ONLINE ISSN 2069-7430
ISSN-L 1841-4737
PRO LIGNO
www.proligno.ro
Vol. 13 N° 4 2017
pp. 500-507

EFFECT OF HEAT TREATMENT ON COMPRESIVE AND TENSILE STRENGTH OF END TO EDGE BUTT JOINT

Sergiu GEORGESCU
Transilvania University of Brasov, Faculty of Wood Engineering
Str. Universitatii nr. 1, 500068 Brasov, Romania
E-mail: sergiu.georgescu@unitbv.ro

Bogdan BEDELEAN
Transilvania University of Brasov, Faculty of Wood Engineering
Str. Universitatii nr. 1, 500068 Brasov, Romania
E-mail: bedelean@unitbv.ro

Abstract:

The effect of heat treatment on the compressive and tensile strength of end to edge butt joint is analysed in this work. The joints were prepared from both untreated and heat-treated ash (Fraxinus excelsior) wood. The end to edge butt joint made of heat-treated wood has a lower resistance both for compression and tensile strength, compared with joints made of untreated wood. The length of dowel has a bigger influence on compressive and tensile strength of joints than the distance between dowels and the ratio of dowel penetration in the main part of joint. An optimal solution to place the dowels is suggested both for the joints made of heat-treated wood and joints made of untreated wood.

Key words: *end to edge butt joint; heat-treated wood; ash; tensile and compressive strength; optimisation.*

INTRODUCTION

The joints used in the manufacture of wooden products must be able to take over, to transmit and to support the load required by their use. One of the most used joints in the construction of furniture is end to edge butt joint (Fig. 1). This type of joint is preferred for the easy of their processing (Negreanu 2003).

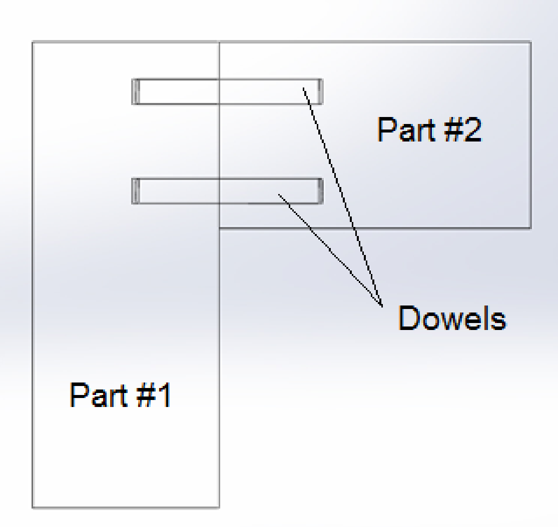


Fig. 1.
End to edge butt joint.

End to edge butt joint sizing is based on the existing recommendations in the literature (Curtu 1988, Cismaru 2009). These recommendations are based on studies that have been developed for solid wood joints, where wood has superior mechanical properties compared to heat-treated wood, whose main disadvantage is the reduced mechanical strength. This disadvantage can be reduced by appropriate sizing of joints used for manufacturing the products (Kuzman et al. 2015).

In order to obtain a proper design of a product made of heat-treated wood, it is necessary to know how much the strength of end to edge butt joint made of heat-treated wood is reduced compared to untreated wood joint. To the best to our knowledge, there is lack of studies that deal with this topic. Also, there is a lack of studies regarding the sizing of end to edge butt joint made of heat-treated wood. This kind of studies could be useful to designers in order to establish an oversizing coefficient and to figure out the optimal dowel length, the distance between dowels and the ratio of dowel penetration in the main part of joint (see part #2 in Fig.1).

OBJECTIVE

The main objective of the present research is to figure out the behaviour of end to edge butt joint made of both heat-treated and untreated wood under the compression and tensile strength tests. Also, the objective is to figure out the optimal dowel length, the distance between dowels and the ratio of dowel penetration in the main part of joint.

