WOOD RESEARCH
61 (3): 2016
495-504

# STRENGTH OF CORNER AND MIDDLE JOINTS OF UPHOLSTERED FURNITURE FRAMES CONSTRUCTED WITH BLACK LOCUST AND BEECH WOOD

Vassilios Vassiliou, Ioannis Barboutis, Vasiliki Kamperidou
Aristotle University of Thessaloniki, Faculty of Forestry and Natural Environment, Laboratory of Wood Products and Furniture Technology
Thessaloniki, Greece

(Received February 2016)

## ABSTRACT

Great interest is attracted lately in the utilization of Black locust (*Robinia pseudoacacia* L.) timber large quantities that are expected to be harvested and enter the market next years, since this species was included in the proposed and financed species for cultivation by the European Union. This study was carried out to evaluate the strength of the two most frequent joints in the upholstered furniture frames, constructed with black locust, using also beech wood (*Fagus sylvatica* L.) for comparative reason. In the specific research, the joints of mortise and tenon and double dowel were selected to be used and were constructed both in corner and middle joints, using two adhesives (PVAc and PUR). Bending moment capacity of the joint specimens was investigated, as well as the coefficient of elasticity of each joint.

KEY WORDS: Adhesive, Black locust, dowel, joint, mortise, PVAc.

## INTRODUCTION

The previous years, black locust wood was included in the European subsidizing programme of tree species cultivation, aiming in the establishing of new plantations in many European countries (Council Regulation (EEC) No. 2080/92 of 30 June 1992, Council Regulation (EC) No. 1257/99 of 17 May 1999) (Lawson et al. 2002). As a result, large quantities of black locust wood will be harvested in the coming years and examination of the properties of the specific wood species and particularly, the strength of several joints would be very useful and crucial for the future utilization of wood in structures and furniture frames construction. Previous researches have investigated the properties of particleboards made of black locust wood (Archanowicz et al. 2013, Kowaluk et al. 2011 etc.) exhibiting satisfying strength results, but there is a lack of data about the strength of joints made of this species. Connections are essential and critical points of the wooden constructions, since they carry loads between elements of the structure, they retain the structure and ensure the uniformity and wholeness of the furniture during its service life charge (Efe et al. 2004, Wang 2007).

Motive and purpose of this research is the utilization possibilities development of black locust wood, which so far in most countries is primarily used as fuel, even though its physical and mechanical properties make it suitable for the furniture construction, gaining a chance to create with this material final products of high added value, of improved mechanical performance and superior quality. Such a possibility would increase the value of black locust wood derived from plantations (of Greece and Hungary) and would provide the opportunity to furniture manufacturing industries worldwide, to use this species domestically as a raw material in their production process with beneficial effects on the balance of imports - exports of wood. Hungary is the country with the largest area of Black locust forest (about 300,000ha) worldwide (Molnar 1995).

Therefore, this research deals with the investigation of the strength of two substantial and frequent corner and middle joints of the upholstered furniture frames (mortise and tenon and double dowel joint) that represent two main and traditional types of joints of upholstered and other sorts of furniture and have been studied so far by many researchers (Hill and Eckelman 1973, Paulenková 1984, Zhang and Eckelman 1993, Smardzewski 2002, Tankut 2007, Kamperidou and Vasileiou 2010 etc.), but the performance of black locust wood in these types of joints has not been so far thoroughly investigated.

Black locust of Greek and Hungarian origin and beech wood of Greek origin was used in this research work. Beech wood was included, with a view to compare the results with a "similar to black locust" type of wood, referring to density and other characteristics, and additionally is a species extensively used in furniture frames construction. In particular, the effect of joint type, joint form, adhesive type and the wood species, on the stability and bending moment capacity of the joints was investigated, while the elasticity of all the constructed joints was also examined.

## MATERIAL AND METHODS

Experiments were carried out with black locust (*Robinia pseudoacacia* L.) of Greek and Hungarian origin and beech wood (*Fagus sylvatica* L.) of Greek origin, naturally dried for one year. Black locust wood was harvested from several plantations of the two countries (mainly from the areas of Sopron in Hungary and Halkidiki in North Greece), while beech wood was harvested from Kalambaka forest areas (Central Greece). The wood material of all species was cut on boards of 25 thickness x 50 mm width, coming from several randomly selected places of the initial boards, in order to obtain a representative behavior of each species and only the boards that were free of defects were included in the experiment. Half of the material was used for the construction of corner joints and the rest for middle joints and in each kind of form, mortise – tenon and double dowel joint types were configurated (Fig. 1).

