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Correlation between bending and tension strength of corner and middle joints constructed with beech and poplar wood

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Abstract: This study was carried out to evaluate the strength of the three most frequent joints in the upholstered furniture frames, made of beech and poplar solid wood. The research included the following joints: Mortise and Tenon, double Dowel and double Gusset Plates, which were constructed and tested both in corner and middle joints. In the corner joints we examined the compression strength of the joints and in the middle joints the tension strength was thoroughly investigated. The results of the bending (compression) test indicated that bending strength values of the four different joints were strongly correlated to tension strength values of the corresponding joints, whether they were constructed with beech or poplar wood. Also, a correlation was noticed between the bending strength values of the joints constructed with beech and the bending strength values of the respective joints made of poplar wood. Relative to tension strength values, a strong relationship was also recorded between the beech wood joints and the poplar ones. Based on these results, it is concluded that the tension strength value of these joints could be sufficiently estimated by the measured bending strength value of the corresponding joints. Furthermore, the calculation of bending or tension strength of each of these three joints constructed with poplar wood gives the opportunity to calculate automatically and quite precisely, the corresponding strength value of the same joint constructed with beech wood.

Keywords: Bending strength, corner joint, Dowel, middle joint, Gusset, Mortise and Tenon, tension strength

INTRODUCTION

The upholstered furniture contributes greatly to the human needs and also represents an integral part of the human every-day life. The strength and stability of this type of furniture depend mainly on the strength and stability of its joints (Eckelman 2003). There is a high interest in the research of the strength of the wooden frame and particularly the strength of the joints of this furniture. This study deals with the investigation of the strength of the three most substantial and frequent corner and middle joints of the upholstered furniture, which are: Mortise and Tenon joint, double Dowel joint and the double Gusset Plates joint.

The Mortise and Tenon joint and the double Dowel joint represent two main and traditional types of joints of upholstered and other sorts of furniture, which have been studied by many researchers, while the strength and the mechanical behavior of the double Gusset Plates joint have not been thoroughly studied so far and is relatively innovative type of connection in furniture. Previous research refer mainly to bending strength of these joints (Hill and Eckelman 1973, Paulenkova 1984, Smardzewski 2002, Tankut 2007, Zhang and Eckelman 1993 etc.) and tension strength (Zhang et al. 2003, Eckelman et al. 2004 etc.). Wood species used in previous studies referring to the investigation of these specific joints strength were mainly poplar (Hill and Eckelman 1973, Erdil et al. 2005 etc.) and, in less extent, beech wood (Kamenicky 1975 etc.).

The present research aims to provide information concerning the correlation between the bending strength of the three different corner joints and the tension strength of the respective middle joints, in cases when the joints were constructed either with beech or poplar wood. Additionally, the correlation of bending or tension strength values of beech wood joints to the respective values of poplar ones is investigated.

MATERIALS AND METHODS

Experiments were carried out with beech wood (Fagus sylvatica) and poplar wood (Populus sp.), both of Greek origin and naturally desiccated for one year. Half of the samples were constructed in corner form (L-shape), and the rest in middle form (T-shape). The corner joint samples were tested in compression (Bending Capacity), and the middle joint samples were tested in tension (Tension strength). The configuration of the tested joints is shown in the following Figures (Fig.1 - 2).

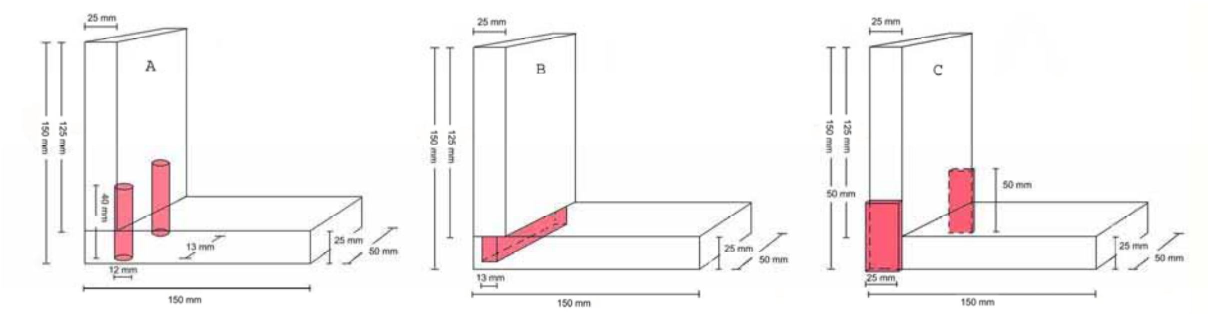

Figure 1. Dowel corner joint (A), Mortise - Tenon corner joint (B), Gusset Plates corner joint (C)

