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# EVALUATION AND COMPARISON OF CONTROL AND HEAT TREATED L-SHAPE FURNITURE JOINTS PRODUCED FROM SCOTCH PINE AND ASH WOOD UNDER STATIC BENDING AND CYCLIC FATIGUE BENDING LOADINGS

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## ABSTRACT

This study investigated how the mechanical properties of L-shape joints produced from heat treated Scotch pine or ash wood behaved under cyclic fatigue loading and compared this with the mechanical properties of non-heat treated wood materials. Additionally, static bending performances of the L-shape of joints were investigated and compared to fatigue bending performance of same type of joints. Results indicated that increasing number of staple from 6 to 8 and density generally increased static bending of L-shape joints. Static bending resistance of L-shape joints produced from control Ash wood significantly higher than those of L-shape joints produced from heat treated Ash wood while no significant difference were observed between static bending resistance L-shape joints produced from control Scotch pine and L-shape joints produced from heat treated Scotch pine wood. The fatigue bending resistances of L-shape joints produced from heat treated samples generally passed and failed the same loading steps with those produced from control samples which means both L-shape joints could be used in same service area. L-shape joints under static and fatigue loadings mostly indicated staple leg shear mode. The one under fatigue loading was more than the one under static loading. Additionally, some joints under fatigue loading indicated staple rupture. The overall ratio of static bending loading to cyclic fatigue bending loading for L-shape joints was obtained as 2.85.

**Keywords:** Ash wood, cyclic fatigue bending, heat treated, L-shape joint, Scotch pine, staple, static bending.

## INTRODUCTION

As a structural and natural material, wood has been used in indoor and outdoor applications for centuries. Recently, with an increasing environmental awareness, the use of heat-treated wood material increased the life of limited amount of forest products in an environmentally friendly. Heat treatment is an effective method to increase the dimensional stability and durability of wood (Kol *et al.* 2015). Heat treatment of wood material above 160 °C increases the durability of the wood material (Metsa-Kortelainen and Viitanen 2009, Candelier *et al.* 2013a), and it becomes darker (Ahajji *et al.* 2009). Such improvements make possible to use beech, ash, poplar or oak sapwood for veneer, window frame and joints (Hannouz *et al*. 2015).

Chemical changes occurring in the structure of wood during heat treatment affect the strength and hardness properties of the wood (Kocaefe *et al*. 2008, Candelier *et al.* 2013b). Therefore, the mechanical properties of the wood structure are deteriorated after heat treatment. Heat treatment also changes the anatomical structure of the wood material (Hannouz *et al.* 2015). However, Boonstra (2008) noticed that no damage was observed in ash wood with two-stage heat treatment under optimized conditions.

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Heat treatment has found a number of application areas such as wood material siding, window and door joinery, panels, garden furniture, sauna furniture, flooring and floor covering, etc. (Yildiz *et al.* 2006, Özçifçi *et al.* 2009). Therefore, mechanical properties of heat treated wood material are vital for the performance of wood material.

Although the effect of heat treatment on wood material properties is well established (Yıldız *et al*. 2006, Gündüz *et al.* 2008), studies on the fatigue strength of heat treated wood are almost nonexistent. Since poor performance after fatigue life of material is the most common form of degradation in furniture, fatigue performance plays very important role in the selection of materials for the joints and other components that make up the furniture (Ratnasingam *et al.* 1997). Today, various material reports of wood material on design stresses for furniture production are available (Eckelman *et al.* 2001, Ratnasingam and Ioras 2011a, Ratnasingam and Ioras 2011b), however; this information on heat-treated wood material is limited. As a result, the use of heat-treated wood material as a load-bearing material in furniture production has been limited. Additionally, metal connections such as staples are widely used to manufacture furniture frames. L-shape joints connected with staples is one of the popular joints used in furniture construction.