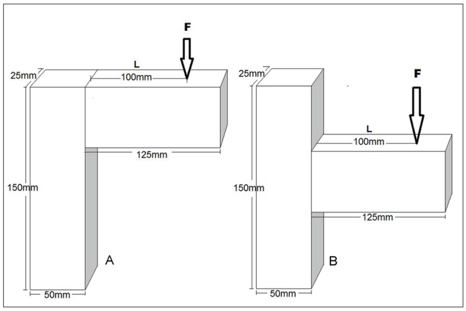


*Fig. 1: Configuration of the corner A) and middle form B) joint specimens.*

The dimensions of the joints specimens are based on the pre-existent research on furniture frames, because of lack of particular international standards on the method of the examination of strength of corner and middle joints. Furthermore, these dimensions comply with the dimensions of joints, used in furniture frames construction by the manufacturers.

All the specimens consisted of two wooden elements, the horizontal and the vertical one. In the construction of mortise – tenon joint, in the edge of one of the joint element, a tenon of 41.65±0.03 width x 9.83±0.02 thickness x 24.7±0.02 mm length was configurated, and in the rest of the joint elements, mortises of 42.43±0.06 width x 9.94±0.05 thickness x 25.08±0.08 mm length were configurated. It was determined to maintain the contact between the whole surfaces of mortise and tenon and for this reason, the cuts of both were semi-cylindrical.

Concerning the double dowel joint, beech wood dowels from local market (MORSETO) of nominal dimensions: 40 length x 10 mm in diameter were provided, while the actual mean values of dimensions after an accurate measurement of the dowels used were: 40.86±0.02 length x 9.45±0.05 mm in diameter. For the placement of dowels, two holes of diameter 9.91±0.01 and depth 21.00±0.05 mm were opened in each element of each joint and the space between the two dowels was 13 mm.

The final dimensions of the assembled specimens, referring to both forms and types of joints were: 150 length x 50 width x 25 mm thickness. These dimensions 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 (Eckelman 2003).

Two widely used adhesives were used in specimens' construction, that of PVAc type of D3 class (Rakoll LP 8022) and that of the polyurethane (PUR of one component, ICEMA R 145 PROFESSIONAL). The adhesives were applied to the joint wooden elements following generally the adhesives bonding parameters and the manufacturer's instructions. Prior the spreading of PUR adhesive to wood, moisturizing of both wood surfaces of the adhesion always proceeded, to contribute to the success of elements bonding, while in the case of PVAc moisturizing was not necessary. Pressure was applied with clamps for 1 hour for PVAc bonded joints and 1.5 hours for PUR bonded joints. The amount of the glue used in the construction of each mortise - tenon joint specimen was 3 g and in dowels joint specimen 2.7 g. A number of 10 specimens was used for each test and since 3 wood species (Greek-Hungarian black locust, beech), 2 adhesive types (PVAc, PUR), 2 joint forms (corner, middle form) and 2 joint types (mortise - tenon, dowels) were the variables, totally a number of 240 specimens was constructed in this research.

After their construction, the specimens were placed into a conditioned room at 20°C temperature and 55 % relative humidity and were allowed to reach a nominal equilibrium moisture content (EMC). 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$^{-1}$, so that the maximum load was reached within 90±30 s throughout the test. The loading continued until a break of the joint occurred.

The strength of the corner and middle joints against the destructive forces of bending was determined by compressing the two elements, using two different ways of supporting the test bodies to a special component that adjusted to the Universal machine (Fig. 2).

