ONLINE ISSN 2069-7430
ISSN-L 1841-4737
PRO LIGNO
www.proligno.ro
Vol. 15 N° 4 2019
pp. 372-379

THE EFFECT OF SHELF BRACKETS ON THE FRONT TO BACK LOAD AND COMPARING OF THE MECHANICAL STRENGTHS IN THE SCHOOL CHAIRS MADE FROM LOTUS (*ZIZIPHUS SPINA-CHRISTI*) AND POPLAR (*POPULUS-NIGRA*) SPECIES

Ali BAYATKASHKOLI
University of Zabol, Faculty of Natural Resources, Department of Paper and Wood Technology Zabol, Iran
Tel: +989177153975, Fax: 0098 543 2232600, E-mail: ali.bayatkashkoli@gmail.com

Mahmoud-Reza HOSSEINI-TABATABAEI
University of Zabol, Faculty of Engineering, Department of Civil Engineering Zabol, Iran
E-mail: mhoseini.tabatabaei@yahoo.com

Toktam HEMATI
University of Zabol, Faculty of Natural Resources, Department of Paper and Wood Technology Zabol, Iran
Tel: +989177153975, Fax: 0098 543 2232600, E-mail: toktam_hemati86@yahoo.com,

Mehdi JAMSHIDZADEH
University of Zabol, Faculty of Natural Resources, Department of Paper and Wood Technology Zabol, Iran
Tel: +989177153975, Fax: 0098 543 2232600, E-mail:m.jamshidzade@yahoo.com

Farhad KOOL
University of Zabol, Faculty of Natural Resources, Department of Paper and Wood Technology Zabol, Iran
Tel: +989177153975, Fax: 0098 543 2232600, E-mail: farhadkool@gmail.com

Ehsan SANEAI-SISTANE
University of Zabol, Faculty of Natural Resources, Department of Paper and Wood Technology Zabol, Iran
Tel: +989177153975, Fax: 0098 543 2232600, E-mail: e_saneii@yahoo.com

Abstract:

The lack of forest resources is the reason of using small diameter silvan species in furniture industries. Lotus and Poplar trees exist frequently in many regions. It is possible to use these species for making chairs. The strength of the furniture must be enough against external loads. One way to increase resistance of the furniture frame corners against the bending moment and bending stress is to use wood shelf brackets and Stretchers. Wooden chairs made of Lotus and Poplar with bracket, tenon and mortise joint, are compared to chairs without bracket. Front to back load was applied on the chairs by Universal Testing Machine according to the DIN EN-1729-2:2006 Standard. The results indicated that the chairs had an acceptable strength and it was possible to use Poplar wood in furniture industry. Chairs with bracket had a maximum strength. Also, chair with lotus wood showed better strength than chair with Poplar wood. Type stretcher and brackets changed the failure location at the joint between the back or front post and side rail. The strength of tenon and mortise, and side rail against bending moment are 2697 and 4162 N.cm, respectively. Chairs with bracket have a higher bending moment of failure than chairs without brackets (approximately; twice). This force distribution transfers the stress to the front post and front rail.

Key words: *Lotus; Poplar; bending moment resistance; school chair.*

INTRODUCTION

Due to the lack of forest resources, furniture durability must be increased against external loads by using small diameter species, in order that the lack of raw material at furniture industry is resolve.

The designs and joints of furniture must be complementary and compatible, and their undesirable effects should be decreased in field conditions. Joints and design of chair are very important to manufacture chairs with higher performance, and can be affect its strength and service life. Failure of wood structures mainly occurs in the joints. One way to increase the bending moment resistance and bending stress of the furniture frame corners is to use wood shelf brackets and stretchers. This is also useful to increase the resistance against applied shear forces in furniture frames. Length of service life is one of the most important considerations in the design of furniture, and in most cases, it is a function of joint construction (Eckelman 2003; Eckelman and Haviarova 2006).