MATERIAL, METHOD, EQUIPMENT

The material used in this research was untreated and heat-treated ash (*Fraxinus Excelsior*) boards. Some technological steps were followed in order to obtain the end to edge butt joint, as follows: drilling the wooden elements, gluing and jointing the parts and joints conditioning. Before gluing, the parts were selected and arranged according to the experimental plan (Table 1).

Table 1

The experimental plan used in the present research

Configuration	**Independent variables**					**Dependent variables**	
	Distance between dowels (X_1), mm	**Hole depth in the parts of the joints (X_2), mm**			**Dowel length (X_3), mm**	**Breaking compression force (Y_1), N**	**Breaking tensile force(Y_2), N**
		part #1 of joint	**part #2 of joint**	**Ratio of dowels penetration in part #2**			
1	16	15	15	0.5	30	788	2330
2	32	15	15	0.5	30	1110	3740
3	16	21	9	0.7	30	1010	2540
4	32	21	9	0.7	30	1040	2180
5	16	30	30	0.5	60	2250	4990
6	32	30	30	0.5	60	2060	4460
7	16	42	18	0.7	60	2610	4730
8	32	42	18	0.7	60	1970	4200
9	24	27	18	0.6	45	2620	5420
10	24	27	18	0.6	45	2490	4510
11	24	27	18	0.6	45	2780	6120
12	24	27	18	0.6	45	2460	4610
13	24	27	18	0.6	45	1990	4460
14	16	27	18	0.6	45	3130	5350
15	32	27	18	0.6	45	3460	4970
16	24	23	22	0.5	45	2960	7460
17	24	32	13	0.7	45	2120	3580
18	24	18	12	0.6	30	1180	3190
19	24	36	24	0.6	60	3030	6310
20	24	27	18	0.6	45	2990	5930
21	24	27	18	0.6	45	2690	5880
22	24	27	18	0.6	45	2420	4450
23	24	27	18	0.6	45	2340	5700
24	24	27	18	0.6	45	2300	4620

Adhesive consumption rate was 350g/m^2, according to Negreanu (2003). In order to find the area of each hole, the SolidWorks software was used to 3D modelling of various holes depth, according to experimental plan. The quantity of adhesives needed to be applied in each hole was calculated by multiplying the adhesive consumption rate by area of each hole. The adhesive was applied by means of a 2ml syringe (Fig. 2).

In order to obtain a good adhesion, after applying the adhesive, the parts waited a period of 10 minutes long before jointed. The possible influence of adhesive excess on the strength of joint was limited by separating the parts of joint by applying wax paper (Fig. 2b). The parts of joint were pressed after jointing in a screw clamping device (Fig. 2c) and were conditioned for two weeks (Fig. 2d).

