a thicker layer, the possibility of cold gluing, the simplicity of preparation and gluing procedure, these adhesives also have disadvantages such as: the irresistance of the emulsion to low temperatures, the irresistance of the hardened glue to water and rise in temperatures, swelling of the glue under the influence of organic solvents and the acidity which causes corrosion of metals.

PVA-c glue of the company RAKOLL, type EXPRESS 25D, was used for joint gluing in this research. Glue was applied both on tenons and motices.

Production of test pieces

Taking into account the fact that beech wood accounts for 50.4 % of wood volume of all trees in Serbian forests and 43.0 % of the wood volume increment (Šoškić and Skakić 1995). Also 72 % of the investigated dining room chairs during 2007 and 2008 in the Quality Control Bureau were made from beech wood (Skakić and Džinčić 2009), we reached the decision to produce test pieces from this most significant species in our industry. The investigations were performed on beech beams of the following dimensions: 32x32x250 mm (leg) and 50x20x250 mm (rail). Fig. 1 shows the layout of test pieces.

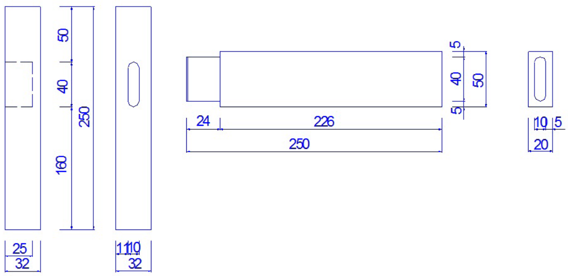

Fig. 1: Layout of test pieces.

In order to make experimental conditions as close to production conditions as possible, the beams on which joints would later on be cut, came by chance i.e. no attention was paid to their position in a log. Moisture content of the samples which amounted to 9±2 % was controlled using an electric wood moisture meter, before the joints production as well as after conditioning.

Before the production of joints, accuracy of the machines for joint making was examined, and it was found that both machines worked in the accuracy class TD 15. Measurements of joints were controlled with a digital calliper accurate to 0.01 mm.

The load of test species

Type and size of strains which occur in a joint in case of a fit with splice were examined with steel templates which were set on a joint. Two templates, analogous to the tenon and mortise in

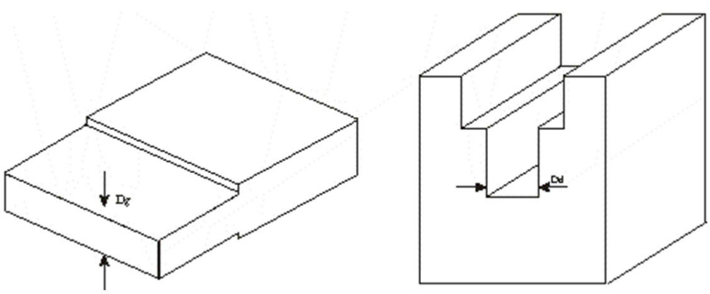

Fig. 2: The layout of templates for the investigation of joint strain.

shape, were produced (Fig. 2). The templates dimensions were the same as the dimensions of the upper threshold value for the tenon (marked with Dg in Fig. 2) and lower threshold value for the mortise (marked with Dg in Fig. 2), in order to investigate threshold situations which can arise while joints are being connected, i.e. to bring about maximum strain of joints. The strain of joints was examined only per thicknes. The dimension of the templates in the shape of a tenon was 10.3 mm, while the dimension of the templates in the shape of the mortise was 10.0 mm.

Measuring of joints was carried out at two measuring points which were located at 10 mm distance from the ends of the joints (Fig. 3).

