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OPTIMISATION OF END TO EDGE BUTT JOINT WITH RESPONSE SURFACE METHODOLOGY: A PRELIMINARY STUDY

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One of the most used joints in the construction of furniture is the end to edge butt joint. This type of joint is preferred for the easy of their processing. The effect of heat treatment on the compressive and tensile strength of end to edge butt joint is analysed in this work. Also, it is analysed the optimal dowel length, the distance between dowels and the ratio of dowel penetration in the main part of an end to edge butt joint. The joints were prepared from heat-treated ash (Fraxinus excelsior) 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 for the joints made of heat-treated wood. The solution implies to have a distance between dowels of 32 mm; a ratio of dowel penetration in the main part of 0,55 and a dowel length of 60 mm.
Keywords: end to edge butt joint; heat-treated wood; ash; tensile and compressive strength; optimisation

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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 [8].

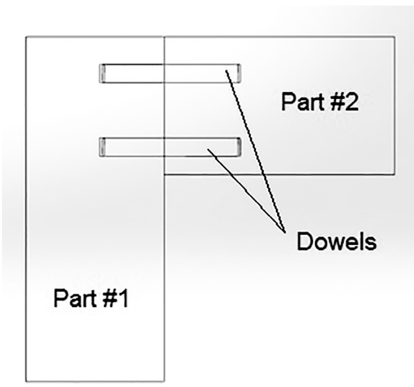


Fig.1. End to edge butt joint
Рис. 1. Соединение торцевого стыка

End to edge butt joint sizing is based on the existing recommendations in the literature [1, 3, 5]. 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 [7]. To the best to our knowledge, there is lack of studies that deal with this topic.

OBJECTIVE

The main objective of the present research is to figure out the optimal dowel length, the distance between dowels and the ratio of dowel penetration in the main part of an end to edge butt joint. In order to obtain our objective, the response surface methodology (RSM), which is a class of designs of experiments, has been applied. RSM allows the reduction in the number of experiments which would be necessary to estimate multiple parameters and their interactions. Thus, time and effort are greatly shortened. One can find more information about RSM in Sova et al. [9].

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).

Adhesive consumption rate was 350 g/m^2, according to Negreanu [8]. 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 2 ml syringe.

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

Table 1

The experimental plan used in the present research

Экспериментальный план, использованный в настоящем исследовании

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

separating the parts of joint by applying wax paper [4]. The parts of joint were pressed after jointing in a screw clamping device and were conditioned for two weeks [6].

The mechanical testing of joints was performed on the universal testing machine Zwick Roell Z10. The load was applied at a constant speed of 3 mm per minute until a significant separation between the two parts occurred [7]. 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. 2) [10]. The devices were especially designed for this kind of test.

RESULTS AND DISCUSSION

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 obtained models are presented in table 2.

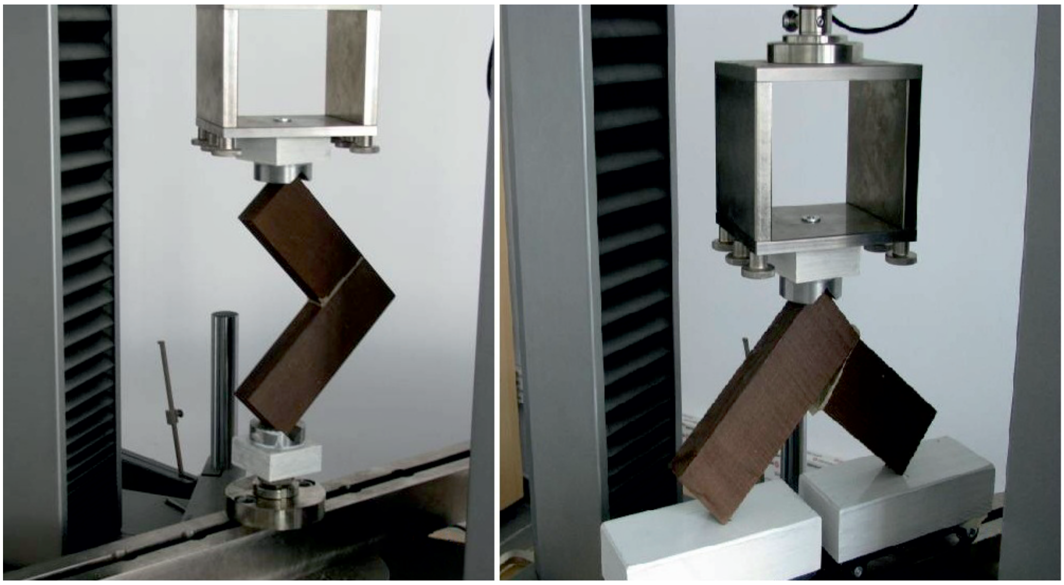
Based on the sign of the coefficients of obtained models, it was found that the heat-treated wood joint strength increases when:

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

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 (fig. 3, *a*, *b*).