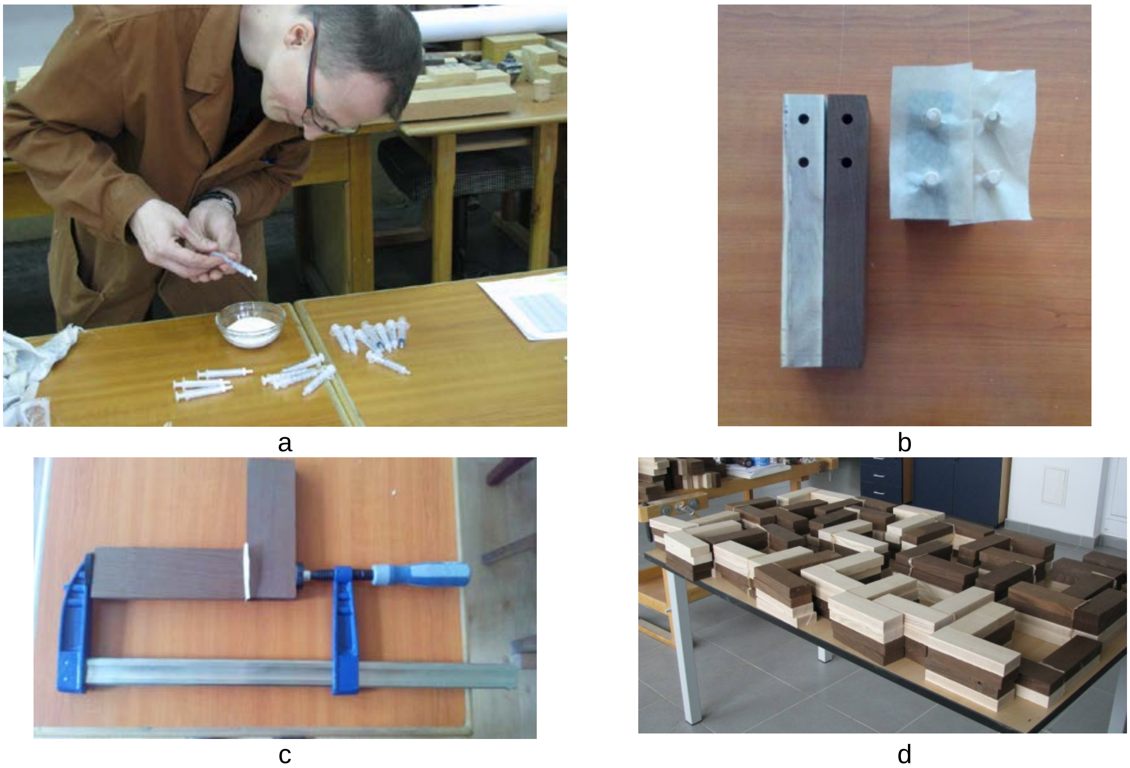

a b c d

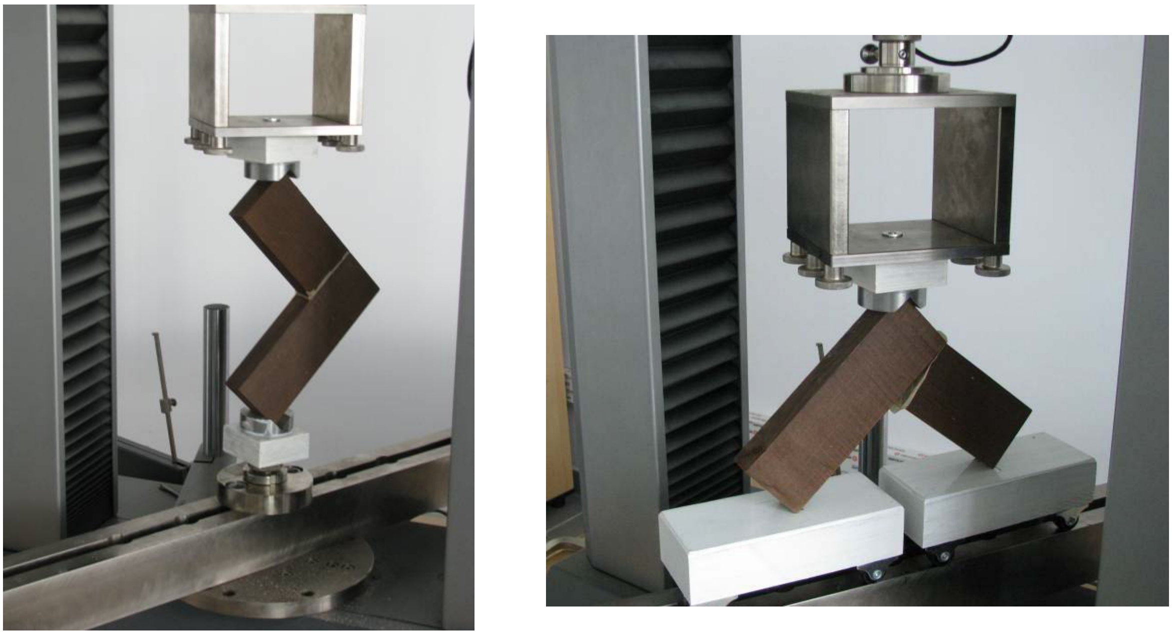
Fig. 2.
Dispensing the adhesive (a), applying the wax paper (b), pressing the parts of joint (c) and conditioning the joints (d).