Eckelman and Haviarona (2006) determined that chairs with tenon and mortice joints were stronger than chairs with other joints. Another study indicated that chairs with round tenon and mortise joint and half lap joint are the most resistant. The loads had distributed desirably in the chairs stretchers and hence, they had high strength (Haviarova et al. 2001). Glued round and rectangular mortise and tenon joints had the highest levels of cyclic load durability whereas bed bolts had the least (Uysal et al. 2015). The effect of cross pinning the tenons of round mortise and tenon joints on the bending moment capacity of the joints is investigated by Eckelman et al. (2004). The shoulders on tenons significantly increase the bending moment capacity of a joint when the shoulders of the tenon fit firmly against the side of the member in which the tenon is inserted. The shoulders have a substantial effect on the bending moment capacity of the joints. In general, the larger the shoulder caused to the greater the effect. To be fully effective, the shoulder must 'butt' up against the wall of the member containing the mortise. A mortise and tenon joint becomes stiffer as either tenon length or tenon depth is increased. Tenon depth has a more significant effect on joint flexibility than tenon length. Furthermore, the presence of a shoulder on the rail member of a mortise and tenon joint substantially contributes to the stiffness of the joint (Erdil et al. 2005).

A stiffness analysis of a statically indeterminate wood-chair side-frame is presented by Hajdarevic and Busuladzic (2015). The results of the calculation indicate that chair side frame becomes stiffer as the position of the stretcher is lowered and/or the stretcher cross section is increased. The results revealed that stiffness of joints in a frame had a considerable impact on the structure deflection. A satisfactory agreement was found between the numerical results and the results obtained by direct stiffness method.

The strength of chairs against the applied loads is important, especially against the front to back load that mostly exists in practice. Physical and mechanical qualities of Lotus wood are more suitable than Poplar wood. Poplar wood is light and is hardly polishing and has a low durability. The defects can be removed with using technique of compressed and laminated wood. Lotus tree also has a very small diameter. The chair structure can be reinforced with shelf brackets. Lotus and Poplar grow in large areas of the world and wood raw materials are less available in their growth regions. Since, small diameter Poplar and Lotus woods can be used in furniture industry. School chairs are one of these products.

OBJECTIVE

The purpose of the study is compare strength of school chairs made from shelf brackets, Lotus and Poplar wood. The present study is a solution for using Poplar and Lotus woods.

MATERIAL, METHOD, EQUIPMENT

Wooden chairs are manufactured with different designs in workshops and factories. The design used in the research is a chair design with stretchers that is largely produced. The chairs are often produced in workshops and factories of Iran. The dimensions of the chair and its components are based on a field survey, Published data (Noll 2007; Jackson and Day 1995; Horwood 1999) and the DIN EN 1729-1. The patterns of manufacture of the chair and their dimensions are shown in Figure 1.

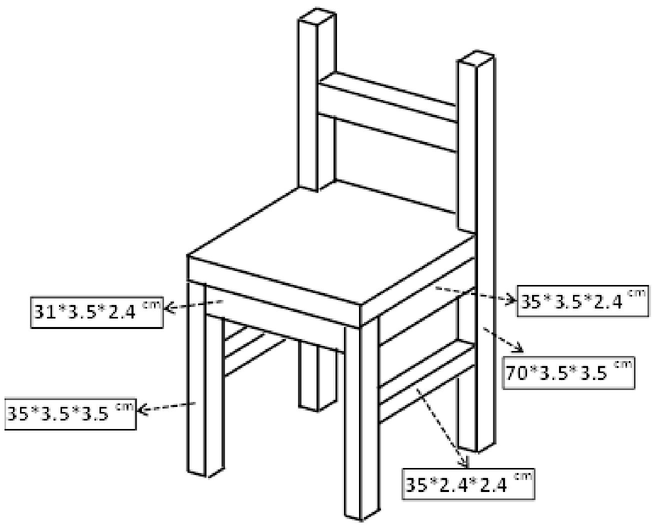

Fig. 1.
The pattern of manufacture of the chair and size of its component parts.

ONLINE ISSN 2069-7430
ISSN-L 1841-4737
PRO LIGNO
www.proligno.ro
Vol. 15 N° 4 2019
pp. 372-379

Poplar (*Populus nigra*) and Lotus (*Ziziphus spina-christi*) species were used in the study. Tenon and mortise joint is largely applied in wooden chairs.

Wooden chairs were constructed with Stretchers, tenon and mortise joint, Poplar and Lotus woods. The wood shelf brackets were used to increase the chair's mechanical strength that located at the between the back post and side rail. The brackets parts were joined at the angle 45˚ with glue and dowel (the diameter 10mm and the penetration depth 1cm) to the back post and side rail of the chairs.

Polyvinyl acetate glue was used as an adhesive. The characteristics of the adhesive are presented at Table 1.