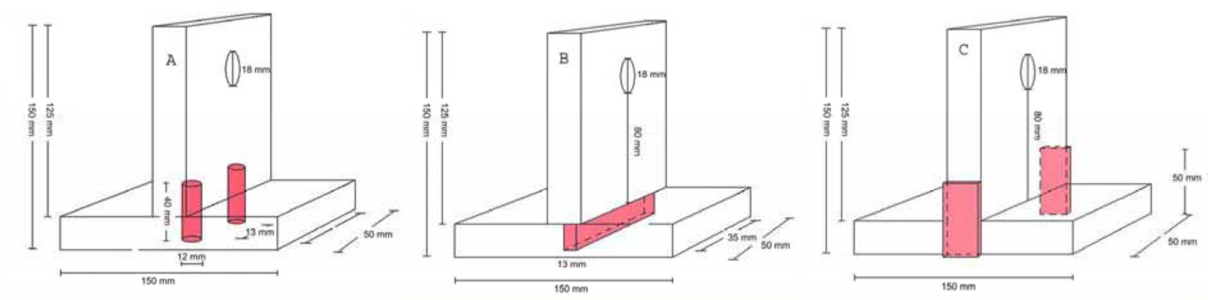

Figure 2. Dowel middle joint (A), Mortise - Tenon middle joint (B), Gusset Plates middle joint (C)

All the specimens consisted of two wooden parts, the horizontal and the vertical one. The samples for the bending strength were constructed in dimensions as follow: 150 mm length x 50mm width x 25mm thickness for the horizontal parts, while the dimensions of the vertical parts were 125mm length x 50mm width x 25mm thickness. These dimensions refer to corner and also middle forms of specimen and are based on the pre-existent research, because of lack of particular international standards on the method of the examination of strength of corner and middle joints.

Concerning the double Dowel joint, it must be mentioned that the dimensions of the dowel were: 40mm length x 12mm in diameter and the space between the two dowels was 13mm. In the construction of the Mortise and Tenon joint it was determined to maintain the contact between the mortise and tenon only in the two surfaces of the mortise, because the mortise cut is semi-cylindrical, whereas the tenon has square cut. On the part of the construction of the double Gusset Plates joint, two wooden gusset plates were used alongside the connection place and each gusset plate was stabilized with the help of two staples.

For every joint 10 specimens were tested. By using two forms of joints (corner and middle joint), three different types of joints (double dowel, mortise and tenon, double gusset plates) and two different wood species (beech and poplar wood), a total of 120 specimens were prepared.

After their construction, the specimens were placed into a conditioned room at 20±2^{o} C temperature and 65±5% relative humidity and were allowed to reach a nominal equilibrium moisture content (EMC) of 10%. At the moment of the tests, the mean density of the beech wood was measured as 0.702 g/cm^3 and of the poplar wood 0.364 g/cm^3, for 9.55 % mean moisture content for the beech wood and 9.29 % for the poplar wood.

All the tests were carried out on a Universal Testing Machine (SHIMADZU UH-300kNA), and the rate of crosshead-movement was adjusted at 8 mm/min, so that the maximum load was reached within 1.5±0.5 min throughout the test. The loading continued until a break of the joint occurred (Figures 4 and 5). The Maximum bending and tension rupture load was measured and expressed in Newton (N).

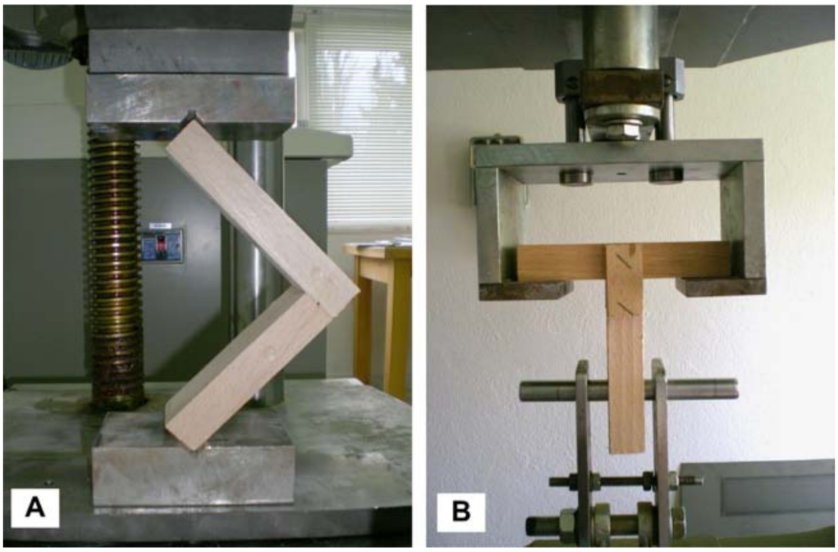

Figure 3. Loading in compression of the corner joint specimens (A), Loading in tension of the middle joint specimens (B)

RESULTS AND DISCUSSION

The results of the bending strength tested are indicated in the table 1.