The mechanical testing of joints was performed on the universal testing machine Zwick Roell Z10. The load was applied at a constant speed of 3mm per minute until a significant separation between the two parts occurred (Kuzman et al. 2015). The value of the maximum breaking force was recorded for each tested specimen. The joints were tested both for compression and tensile load, as it is recommended in the literature (Fig. 3). The devices were especially designed for this kind of test.

RESULTS AND DISCUSSION

The results show that most of the heat-treated joints have a lower compressive strength than untreated joints (Fig. 4). However, there are some exceptions for the configurations # 1, 4, 6, 12, 13, 18 and 24 (Table 1). Heat – treated wood joints has generally lower tensile strengths than untreated wood joints (Fig. 5). The exceptions are configurations # 5, 6 and 15 that have higher tensile strengths than untreated wood joints (Table 1).

The heat-treated wood joints have a lower resistance than untreated wood joints values both at compression and tensile strength, respectively 13% and 21%. The percentage of reduction in the strength of the end to edge butt joint was calculated based on the central configuration (X_1=24mm, X_2=0.6 and X_3=45mm) that was imposed by the experimental plan (Table 1). The central configuration was repeated ten times.



a b

Fig.3.
Testing of end to edge butt joint at compression (a) and tensile (b).

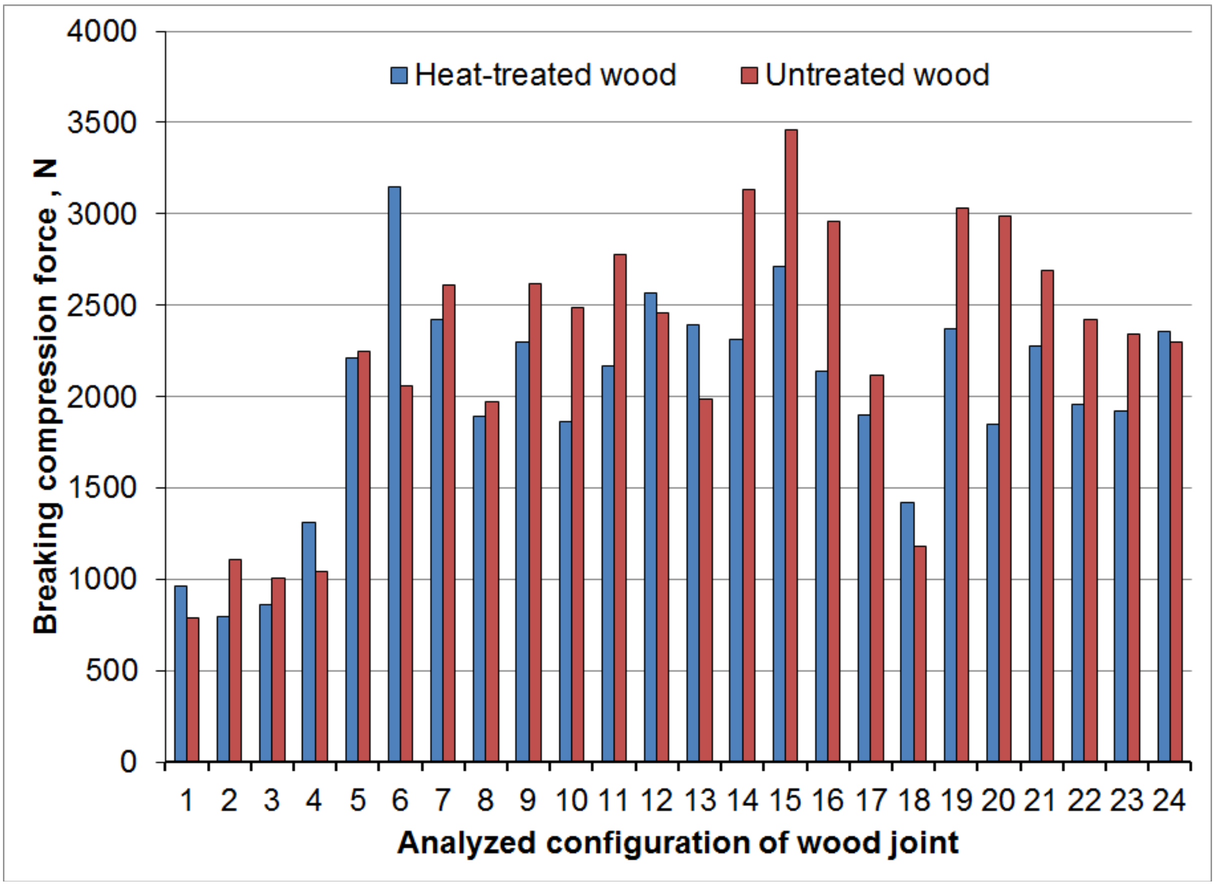


Fig. 4.
Breaking compressive force for end to edge butt joint made of heat treated and untreated wood.