Table 1

The characteristics of the polyvinyl acetate glue

Appearance	Milky white, smooth and free of foreign particles
pH	3.2
Film forming properties	Smooth and colorless and transparent
Minimum film forming temperature	20° C
Storage time	6 months
Solid materials	32%
Assembly time	10 minutes
Preparation	Not need

The final assembly of the chairs was accomplished with Polyvinyl acetate glue and fastener in four different types patterns. The chairs were kept at normal atmospheric conditions for a period of 24 hours for the adhesive used in the joints to become completely cured. Front to back load was applied on the prepared chairs by Universal Testing Machine according to the DIN EN-1729-2:2006 Standard and Eckelman (1999). The loading speed was set at 6.5 mm/min to measure the maximum load. The chair was fixed on the machine's span. The fixed chair does not slide when loading from front to back. Loading method applied from front to back on the chair by the Universal Testing Machine. The experimental error decreases for uniform conditions of construction, including the same of glue line thickness, size of dimensions parts and joints size.

Analysis of chair side-frame

Chair side-frame analysis is not possible with static balancing rules. But if the behavior of dimension parts of chair is known, the analysis can be performed approximately. The presumptions are used to simplify the analyses.

Moment capacity

At the first, the chair was modeled as a two 2D frame. Moment capacity is calculated from the sum of the moments of the external forces loaded on the chair. The modeled chair is analyzed by applied forces as follows.

Loading distribution is showed at frames of chairs structure (Figure 2).

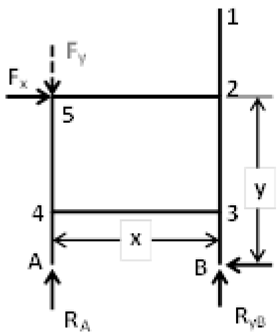

Fig. 2.
Loading distribution on the chair frame.

Analysis of modeled chair under applied forces:

$$F_y = \frac{F_{max}}{2}$$
$$F_x = \frac{F_{max}}{2}$$
$$\sum M_c = c = -R_B \times X + F_y \times X - F_x \times Y = 0 \longrightarrow \qquad R_B = \frac{F_y \times X - F_x \times Y}{X}$$
$$\sum F_y = R_{yc} + R_B - F_y = 0 \longrightarrow \qquad R_{yc} = F_y - R_B$$
$$\sum F_X = F_X - R_{Xc} = 0 \longrightarrow \qquad R_{Xc} = F_X$$

where: maximum load on the chair (N), Mc: sum of produced bending moments around the C point (N.cm), RB: reaction of chair frame at B support (N), Ryc,Rxc: vertical and horizontal reactions of chair frame at C support (N), respectively.

Formula of moment capacity:

$$M_{failure} = -F_x \times Y + F_y \times X$$

Bending moment of side rail.

The presumptions are used that load is applied as horizontal from front to back. The load is located at node 5.

The bending moment at both ends of the stretchers is obtained from the following formula approximately:

$$\frac{\boldsymbol{2M_{34}}}{\boldsymbol{L_{34}}} + \frac{\boldsymbol{2M_{25}}}{\boldsymbol{L_{25}}} = -\boldsymbol{P_H}\left(\frac{\boldsymbol{Y}}{\boldsymbol{X}}\right)$$

According to the assumption:

$$M_{34} = M_{25}\frac{L_{25}}{L_{34}}$$

as a result:

$$\frac{2M_{25}\frac{L_{25}}{L_{34}}}{L_{34}} + \frac{2M_{25}}{L_{25}} = -P_H\left(\frac{Y}{X}\right)$$

$$2M_{25}\left[\frac{1}{L_{25}} + \frac{1}{L_{25}}\right] = -P_H\left(\frac{Y}{X}\right)$$

$$M_{25}\left[\frac{2}{L_{25}}\right] = -\frac{P_H}{2}\left(\frac{Y}{X}\right)$$

The bending moment formula of stretchers:

$$M_{25} = -\frac{P_H}{4}\left(\frac{Y}{X}\right)L_{25}$$

where:

P_H : the horizontal force applied at 5 point of the chair frame (N);
L25: side rail length (cm);
L34: back rail length (cm);
M25: stretcher bending moment (N.cm);
M34 : back rail bending moment (N.cm).

Shelf bracket bending moment

The moment capacity of the chair with shelf bracket is subtracted from that haven't the shelf bracket and the bending moment of the shelf bracket is obtained.

$$M = M_1 + M_2$$

M1= moment capacity of the chair without shelf bracket (N.cm);
M2 = moment capacity of the shelf bracket (N.cm).

Shelf bracket has seen at frames of chairs structure (Figure 3).