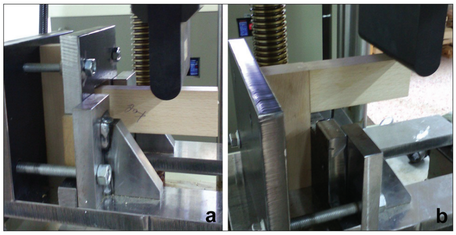


*Fig. 2: Way of support and loading the specimens of middle joints a), and of corner joints b).*

The corner joints specimens were mounted during the bending test from the one element, while the crosshead was moving down loading the specimen to a distance of 100 mm from the adhesive line between the two elements of the specimen, to compress the two sides of the joint and assess the maximum rupture value (Fig. 2a). In the case of middle joints, an additional metal plate was used and adjusted with bolts onto the fitting and ensure the correct mounting of the test bodies (Fig. 2b). The distance between the loading point and the adhesive line of the specimen was in the case of middle joints also 100 mm. The strength of the joints (modulus of rupture) to bending forces was calculated using the following Eq. (1) (Derikvand et al. 2014):

$$M = Fmax * L \tag{1}$$

where: M - the bending moment capacity (N.mm),
Fmax - the maximum force that caused the destruction of the joint (Max. rupture load) (N),
L - the length of the vertical element of the joint, measured till the loading point and in this experiment this distance was for both corner and middle joints 100 mm.

During the test of corner and middle joints strength in bending forces, as mentioned above, the elasticity of joints was also investigated. The relationship between stress and deformation (strain) determines the modulus of elasticity and is calculated by Eq. 2 (Tsoumis 2002):

$$CE = \frac{P * L}{A * D} \tag{2}$$

where : CE - the coefficient of elasticity of specimens (N.mm$^{-2}$), measured during bending tests,
P - the load at elastic limit (N) which is calculated abstracting the load that corresponds to 10 % of destructive force value from the load that corresponds to 40 % of destructive force (N),
L - the distance between the bonding line of the two elements of the

specimen and the point of the specimen where the load is performed (mm) (Fig. 1),

A - the cross section of the sample (width*thickness) ($mm^2$).

D - the deflection in elastic limit (mm), which is calculated abstracting the deflection that resulted from the load that corresponds to 10 % of destructive force, from the deflection caused by the load that corresponds to 40 % of destructive force (mm).

After the completion of strength tests, samples for the determination of density and moisture content of the wood were formed by the edges of 20 specimens of Greek, Hungarian black locust and 20 specimens of beech wood. The average density of Greek black locust wood was found to be 0.780, 0.750 for Hungarian black locust and 0.722 $g.cm^{-3}$ for beech wood, while the average moisture content of specimens at the moment of strength tests was 10.44 for Greek black locust wood, 8.77 for the Hungarian black locust and 9.32 % for that of beech wood.

For the statistical analysis and processing of the test results, the statistical package SPSS PASW 18 was used, giving an analysis of the variability of the resistance mean values with method of Bonferoni and Tamhane (ANOVA).

## RESULTS

The results of tests of mechanical strength are listed in separate tables for bending strength (Tab. 1) and coefficient of elasticity (Tab. 2).

*Tab. 1: Mean values of bending moment capacity of the corner and middle joints (N.m).*

| Joint Type | Adhesive Type | Greek black locust | | Hungarian black locust | | Greek beech | |
|---|---|---|---|---|---|---|---|
| | | Corn | Mid | Corn | Mid | Corn | Mid |
| Mortise and tenon | PVAc | 274.54 (28.46) | 272.02 (36.55) | 248.24 (22.79) | 261.06 (15.17) | 263.2 (16.29) | 318.97 (19.57) |
| | PUR | 223.20 (41.93) | 196.25 (35.63) | 212.46 (20.12) | 213.06 (21.57) | 166.62 (32.73) | 146.42 (15.6) |
| Double dowel | PVAc | 142.17 (12.76) | 125.57 (11.25) | 150.84 (21.02) | 148.14 (19.77) | 192.08 (9.55) | 169.17 (16,24) |
| | PUR | 129.00 (36.11) | 100.92 (17.09) | 135.66 (26.67) | 137.42 (23.6) | 102.91 (15.05) | 83.96 (10.72) |

Mean values of standard deviation of 10 specimens in parenthesis.

The results indicate that the mechanical strength of the joints constructed with black locust wood, both of Greek and Hungarian origin, is very high, reaching the strength levels of the joints constructed with beech wood, a wood species of high density and strength. Especially in the case of PUR adhesive, Greek and Hungarian black locust exhibited higher strength values compared to the corresponding values of beech wood, which is a species that does not present satisfying behavior in combination with PUR adhesive, a fact probably attributed to the chemical constituents (extractives) or structure of this species (Fig. 3).