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 Table 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. The solution implies to have a distance between dowels of 32 mm; a ratio of



a *b*

Fig. 2. Testing of end to edge butt joint at compression (*a*) and tensile (*b*)
Рис. 2. Испытание концевого стыкового стыка при сжатии (*a*) и растяжение (*b*)

Table 2

Mathematical models that describes the relationship between independent and dependent variables

Математические модели, описывающие взаимосвязь между независимыми и зависимыми переменными

Type of joints	Form of presenting the equation	Obtained Equation	Coefficient of determination (R^2)
Breaking compression force	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	$Y = -16751{,}86 - 66{,}84X_1 + 41980{,}55X_2 + 278{,}41X_3 - 132{,}34X_1X_2 + 0{,}13X_1X_3 - 121{,}75X_2X_3 + 3{,}20X_1^2 - 28503{,}79X_2^2 - 1{,}82X_3^2$	
Breaking tension force	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	$Y = -31290{,}94 - 748{,}41X_1 + 103954X_2 + 547{,}97X_3 - 226{,}66X_2X_3 + 16X_1^2 - 81928{,}27X_2^2 - 3{,}77X_3^2$	

dowel penetration in the main part of 0,55 and a dowel length of 60 mm. The fulfilment of optimization criteria (*D*) was high (*D* = 0,91). 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:

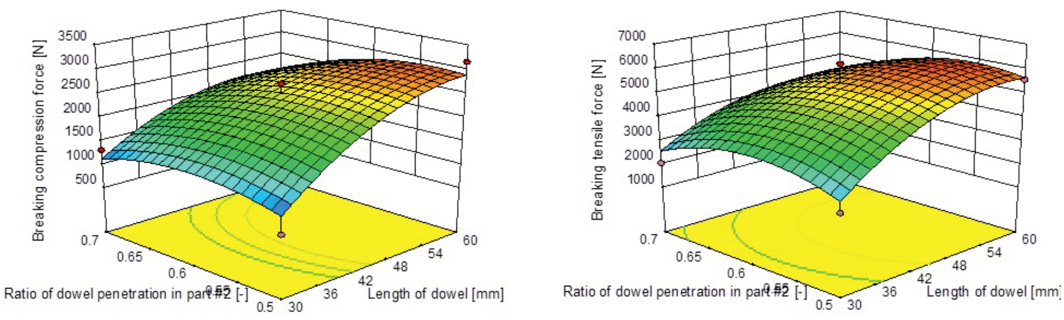
• the distance between dowels is suggested at 32 mm due to technological constraints (distance between axes of the drilling tools mandrels) [1]:

• the ratio of dowel penetration in the main part of joint is recommended to be 0,50 [2, 3];

• the dowel length could be either 50mm or 60mm [3, 8].

CONCLUSIONS

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. The joints were tested both for compression and tensile load. The main variable affecting the resistance joints is the length of dowels. The independent variables interact for a better compressive and tensile strength. The proposed optimal solution could be considered suitable for the joints made of heat-treated 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



a *b*

Fig. 3. 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) and breaking tensile force (b). The distance between dowels was considered equal to 32 mm

Рис. 3. Диаграмма поверхности реакции, показывающая влияние отношения проникновения дюбеля в основной части стыка и длины дюбеля на разрывную сжимающую силу (*a*) и разрывное растягивающее усилие (*b*). Расстояние между дюбелями считалось равным 32 мм

practical recommendations needed during the design phase of wooden products.

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ОПТИМИЗАЦИЯ УГЛОВОГО КОНЦЕВОГО СОЕДИНЕНИЯ, ОСНОВАННАЯ НА МЕТОДОЛОГИИ ПОВЕРХНОСТИ ОТКЛИКА: ПРЕДВАРИТЕЛЬНОЕ ИССЛЕДОВАНИЕ

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Одним из наиболее часто используемых видов соединений при сборке мебели является угловое концевое соединение деталей. Этот тип соединения является предпочтительным из-за легкости процесса. В данной работе анализируется влияние термической обработки на прочность при сжатии и растяжении углового концевого соединения. Также анализируется оптимальная длина шканта, расстояние между шкантами и соотношение глубины установки шканта к основной части углового концевого соединения. Соединения деталей были сделаны из термически обработанной древесины ясеня (Fraxinus excelsior). Длина шканта оказывает большее влияние на прочность соединения при сжатии и растяжении, чем расстояние между шкантами и глубина установки шканта. Предложено оптимальное решение размещения шкантов для соединений, изготовленных из термически обработанной древесины. Данное решение предполагает наличие расстояния между шкантами 32 мм; соотношение глубины установки шканта к основной части углового концевого соединения — 0,55 и длину шканта — 60 мм.

Ключевые слова: угловое концевое соединение, термически обработанная древесина, ясень, прочность на растяжение и сжатие, оптимизация

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