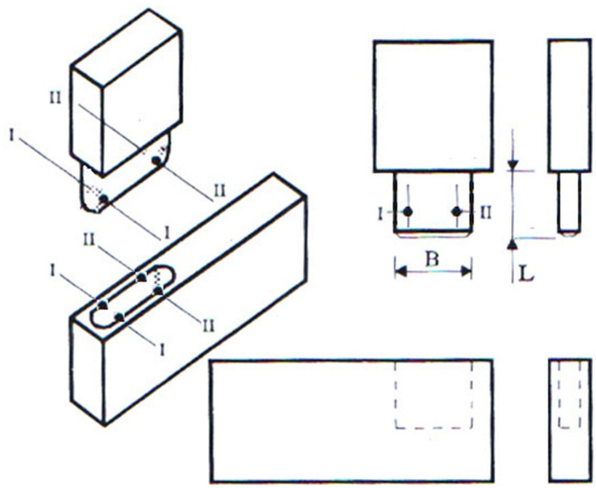

Fig. 3: Measuring points on the joints.

Six measurements were made at each joint in the following time intervals (Tab. 2). Templates remained in the joints for 2 h.

Tab. 2: Order of operations and time intervals in which measurements of joint strains were performed.

Measuring order	**Measurement time intervals**
1st measuring	Before gauge positioning
templet positioning	
templet set in joint	2 h
removal of templet	
2nd measuring	15 min. after templet removal
3rd measuring	30 min. after templet removal
4th measuring	1 h after templet removal
5th measuring	24 h after templet removal
6th measuring	48 h after templet removal

RESULTS AND DISCUSSION

Values obtained from measurements during the investigation of the size of strain in a joint due to the fitting with splice are shown in the tables for sample groups (Tab. 3 and Tab. 4).

Tab. 3: Dimensions obtained by measurement of mortises.

Sample number	Measuring place	Mortise hight (mm)					
		Before templet positioning	15 min. after templet removal	30 min. after templet removal	1 h after templet removal	24 h after templet removal	48 h after templet removal
1	1	10.06	10.11	10.1	10.07	10.06	10.06
	2	10.05	10.1	10.07	10.09	10.07	10.06
2	1	10.04	10.12	10.11	10.1	10.08	10.07
	2	10.05	10.14	10.11	10.11	10.09	10.08
3	1	10.02	10.12	10.1	10.08	10.08	10.08
	2	10.04	10.11	10.1	10.1	10.06	10.05
4	1	10	10.08	10.05	10.02	10.02	10.01
	2	10	10.07	10.04	10.02	10.02	10.01
5	1	10.06	10.09	10.05	10.04	10.04	10.04
	2	10.02	10.06	10.05	10.04	10.02	10.02
6	1	10.03	10.05	10.04	10.04	10.03	10.03
	2	10.01	10.07	10.04	10.04	10.04	10.03
7	1	10.01	10.05	10.02	10.02	10.02	10.02
	2	10	10.04	10.03	10.01	10	10.01
8	1	10.03	10.1	10.06	10.05	10.04	10.04
	2	10.05	10.08	10.07	10.05	10.04	10.03
9	1	10	10.05	10.02	10.02	10.02	10.01
	2	10	10.06	10.03	10.03	10.03	10.01
10	1	10.02	10.06	10.04	10.03	10.04	10.04
	2	10	10.05	10.04	10.04	10.04	10.03
σ –st.dev. (mm)		0.0218789	0.029105	0.030136	0.030779	0.024192	0.023458
ν - coefficient of variation (%)		0.0021825	0.002887	0.002996	0.003063	0.002409	0.002337
X – average (mm)		10.0245	10.0805	10.0585	10.05	10.042	10.0365

Tab. 4: Dimensions obtained from the measurement of tenons.