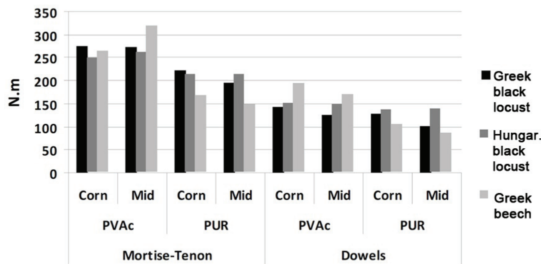


*Fig. 3: Configuration of mean bending moment capacity values of joints constructed with Hungarian black locust, Greek black locust and Greek beech wood.*

Joints of Greek black locust presented slightly higher strength values, compared to the Hungarian black locust in the case of mortise – tenon joints especially with PVAc adhesive, while in the case of dowels joints higher strength was recorded by Hungarian black locust for both PVAc and PUR adhesives, although these differences were not statistically significant. In general, the Hungarian black locust joints specimens presented lower variance and standard deviation values, compared to Greek black locust wood. Beech wood joints specimens in all cases exhibited also very stable performance (low standard deviation values). Furthermore, very small differences were recorded between the strength of corner and middle joints in each wood species. Middle joints of black locust showed slightly lower strength values compared to the corresponding corner joints, whereas the opposite was observed in the case of beech wood bonded with PVAc.

By studying the performance of all the joints, it could be claimed that the mortise – tenon joint in combination with PVAc adhesive, provided the best strength results between the three species used in this research. In almost all cases, the joint of mortise - tenon revealed higher strength, compared to the double dowel joint, referring to either PVAc, or PUR adhesive, except for mortise – tenon joint made of beech with PUR adhesive that exhibited lower strength compared to the double dowel joint in the presence of PVAc adhesive, which shows that beech joints strength is affected more by the adhesive type and less by the joint type. According to the results of this survey, mortise – tenon joint, proves to be one of the most suitable joints for frames of upholstered or non-upholstered furniture, probably due to the edges form of the elements and the relatively large adhesive surface of the joint.

PVAc adhesive provided better strength results, in comparison with PUR adhesive, as regards to both joint types studied in this research project. According to variance analysis results, statistically significant differences (with a 5 % error) between the mean values of the strength results of PVAc and PUR were recorded almost in all cases, with PVAc to mark much higher strength.

*Tab. 2: Mean values of modulus of elasticity (N.mm$^{-2}$) of the joint specimens measured in bending test (N.mm$^{-2}$).*

| Joint type | Adhesive type | Greek black locust | | Hungarian black locust | | Greek beech | |
|---|---|---|---|---|---|---|---|
| | | Corn | Mid | Corn | Mid | Corn | Mid |
| Mortise and tenon | PVAc | 49.77 (6.34) | 62.50 (8.57) | 45.66 (9.63) | 55.30 (4.57) | 54.28 (7.51) | 78.10 (19.22) |
| | PUR | 52.03 (4.41) | 61.33 (10.74) | 46.81 (3.81) | 53.36 (6.22) | 51.89 (5.96) | 59.44 (5.97) |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Double dowel | PVAc | 43.76 (5.96) | 60.29 (6.68) | 51.62 (7.04) | 57.50 (5.2) | 53.31 (7.08) | 76.90 (5.38) |
| | PUR | 53.18 (14.2) | 62.50 (12.95) | 49.65 (8.87) | 56.20 (7.1) | 51.56 (11.15) | 69.63 (11.57) |

Mean values of standard deviation of 10 specimens in parenthesis.

According to the findings of coefficient of elasticity measurement (Tab. 2), the joints constructed with Greek and Hungarian black locust wood seem to be characterized by very high modulus of elasicity values reaching the elasticity level of beech wood joints. The Hungarian black locust provided slightly lower elasticity values, compared to the Greek black locust wood, regardless the connection or adhesive type, except in the case of double dowels joint in the presence of PVAc, that presented a higher elasticity coefficient value. In modulus of elasticity results , statistically significant differences were observed between the joints or adhesives concerning the black locust wood of Greek and Hungarian origin. Middle joints made of beech wood presented very high modulus of elasticity values that corresponds to a statistically significant difference in modulus of elasticity from the rest of the constructed joints of this experiment (of the 2 joint types and 2 adhesives).