Fig. 3.
The shelf bracket piece and the joint of the component in the chair.

RESULTS AND DISCUSSION

The physical and mechanical qualities of Lotus wood and Poplar wood are presented in Table 2. The results of the calculation of the maximum load means and its standard deviations of the treatments are presented in Table 3. Means of maximum load of the chairs designs with shelf bracket or without shelf bracket are determined.

Table 2

Physical and mechanical qualities of Lotus and Poplar wood

Species	Physical properties	mechanical properties	
	Density gr/cm3	MOE (Mpa)	MOR (Mpa)
Poplar	0.37	1426	30
Lotus	0.56	2137	72

Table 3

Means of maximum load and its standard deviations of the treatments

Species type	Design type	Means of maximum load (N)	standard deviations
Poplar	With shelf bracket	2043.67	58.8
Poplar	Without shelf bracket	1019.47	39.1
Lotus	With shelf bracket	2336.33	216.8
Lotus	Without shelf bracket	1423.67	30.4

The results of the statistical analyses are presented in table 4, and are showed that the treatments and their intercept are significantly different. The results of the front to back load test on the chairs have showed that the chairs with shelf brackets are the highest strength. Chairs with Lotus wood are stronger than chairs with Poplar wood (Table 4 and Figure 4). Therefore, the chairs with shelf brackets and without brackets are significantly different, and chairs with Poplar and Lotus woods also are significantly different (Table 4).

ONLINE ISSN 2069-7430
ISSN-L 1841-4737
PRO LIGNO
www.proligno.ro
Vol. 15 N° 4 2019
pp. 372-379

Table 4

ANOVA results of the treatments

Source✷	Mean square	df	F	Sig.
Corrected model	1062378.830	3	80.300	0.000
Intercept	3.492×107	1	2.639×103	0.000
Species	364217.363	1	27.529	0.001
Design	2813589.363	1	212.666	0.000
Species*Design	9329.763	1	0.705	0.425
Error	13230.093	8		
Total		12		
✷R Squared =0 .968 (Adjusted R Squared =0 .956)				

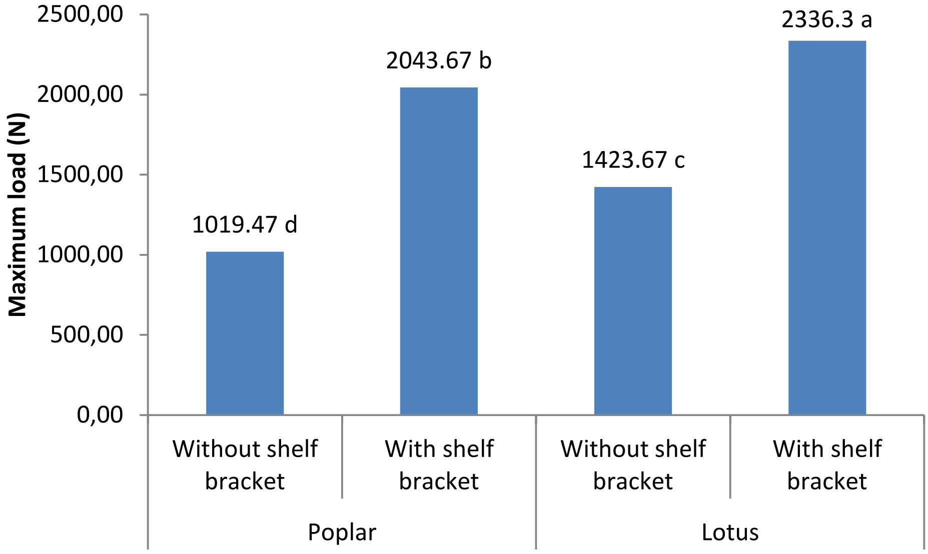

Fig. 4.
The intercept of the design and wood species on the chairs' strength.

Duncan's test shows that the following treatment groups have the highest to the lowest strength, respectively: chair with shelf brackets made from lotus wood, chair with shelf brackets made from Poplar wood, chair without shelf brackets made from lotus wood and chair without shelf brackets made from Poplar wood (Figure 4). Type stretcher and brackets changed the failure location at the joint between the back or front post and side rail. Failure location for chair without shelf brackets under front to back load occurred at the joint between the back post and side rail, but for chair with shelf brackets located at the joint between the front post and side rail.