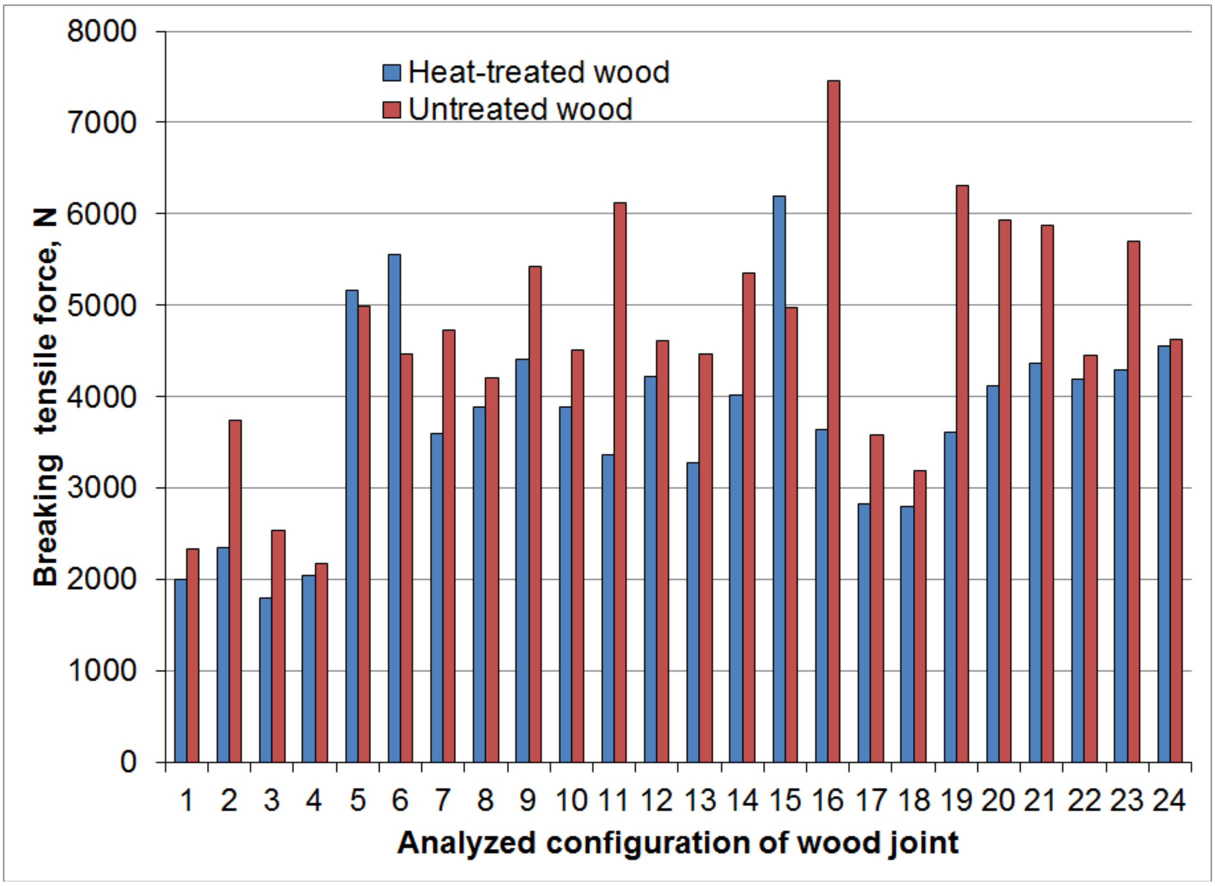


Fig. 5.
Breaking tensile force for end to edge butt joint made of heat treated and untreated wood.

Mathematical models (multiple regression equations) were established based on the experimental results by using the Design-Expert Version 9 – Stat-Ease. The models describe the relationship between independent variables (the distance between dowels, ratio of dowel penetration in the main part of joint and the length of the dowel) and the dependent variables (breaking compression force and breaking tensile force). The models were developed both for heat treated and untreated wood joints (Tables 2 and 3).

Table 2
Mathematical models that describes the relationship between independent variables and breaking compression force

Type of joints	**Form of presenting the equation**	**Obtained Equation**	**Coefficient of determination (R^2)**
Heat-treated	Coded	$Y=2208.01+108.90X_1-87.90X_2+669.30X_3-105.87X_1X_2+16.38X_1X_3-182.62X_2X_3+204.96X_1^2-285.04X_2^2-410.04X_3^2$	0.82
	Real	$Y=-16751.86-66.84X_1+41980.55X_2+278.41X_3-132.34X_1X_2+0.13X_1X_3-121.75X_2X_3+3.20X_1^2-28503.79X_2^2-1.82X_3^2$	
Untreated	Coded	$Y= 2571.96 - 14.80X_1-41.80X_2+679.20X_3+395.23X_1^2-359.77X_2^2-794.77X_3^2$	0.80
	Real	$Y= -15718.15 -298.27X_1+42754.68X_2+363.18X_3+6.17X_1^2-35977.24X_2^2 - 3.53X_3^2$	

Table 3

Mathematical models that describes the relationship between independent variables and breaking tensile force