## DISCUSSION

By placing the joint elements at the same level ("in plane" placement) the strength values against bending forces seem to be significantly higher, than out of plane placement, including the results of this experiment. In a similar previous research of the laboratory, where such an element placement (at the same level-in plane) was used, corner mortise and tenon joints with PVAc recorded a mean bending moment capacity value of 132.78, while the corner joints of double dowel recorded 91.42 N.m. respectively (Kamperidou and Vasileiou 2010, 2012). In a similar study of Efe et al. (2005), the middle mortise - tenon joints (in-plane placement) recorded in edgewise bending test the highest strength values (256 for pine, 447 for beech and 302 N.m for oak wood), while the double dowel joint yielded comparable strength to the dowel joint of the present experiment (93 for pine, 133 for beech and 115 N.m for oak wood).

In a prior corresponding survey, the mortise and tenon corner joint made of beech wood had recorded an elasticity modulus mean value of 33.2, the double dowel corner joint recorded 42.5, respectively, whereas poplar wood exhibited much lower values of elasticity, 28.7, for the mortise-tenon corner joint and 26.9 $N.mm^{-2}$, for dowels corner joint, respectively (Kamperidou and Vasileiou 2010).

By the visual observation of the test bodies after the completion of the tests, the way of destruction of each joint was easily detected. In the case of PVAc adhesive, the strength of the bond seem to exceed the strength of wood and the destruction most of the times was caused after a breakage of one of the wooden elements of the specimen and not in the adhesive line, whereas in the case the PUR adhesive, the specimen usually was destroyed due to poor bonding and in most of the times a separation and scrolling of the two elements was observed, recording lower strength values.

## CONCLUSIONS

According to this research work results, the mechanical strength of the black locust joints of both Greek and Hungarian origin, was proved very high, reaching the strength levels of the beech wood joints. Greek and Hungarian black locust exhibited higher strength than beech wood joints in the presence of PUR adhesive. Hungarian black locust as well as beech wood joints specimens in all cases presented lower variance and standard deviation values, due to higher structure and density uniformity.

PVAc adhesive provided better strength results, in comparison with PUR adhesive, as regards to both joint types studied in this research project. It is worth mentioning that PVAc was also easier applied on wood and required less tightening time (1 hour). On the contrary, PUR adhesive was proved to provide joints of low reliability in strength and performance.

Mortise – tenon joint in combination with PVAc, provided the best strength results for all wood species. In almost all cases, the joint of mortise - tenon revealed better strength results compared to the double dowel joint, referring to either PVAc or PUR adhesive, except for mortise - tenon joint made of beech with PUR adhesive that exhibited lower strength compared to the double dowel joint in the presence of PVAc adhesive.

According to the findings of elasticity modulus measurement, Greek and Hungarian black locust joints seem to be characterized by very high modulus of elasicity values reaching the elasticity level of beech wood.

Generally, it could be claimed that black locust wood could be successfully utilized in the production of upholstered furniture frames, since this species joints presented satisfying performance and strength levels, while parallel choosing this kind of application, one of the most significant drawbacks of black locust wood, that of its wood mass color unevenness is being eliminated and does not affect the final product.

## ACKNOWLEDGMENTS

This work was funded by the EU through the support of the Greek General Secretariat for Research and Development, Hungarian – Greek Intergovernmental S&T Cooperation Programme for 2010-2011 Project Proposal, Project code HUN-59 “Utilization of Black locust wood species (*Robinia pseudoacacia* L.) in the upholstered furniture skeleton manufacturing.”

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Vassilios Vassiliou, Ioannis Barboutis, *Vasiliki Kamperidou
Aristotle University of Thessaloniki,
Faculty of Forestry and Natural Environment
Laboratory of Wood Products and Furniture Technology
54124 Thessaloniki
Greece
Phone: 2310 998895
Corresponding author: vkamperi@for.auth.gr