Sample number	Measuring place	Tenon thickness (mm)					
		Before templet positioning	15 min. after templet removal	30 min. after templet removal	1 h after templet removal	24 h after templet removal	48 h after templet removal
1	1	10.22	10.17	10.16	10.12	10.14	10.16
	2	10.18	10.11	10.12	10.12	10.12	10.16
2	1	10.2	10.1	10.11	10.12	10.12	10.13
	2	10.18	10.09	10.1	10.1	10.11	10.12
3	1	10.19	10.13	10.07	10.11	10.11	10.14
	2	10.24	10.13	10.11	10.17	10.18	10.2
4	1	10.14	10.12	10.09	10.08	10.05	10.06
	2	10.19	10.12	10.13	10.14	10.14	10.15
5	1	10.18	10.14	10.12	10.15	10.16	10.16
	2	10.17	10.1	10.1	10.1	10.1	10.1
6	1	10.17	10.1	10.11	10.12	10.12	10.13
	2	10.12	10.1	10.12	10.12	10.12	10.15
7	1	10.16	10.11	10.1	10.1	10.12	10.12
	2	10.14	10.1	10.12	10.12	10.12	10.13
8	1	10.16	10.09	10.13	10.13	10.14	10.14
	2	10.14	10.09	10.09	10.1	10.11	10.11
9	1	10.2	10.13	10.12	10.06	10.12	10.12
	2	10.17	10.11	10.11	10.11	10.11	10.11
10	1	10.16	10.07	10.08	10.08	10.09	10.11
	2	10.18	10.12	10.12	10.1	10.12	10.13
σ –st.dev. (mm)		0.028557	0.02207	0.019861	0.024895	0.026157	0.028887
ν - coefficient of variation (%)		0.002807	0.002183	0.001964	0.002462	0.002585	0.002851
X – average (mm)		10.1745	10.1115	10.1105	10.1125	10.12	10.1315

Based on the results obtained on the basis of investigation of joint strain due to the presence of uncertain fitting K/p, we can see that:

The strain of joints was caused upon templet positioning. After removing the templates, neither of test-pieces had template dimensions at any of the measuring points, which means that the strains formed belonged to the group of temporary, highly-elastic strains. In the period of joint relaxation, i.e. during measurements 3, 4, and 5, occurred further regression of temporary strains. In the last measurement, 48 hours after templet removal, the occurrence of permanent, highly–plastic strain, which amounted to 0.043 mm in tenons (calculated as difference between mean values of "48 hours after templet removal" and "before template positioning") and 0.012 mm in mortise, was recorded. In neither of the test-pieces did dimensions completely return to the initial level 48 hours after templet removal. Total average permanent strain size in the tenon-mortise joint, with the uncertain K/p fitting and and accuracy class TD15, measured per joint diameter, is 0.055 mm. The obtained value of the average permanent strain is almost 1/6 of the value of the maximum splice.

Variation of the measured values of joint dimensions in test-pieces 1/2, 7/2 and 10/1 in beams which bore the mortise and test-pieces 1/1 and 4/1 in beams which carried tenons can be explained as measurement errors. Differences in values of strain sizes, which were recorded in all measurements after templet removal can be explained by the position of beams which come by chance in a log.

Beside the other settings, analysis of joints by application of finite elementh method, demands definning a material. Regardless to the software package applied, this type of material is usually defined by Young's modulus of elasticity, Poisson's coefficients and Shear modulus. All types of glued joints used in furniture with spatial construction, are designed and produced as fit with overlap. Apperance of fit with overlap leads to the strain which has impact on the changes in the Young's modulus of elasticity, which is the basic parameter in the defining of the material of the model.

If Laplace function is applied for the interval of natural tolerance $\pm 3\sigma$, we calculate the percentage of joints whose measures are of the lower or the upper threshold value, we get that the amount of such beams for both the tenon and the mortise is 0.14 % for each threshold value. The probability that during gluing of beams tenon of the upper threshold value joins the mortise of the lower threshold value in that case is 1.96 %. In other words, the probability of the upper splice occurrence and permanent strain is 1.96 %.

During modelling of joints with overlap using the FEM in the phase of defining the material, only in situation when upper overlap occurs, values abowe yield point should be taken for the Young's modulus of elasticity.

In all other cases, values below the yield point should be taken for the Young's modulus of elasticity.

CONCLUSIONS

By investigating the strength of strains which occurs in a joint due to the uncertain fit K/p, we obtained results which can lead to the following conclusions:

- During joining of joints in the presence of the fit with splice, a permanent change occurs in the dimensions of the plug and hole.
- Total average permanent strain in the tenon-mortise joint, with uncertain fit K/p and the accuracy class TD 15 was, measured per joint diameter at 0.055 mm.
- During joining of joints with a fit with splice, most strains belong to the group of elastic strains, which by all means contributes to the joint strength.
- During joint modelling using the finite element method, only in case of the upper splice, values above the yield point should be taken for the Young's modulus of elasticity, in the phase of defining of the material.

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