Table 1 Mean values of Bending and Tension strength of the joints

Joint Type	Wood Species	Maximum bending rupture load (N)	Stand. Deviation s	Maximum tension rupture load (N)	Stand. Deviation s
Double Dowel	Beech	1179.6	66.548	4671.0	407.164
	Poplar	875.4	61.996	4259.2	688.943
Mortise and Tenon	Beech	1063.6	60.620	5438.4	545.866
	Poplar	374.4	50.047	2334.8	395.336
Double Gusset Plates	Beech	529.6	53.547	3863.5	570.852
	Poplar	499.8	52.902	3829.5	569.207

As can easily be noticed, all the joints constructed with poplar wood resulted in lower strength values, compared to the respective joints constructed with beech wood, whether in bending or tension strength test.

Additionally, there is an obvious relationship between the bending strength values of corner joints and the tension strength values of the respective middle joints, in both of the cases of beech and poplar wood. Statistical analysis of the covariance between the two strength properties values showed that these two are strongly correlated each other (table 2). That means that the bending strength (Y) of corner joints could be sufficiently estimated by the corresponding measured tension strength (X) values of the respective middle joints whether they were constructed with beech or poplar wood.

Table 2 Equations of covariance between bending strength (Y) and tension strength values of joints (X)

Joint Type	Wood Species	Equation	Correlation coefficient (r^2)
Double Dowel	Beech	Y=445.6640537+0.157666655·X	0.930
	Poplar	Y=525.4389074+0.082165921·X	0.833
Mortise and Tenon	Beech	Y=520.6785972+0.099831091·X	0.808
	Poplar	Y=79.03639872+0.126504883·X	0.998
Double Gusset Plates	Beech	Y=181.1245451+0.090196831·X	0.924
	Poplar	Y=172.4521459+0.085480573·X	0.845
All joints	Both species	Y=0.293979382·X - 455.2755805	0.880

There is also a correlation between the bending strength values of beech wood and the respective values of poplar wood joints (table 3). That means that the bending strength values (Y) of these three different joints constructed with beech wood, could be sufficiently estimated by the corresponding measured bending strength values of the same joints constructed with poplar wood.

Table 3 Equations of covariance between bending strength of beech wood joints (Y) and bending strength of poplar wood joints (X)

Joint Type	Equation	Correlation coefficient (r^2)
Double Dowel	Y=333.7005+0.959387·X	0.906
Mortise and Tenon	Y=672.1003+1.045672·X	0.745
Double Gusset Plates	Y=57.42953+0.944719·X	0.871

The corresponding correlation coefficient (r^2) ranged from 0.745 up to 0.906, so the accuracy of the estimation appeared to be quite high.

In figure 4(A), where the equations of covariance between the bending strength values of beech wood joints and the respective values of poplar wood joints are pictured, it is quite remarkable the fact that the straight lines are almost parallel, which means that all the equations can be represented by only one equation, the following one:

$$Y = A + 0.983 \cdot X$$

where Y is the bending strength value of beech wood joint, X is the bending strength value of the poplar wood joint, 0.983 is the mean value of the three respective values of the three individual equations, corresponding to the slope of the equation, and finally, A is a value that varies for each joint and specifically, as it concerns the bending strength, A proved to be 334 for the double Dowel joint, 672 for the Mortise and Tenon joint and finally, 57 for the Gusset Plates joint. This general equation and the known for each joint variable A, as well, give the opportunity to accurately estimate the bending strength of each of these three beech wood joints from the respective value of the corresponding poplar wood joint and vice versa.

Table 4 Equations of covariance between tension strength of beech wood joints (Y) and tension strength of poplar wood joints (X)

Joint Type	Equation	Correlation coefficient (r^2)
Double Dowel	Y=1082.91 + 0.794748·X	0.902
Mortise and Tenon	Y=2699.186 + 1.173211·X	0.721
Double Gusset Plates	Y=119.173 + 0.977759·X	0.950

According to the table 4, a strong correlation was also detected between the tension strength values of beech wood and the respective values of poplar wood joints. Therefore, the tension strength values (Y) of these three different joints constructed with beech wood, could be sufficiently estimated by the corresponding measured tension strength values of the same joints constructed with poplar wood.

The corresponding correlation coefficient (r^2) ranged from 0.721 up to 0.950, so the accuracy of the estimation appeared to be quite high.