The fixed support elements of the chair with shelf brackets are larger than that without brackets. In addition, the load distribution is better in chair with shelf brackets. The front to back load is transferred by the shelf brackets to other parts of the chair such as the side rail and the front post. While chair without brackets, the front to back load is concentrated in the joint between back post and side rail, and the joint line is split in this position. The front to back load is applied to chair with shelf brackets has transferred through bracket elements to the front post, and stress concentration is located in the joint line between front post and side rail that is split position. Therefore, chairs have a different failure location that due to different force distribution. Front to back load on the chair frame caused to the shear strength and axial forces and bending moment occurred, and the load is transferred to side rail and joint line. It is useful to use the wood shelf brackets which increase the shear strength and bending moment in the armchair and furniture frame exposed to large loads.

As a result is showed at Figure 4, chairs made of Lotus wood are stronger than those made of Poplar wood. The reason can be related to better mechanical and physical properties of Lotus wood than Poplar wood (Table 2). On the other hand, if the joint elements have a smooth surface, the contact angle between the glue and surface is low and glue line very clearly show the superior performance. Therefore, the strength of the structure frame increases against applied stress at the glue line. Generally, Lotus wood has a smooth surface is because the high density and condenser texture when compared with samples of Poplar wood. Since, samples of lotus wood have a better glue line performance than Poplar wood. Chairs made of oak species are stronger than those made of Poplar species, because the mechanical and physical properties of

ONLINE ISSN 2069-7430
ISSN-L 1841-4737
PRO LIGNO
www.proligno.ro
Vol. 15 N° 4 2019
pp. 372-379

oak wood are better than those of Poplar wood. Hence, chairs made of oak species are more resistant to the applied load (Eckelman and Havriarova 2006).

Failure locations of chair frame are changed from back post-side rail to front post-side rail due to the shelf brackets. Failure of chair frame without brackets is due to the difference between the bending moment of the side rail and that of the joint. The bending moment of the joint is less than that of the side rail. For example, the tenon and mortise bending moment is 2697 N.cm and the side rail bending moment is 4162 N.cm. Chairs with brackets have higher moment capacity (7357.2 N.cm and 6590.4 N.cm) compared with chairs without brackets (3670.28 N.cm and 3198.6 N.cm), and the stress transfers to the front post-side rail. Transfer of load to front post creates a deflection in the front stretcher. The deflection caused to the glue line separation between the front post and stretcher. The moment capacity of the chairs and the bending moment of stretcher were calculated and the calculations results are shown in Figures 5 and 6.

The results of the front to back load test of chairs showed that the chair with shelf brackets had the highest side rail bending moment. Also, Lotus wood showed better strength than Poplar wood (Figure 5). Therefore, chairs with brackets and without brackets, on the other hand, which made from Poplar and Lotus woods, are significantly different.

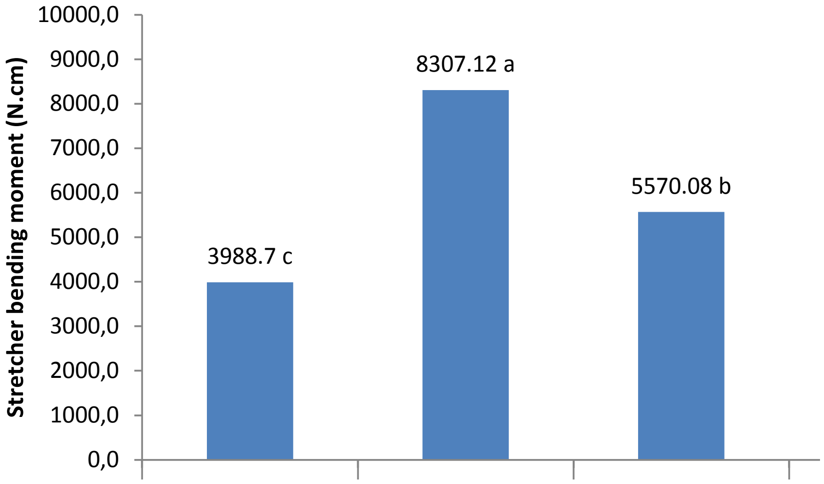

Fig. 5.
The intercept of design and species type on the stretcher bending moment.

The results of the front to back load test of chairs showed that the chairs with brackets had the highest moment capacity (Figure 6). Therefore, the moment capacity of chairs with brackets and without brackets, and on the other hand, which made from Poplar and Lotus woods are significantly different.