Zhang *et al.* (2006) investigated fatigue performances of T-shape, end-to-side, metal-plate-connected (MPC) joints in furniture grade pine plywood. Tested joints were subjected to one-sided cyclic stepped bending loads. The purpose of the study was to obtain joint static to fatigue moment capacity ratios. Performance test results showed that a MPC plywood Joint would fail within 25000 cycles when a stepped load level reached 46 percent of the static moment capacity of the tested joint. The static to fatigue moment capacity ratio for tested joints averaged 2,5 with and a range of 2,2 to 3,1.

Ratnasingam and Ioras (2013) investigated the load bearing characteristics of heat-treated rubberwood furniture components and joints. It was found that heat-treated samples had significantly lower fatigue strength compared to the rubberwood control samples. The results of this study revealed that the allowable design stresses for heat-treated rubberwood components could be set at 40 % of its ultimate bending strength, while heat-treated rubberwood joints could be safely used to withstand repeated loadings at 25 % of its ultimate bending moment. At these load levels, the specimens would complete the minimum furniture performance standard of 200000 cycles of load.

Studies on the comparison of heat treated and untreated wood materials have always been based on static tests until now. In other words, after static measurements, the heat treated wood material performs lower than the non-heat treated wood material in terms of resistance properties. On the other hand, there are almost no studies examining the performance of heat treated wood material under fatigue loads. There is perhaps no study conducted on the cyclic fatigue performance of furniture joints made of solid wood, especially assembled with staples.

The main objective of this study was to evaluate and compare static and fatigue performance of staple-connected L-shape gusset-plate joints produced from control and heat-treated Scotch pine and ash wood. The specific objectives of this study were to: 1) evaluate the static bending moment resistance of L-shape joints produced from control and heat-treated Scotch pine and ash wood; 2) evaluate the repeated fatigue bending moment resistances of L-shape, joints produced from control and heat-treated Scotch pine and ash wood by subjecting these joints to GSA FNAE-80-214A (1998) arm test loading schedules; 3) Compare static and fatigue performance of control and heat treated L-shape gusset plate joints.

## MATERIAL AND METHODS

### Materials

L-shape joints produced from heat treated and control Scotch pine and ash wood were supplied from the heat treatment companies of NOVA and NAS. The heat treatment was carried out based on Thermo-wood method. It was carried out in a boiler in the size of 9500 mm long, 3500 mm wide and 3500 mm high. The dimensions of the treated wood materials were 2100 mm long, 125 mm wide and 25 mm thick. The heat treatment procedure consisted of three main stages which were preparing for heat, the heat treatment, and cooling-conditioning. The first stage consists of two steps. First step starts at 25 ºC degree and reaches 120 ºC degree in 10 and 14 hours for Scotch pine and ash wood, respectively. The second step starts at 120 ºC and reaches 212 ºC in 9 h and 13 h for Scotch pine and ash wood, respectively. For both Scotch pine and ash wood were subjected to heat treatment for 2 hours at 212 ºC temperature. After heat treatment stage, the cooling is applied to the wood materials. The cooling stage consists of cooling and conditioning steps. Cooling stage takes 11 hours and 14 hours for Scotch pine and Ash wood, respectively and wood materials are cooled to 120 ºC degree. Then conditioning takes 6 hours and 7 hours for Scotch pine and ash wood, respectively. At the degree of 60 ºC, wood materials are taken out from the boiler and heat treatment procedure is ended. A general configuration of the L-shape joints prepared for this study is shown in Figure 1.