Type of joints	Form of presenting the equation	Obtained Equation	Coefficient of determination (R^2)
Heat-treated	Coded	$Y = 4022.32+347X_1-456X_2+1084X_3-340X_2X_3+1055.72X_1^2-819.28X_2^2-849.28X_3^2$	0.85
	Real	$Y = -31290.94-748.41X_1+103954X_2+547.97X_3-226.66X_2X_3+16X_1^2-81928.27X_2^2-3.77X_3^2$	
Untreated	Coded	$Y = 4698.99-39X_1-575X_2+1071X_3$	0.45
	Real	$Y = 5052.98-4.87X_1-5750X_2+71.4X_3$	

Based on the sign of the coefficients of obtained models, it was found that the heat-treated wood joint strength increases when:

- the dowel length increases;
- the distance between holes ***increases;***
- the ratio of dowel penetration in the main part of joint decreases.

In the case of untreated wood joints was found that strength increases when:

- the dowel length increases;
- the distance between holes ***decreases;***
- the ratio of dowel penetration in the main part of joint decreases.

Based on the value of coefficients of models, it was found the most important independent variable that affects the strength of joint is the length of dowel. Moreover, the length of dowel has a nonlinear effect on breaking compression force that was obtained both for joints made of heat-treated and untreated wood (Figs.6a and 6b). In the case of breaking tensile force, the nonlinear effect of the length of dowel was observed only for joints made of heat-treated wood (Figs.6c and 6d).