The mean bending moment of brackets is 3686.92 N.cm (chair with tenon and mortise joint) and 3115.453 N.cm (chair with double joint), and the bending moment of tenon and mortise joint is 2697.6 N.cm and wooden double joint is 405.93 N.cm.

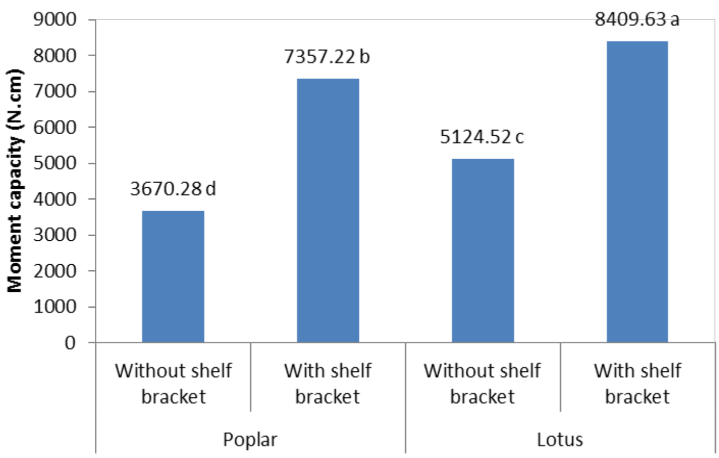

Fig. 6.
The intercept of design and species types on the moment capacity.

Availability of Poplar wood is advantage, but its low quality is disadvantage. Low quality of Poplar wood can be modifying by compression and lamination. Since, Poplar wood can be used for furniture through lamination and compression.

CONCLUSIONS

It is possible that the chairs made from Poplar and Lotus wood with acceptable strengths. The maximum front to back load of the chairs exceeds the standard value. Chairs made of Lotus wood have the highest strength, because its physical and mechanical properties are better than Poplar wood. Lotus wood has a higher density, denser texture, smooth surface and more suitable adhesive bonding, and hence, its glue line occurred firm. Also, chair with shelf brackets has a maximum front to back load. The loads distribution of chair with brackets has the best performance. Force uniform distribution in chair frame with brackets cause that the stress transfers to the front post-side rail. While, the front to back load on the chair without brackets is concentrated in the back post-side rail. Therefore, failure locations of glue line at chair frame with brackets and without brackets are different. The wood shelf brackets caused to increases the shear strength and bending moment of school chairs. The technique used which Poplar wood can be used in furniture industry.

ACKNOWLEDGEMENT

This paper is supported by University of Zabol (Reference No. UOZ-GR-9517-25).

REFERENCES

Buyuksari U (2012) Physical and mechanical properties of particleboard laminated with thermally compressed veneer. Laminated particleboard properties, bioresources 7(1):1084-1091.

DIN EN 1729-1: 2006. Furniture –Chairs and tables for educational institutions - Part 1: Functional dimensions.

DIN EN 1729-2: 2006. Furniture –Chairs and tables for educational institutions Part 2: Safety requirements and test methods.

Eckelman CA (1999) Performance testing of side chairs. springer–verlag journal 57(4):227-234.

Eckelman CA (2003) Textbook of Product and Strength Design of Furniture, Purdue University, West Lafayette.

Eckelman C, Haviarova E (2006) Performance test of school chairs constructed with round mortise and tenon jounts. Forest products journal 56(3):51-57.

Eckelman C, Haviarova E, Erdil Y, Tankut A, Akcay H, Denizli N (2004) Bending moment capacity of round mortise and tenon furniture joints. Forest products journal 54(12):192-197.

Erdil YZ, Kasal A, Eckelman CA (2005) Bending moment capacity of rectangular mortise and tenon furniture joints. Forest products journal (55)12:209-213.

Jackson A, Day D (1995) Good wood joints. Harpercollins publisher London.

Hajdarevic S, Busuladzic I (2015) Stiffness analysis of wood chair frame. Procedia Engineering 100:746 – 755.

Haviarova E, Eckelman C, Erdil Y (2001) Design and testing of environmentally friendly wood school chairs for developing countries. Forest products journal 51(3):58-64.

Horwood R (1999) Wood workers hand book. New Holland publisher London.

Noll T (2007) Wood workers joints book. Apple press, United Kingdom.

Uysal M, Haviarova E, Eckelman CA (2015) A comparison of the cyclic durability, ease of disassembly, repair, and reuse of parts of wooden chair frames. Materials and Design 87:75–81.