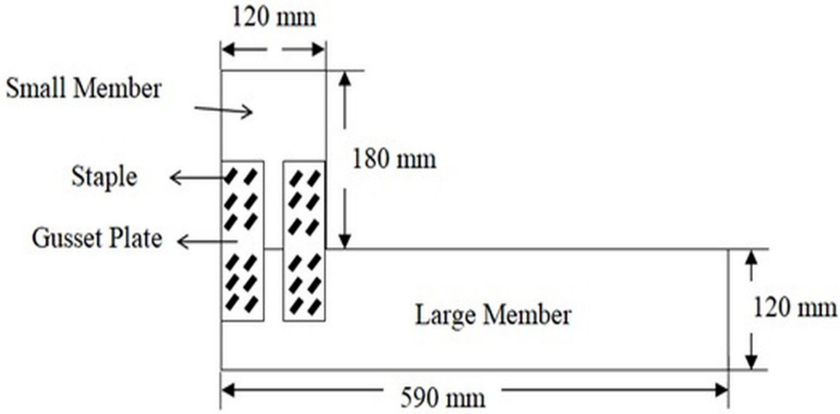


**Figure 1:** Typical configuration of L-shape joint.

### Experimental design

In order to evaluate the significance of factors on the moment capacity of L-shape joints, a SAS statistical analysis of 2 × 2 × 2 with 5 replications per group was performed. Factors are the number of staples (6 and 8), the type of chemical modification (control and heat treatment) and the type of wood (Scotch pine and ash wood).

### L-shape joint

L-shape joints consisted of a combination of two members, one big and one small. These two members were connected by a pair of gusset plates attached to one side of the joint. The gusset plates are made of beech wood (*Fagus orientalis*). The large members are in the size of 590 mm long, 120 mm wide, 18 mm thick, while the small members are in the size of 180 mm long, 120 mm wide, 18 mm thick as shown in Figure 1. Large members and small members were separately produced from the control and heat treated versions of Scotch pine and ash wood, and a total of 40 samples were prepared for the static bending test. The gusset plates are in the size of 152 mm length and 52 mm width. The number of staples used in the construction of these gusset plates were 6 and 8, totally 24 and 36 staples were used in one joint, respectively. The staples are SENCO-16 brand, galvanized and leg ends are chisel type. The crown width of the staples is 11 mm and their leg length is 38 mm. The staples are covered with nitro-cellulose-based plastic to prevent rusting (Sencote coating).

All samples were conditioned in the chamber at 20 ºC ± 5 º C temperatures and 65% ± 5% relative humidity before testing. The joint members were assembled by driving the staples through the gusset plates by a staple gun with a pressure of 483 kPa. The staples were applied at 45º angles to the grain direction of the gusset plates to ensure the best holding capability of the staple (Demirel and Kalayci 2020). All L-shape joints were subjected to static bending test immediately after the joint production.

### Static bending test

L-shape joint prepared for the static bending test were loaded in the hydraulic MTS universal testing machine at a loading speed of 2,5 mm/min based on ASTM D1761 (2010) standard. Placement of L-shape joints in universal machine for bending test is shown in Figure 2. The loading is carried out on the large member and it is 320 mm away from the small member. Before starting the loading, it was calibrated so that there was no gap between the load head and the loaded part of the joint. The loading continued until L-shape joints failure. At the end of the bending test, the failure modes of the L-shape joints were recorded.