In the case of heat-treated wood joints the independent variables interact for a better compressive and tensile strength, as it could be observed based on the equations presented in Tables 2 and 3. The most important interaction is between the ratio of dowel penetration in the main part of joint (X_2) and the length of the dowel (X_3).

Based on the developed models, the optimisation algorithm that is included in the Design- Expert Software and technological constraints, it was obtained a single optimal solution both for heat-treated and untreated wood joints. The solution implies to have a distance between dowels of 32mm; a ratio of dowel penetration in the main part of 0.55 and a dowel length of 60mm. The fulfilment of optimization criteria (D) was higher in the case of heat treated wood joints (D = 0.91) than in the case of untreated wood joints (D=0.74). The optimisation criteria consisted in maximizing both the compressive and tension breaking force.

The optimal values obtained are close to those found in the literature, as follows:

- the distance between dowels is suggested at 32mm due to technological constraints (distance between axes of the drilling tools mandrels) (Cismaru 2009):
- the ratio of dowel penetration in the main part of joint is recommended to be 0.50 (Curtu et al. 1988, Craftmanspace 2016);
- the dowel length could be either 50mm or 60mm (Curtu et al. 1988, Negreanu 2003).

The selected optimum solutions were, also, experimentally verified. The sample size was of nine joints for each requested test. The values obtained for each sample are shown in Table 4. The relative error obtained for each model was calculated using equation (1).

$$\varepsilon = \frac{F_E \quad F_S}{F_E} 100 \qquad [\%] \qquad (1)$$

where: F_E - is the compression or tensile breaking force applied to joint that was experimentally determined, in N;

F_S - is the compression or tensile breaking force applied to joint that was calculated with the developed mathematical models, in N.