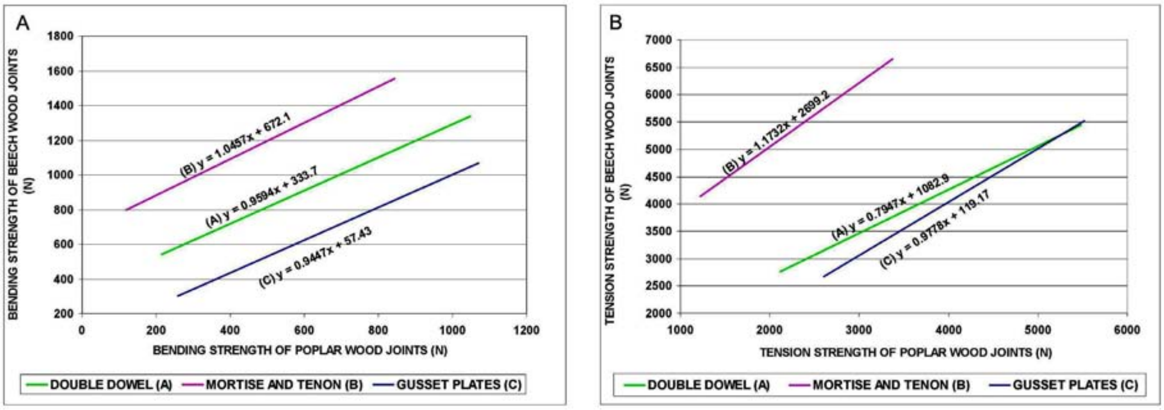

Figure 4. Equations of covariance between values of beech wood joints and values of poplar wood joints in bending (A) and tension (B) strength

Similarly to bending strength, the equations of covariance between the tension strength values of beech wood joints and the respective values of poplar wood joints also, tend to be parallel (figure 4B), which means that all the equations can be represented by only one equation, the following one:

$$Y = A + 0.982 \cdot X$$

where Y is the tension strength value of beech wood joint, X is the tension strength value of the poplar wood joint, 0.982 is the mean value of the respective values of the three individual equations, and A value, referring to tension strength, proved to be 1083 for the double Dowel joint, 2699 for the Mortise and Tenon joint and finally, 119 for the Gusset Plates joint.

Therefore, this equation provides the opportunity to accurately estimate the tension strength of each of these three beech wood joints from the respective value of the corresponding poplar wood joint. The equations of covariance between values of beech wood joints and the respective poplar wood joints in bending and tension strength that were previously presented, as can easily be noticed, are almost similar, so one equation would be sufficient to cover both cases of bending and tension strength. Additionally, the A values used in the equations of each of the three joints tension strength, taking into account the standard deviation of mean strength values, proved to be almost threefold to the respective A values used in the bending strength equations and therefore, this relation can be sufficiently used for accurate estimations concerning either of them.

CONCLUSIONS

The investigation of the strength of three substantial and most frequent corner and middle joints of the upholstered furniture (Mortise and Tenon joint, double Dowel joint and double Gusset Plates joint) was accomplished in this research. Based on the results of this current project, it is concluded that the tension strength value of these three middle joints could be sufficiently estimated by the measured bending strength value of the corresponding corner joints. Furthermore, the calculation of bending or tension strength of each of these three joints constructed with poplar wood gives one the opportunity to calculate easily and quite precisely, the corresponding strength value of the same joint constructed with beech wood. In this study, a general equation which provides the opportunity to calculate automatically the bending or the tension strength of beech wood joints, independently of the joint form, from the respective values of poplar wood joints and vice versa, was also discovered. All in all, the structure and the physical properties of wood species, used in the joints construction were proved to be the most significant factors that affect the correlation extent between the joint strength values and the general behavior of them, independently of the joint type and the kind of load.

According to the results, it could be claimed that there might also be a correlation between the bending strength and tension strength value in the cases of the above studied joints, even if these joints were constructed with several other wood species, apart from beech and poplar. So, it would be very interesting and helpful, mainly for manufacturers, to expand and deepen the research on the strength properties correlation of these and several other joints, constructed with different wood species, so that they would be able to comprehend and calculate accurately the joints strength and behavior and therefore, to construct even stronger joints and wooden structures.

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Streszczenie: *Korelacja pomiędzy wytrzymałością na zginanie i rozciąganie połączeń kątowych i półkrzyżowych ściennych z drewna buka i topoli*. Praca miała na celu określenie wytrzymałości 3 najbardziej popularnych złączy w stelażach mebli tapicerowanych z drewna litego buka i topoli. Do tych złączy zaliczono złącze czopowe, dwukołkowe oraz złącze z podwójnymi nakładkami (Gusset Plates). Wykazano, że niektóre badane połączenia charakteryzują się wysoką korelacją pomiędzy wytrzymałością na zginanie a wytrzymałością na rozciąganie.

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