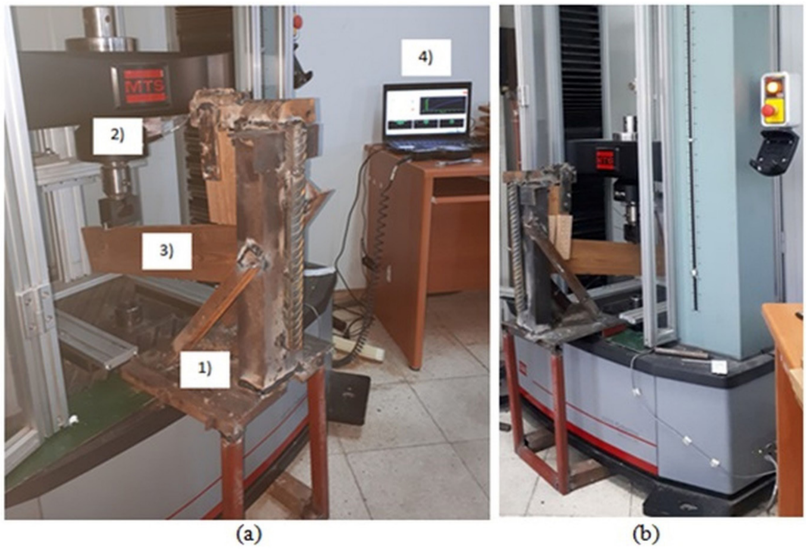


**Figure 2:** Placement of L-shape joints in the MTS universal machine for bending test: (a) Left view, 1) Fixture in which the L-shape joint is placed, 2) Loading head, 3) Tested joint, 4) Computer on which the loading is monitored; (b) Right view.

**Cyclic fatigue test**

In this part of the study, all L-shape joints were subjected to repeated (cyclic) fatigue testing based on the outward arm test of the seat test plan of the American General Service Administration (GSA).

**Experimental design**

Table 1 gives the repeated and load-levels on fatigue load values specified in the GSA scheme for the arm of sofa frame. According to this plan, there are three service levels, which are light, medium and heavy. The acceptance values for these service levels are 75, 150 and 200 pounds (lb.) respectively. These values are 34, kg, 57 kg and 79 kg, respectively.

**Table 1:** GSA repeated and step fatigue loading schedule.

| Loads (lb.) | 50 | 75 | 100 | 125 | 150 | 175 | 200 |
|---|---|---|---|---|---|---|---|
| Loads (kg) | 23 | 34 | 45 | 57 | 68 | 79 | 91 |
| Number of cycles | 25 | 50 | 75 | 100 | 125 | 150 | 175 |
| Service acceptance level | | Light | | | Medium | | Heavy |

**Fatigue loading system**

The repeated fatigue loading for L-shape joints was carried out in a test system consisting of 4 air cylinders placed on a metal frame made of specially designed 50 mm × 50 mm profile square pipes shown in Figure 3. In all fatigue tests, a vertical fatigue load was applied on large member 320 mm away from small member by an air cylinder at a speed of 20 cycles per minute for each joint. The loading schedule is given in Table 1. Tests were started at 23 kg load and after 25000 cycles loading, the load was increased by 11 kg and the loading moved the next step. In the next step, the joint was subjected to an additional fatigue load of 25000 cycles, the fatigue test was continued for 25000 cycles. After completing 25000 cycles, the load increased again and the loading was continued until the joint failed. The counter in the loading system indicated cycling loading numbers.

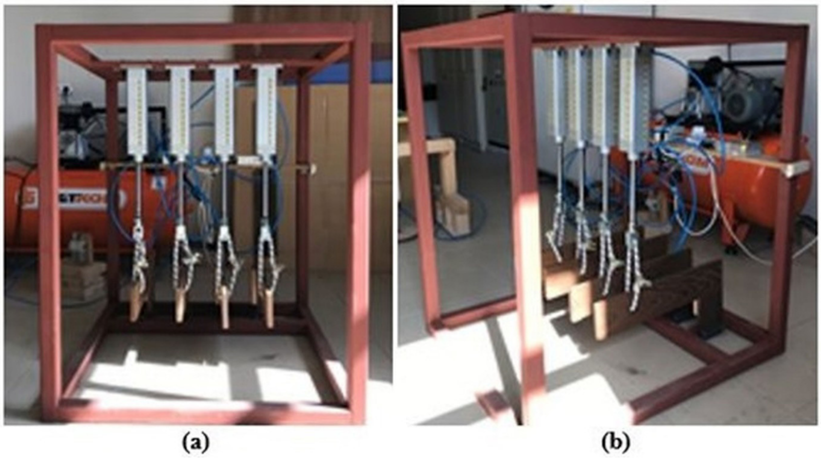

**Figure 3:** Fatigue Loading System: (a) Front view; (b) Diagonal view.

Fatigue test system consists of four MAC brand air pistons, an air valve, air compressor, air regulator, load cycle counter, timing counter and 8 mm diameter hoses carrying air. In the cyclic loading system, the air comes from the compressor to the pistons with the hoses which lead the pistons to apply pressure or load on the L-shape joints. The timing counter sets how many hours the system run, while the load cycle counter reads how many load is applied to the joint. Figure 4 shows the counters in the fatigue test system.