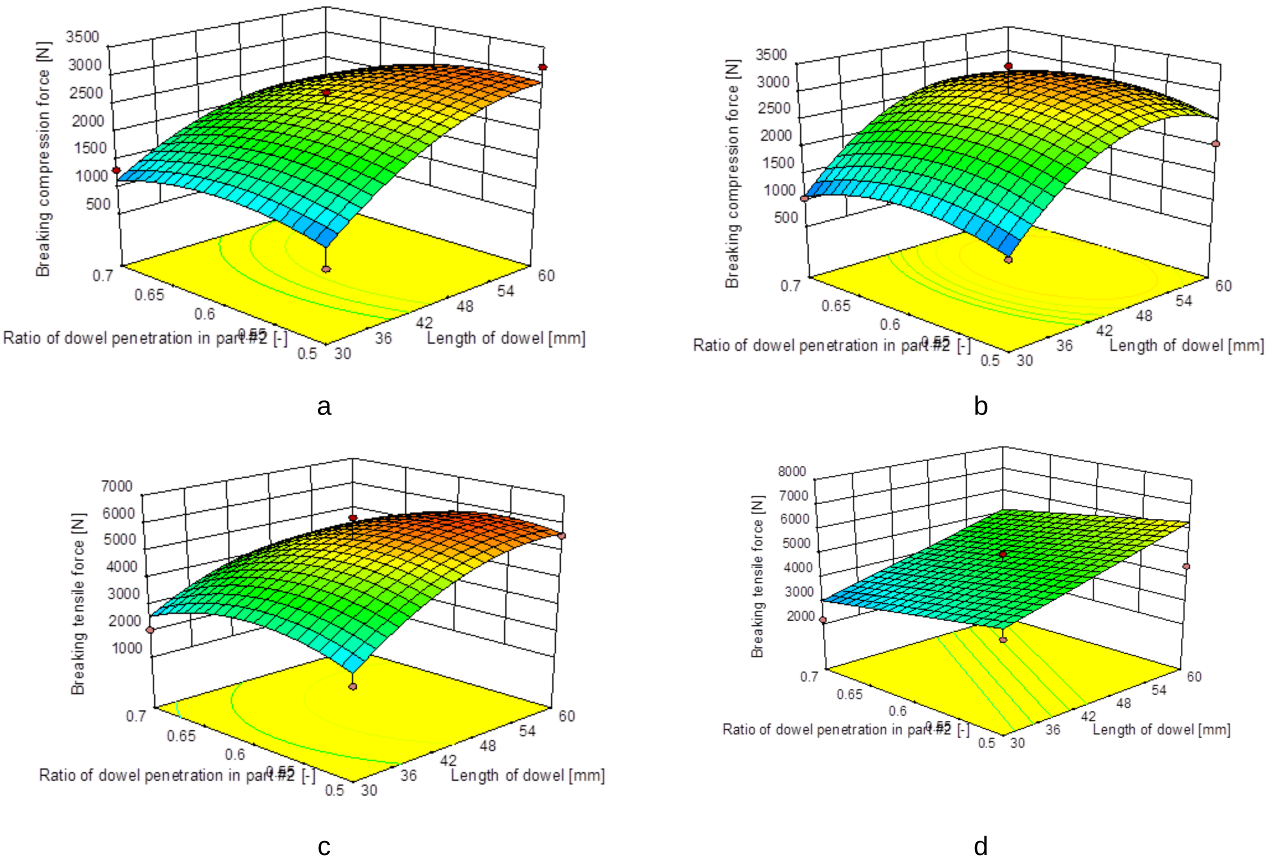


Fig. 6.

Response surface plot showing the effect of ratio of dowel penetration in the main part of joint and the length of dowel on the breaking compressive force (a - heat-treated material and b - untreated material) and breaking tensile force (c-heat-treated material and d – untreated material). The distance between dowels was considered equal to 32mm.

Table 4

The relative error obtained for the optimal solutions

Type of material	**The method of determination**	**The distance between dowels, mm**	**The ratio of dowel penetration in the main part of joint**	**Length of dowels, mm**	**Compression breaking force, N**	**Tensile breaking force, N**
Heat-treated wood	Mathematical model	32	0.55	60	2912	5900
	Experiment				2429	4779
	The relative error of modelling, in %				-20	-23
Untreated wood	Mathematical model	32	0.55	60	2901	5836
	Experiment				3205	5235
	The relative error of modelling, in %				9.5	11

CONCLUSIONS

The end to edge butt joint made of heat-treated wood have a breaking compression and tensile force lower than the joints made of non-treated wood. However, several heat-treated joints made an exception to that rule. Therefore, a study is under way in order to check the obtained results and to figure out this unexpected finding. Also, it was found that the compressive breaking force is generally smaller than the tensile breaking force both for heat-treated wood joints and untreated wood joints. The main variable affecting the resistance joints is the length of dowels. The obtained optimal solution could be considered suitable both for the joints made of heat-treated wood and to joints made of untreated wood. In a further study more variables that influence the compression and tensile strength of end to edge butt joints must be considered, in order to develop practical recommendations needed during the design phase of wooden products.

ACKNOWLEDGEMENT

This research was done with funds offered by Transilvania University of Brasov for the Master thesis: *Comparative analysis of a L-shaped corner joint made of heat-treated and untreated wood*. During this work the infrastructure of R&D Institute of the Transilvania University of Brasov was used too.

REFERENCES

Cismaru M (2009) Wood strucures (in Romanian). Transilvania University Publishing House, Brasov.

Craftsmanspace (2016) Dimensioning woodworking and carpentry joint. Online at: http://www.craftsmanspace.com/knowledge/dimensioning-woodworking-and-carpentry-joints.html

Curtu I, Nastase V, Mihai D, Mihăilescu T, Stoian O (1988) Joints in wood: Structure, technology and reliability (in Romanian). Technical Publishing House, Bucharest.

Kuzman MK, Kutnar A, Ayrilmis N, Kariz M (2015) Effect of heat treatment on mechanical properties of selected wood joints. European Journal of Wood and Wooden Products 73:689-691.

Negreanu C (2003) Contributions to the study of dowel joints that are used in the structure of furniture made of solid wood (in Romanian). PhD thesis. Transilvania University of Brasov.