**Figure 4:** (a) Timing counter (b) Load cycle counter.

## RESULTS AND DISCUSSIONS

### Density and moisture content of wood materials

Table 2 shows physical properties of wood materials used in this study such as density and moisture content values. Accordingly, physical properties of heat-treated wood materials are lower than the ones of control wood materials.

**Table 2:** Density and moisture content values of wood material.

| Wood Material | Density (kg/m³) | Moisture content (%) |
|---|---|---|
| Scoth pine | 491 | 10,9 |
| Heat treated Scoth pine | 364 | 4,37 |
| Ash wood | 778 | 9,85 |
| Heat treated ash wood | 674 | 3,48 |

**Static bending loading**

In this study, the maximum bending resistance values and average values of L-type joints produced from two rows of 6-staple and 8-staple Scotch pine and ash wood joints are shown in Table 3.

**Table 3:** Average maximum bending strength values of 6 and 8 stapled L-type joints produced from Scotch pine and ash wood samples in N.

| | Number of staple | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 6 | | | | 8 | | | |
| Number of sample | Control Scotch pine | Heat treated Scoth pine | Control ash wood | Heat treated ash wood | Control Scotch pine | Heat treated Scoth pine | Control ash wood | Heat treated ash wood |
| Average (N) | 1010(7) | 941(15) | 1917(12) | 1303(17) | 1321(5) | 1291(13) | 2629(5) | 1399(17) |

As seen in Table 3, the average bending strength value of the 6-staple L-type joints produced from the scotch pine control samples was higher than the L-type joints produced from heat treated scotch pine samples with the same number of staple. Similarly, the average bending strength value of the 6-staple L-type joints produced from the ash wood control samples was higher than the L-type joints produced from the heat treated ash wood samples with the same number of staples. As can be seen from the table, the situation is similar for 8 stapled joints. Accordingly, the average bending strength value of the 8-staple L-type joints obtained in the Scotch pine control samples was higher than the L-type joints produced from heat treated Scotch pine samples with the same number of staples. Similarly, the average bending strength value of 8-staple L-type joints obtained in the ash wood control samples was higher than the L-type joints produced from heat treated ash wood samples with the same number of staples.

Using the data of each L-shape joint, a three-factor ANOVA general linear model was run in SAS statistical program with 5 % confidence level and their interactions on the mean values of the L-shape joints were investigated. Based on ANOVA table from SAS analysis, triple interaction among the factors of number of staple, wood specie, and treatment condition is statistically significant because the P value, 0,0046, of the triple interaction is less than P = 0,05. Accordingly, this triple interaction was analyzed. The results are shown in Table 4, Table 5 and Table 6.

**Heat treatment effect**

The important evaluation for this study is the statistical comparison of heat treated and control samples. As shown in Table 4, although the average static bending strength values of the 6-staple L-shape joints obtained from Scotch pine control samples were mathematically higher than the average bending strength values of the heat treated Scotch pine joints in the same staple number, this difference is not statistically significant. The same relation was observed between the average static bending strength values of the 8-staple L-shape joints produced from Scotch pine and heat treated Scotch pine.

**Table 4:** Heat treatment effect on L-shape samples.

| Wood specie | Number of staple | Treatment condition | |
|---|---|---|---|
| | | Control | Heat treated |
| Scotch pine | 6 | 1010(A) | 941(A) |
| Ash wood | | 1917(A) | 1303(B) |
| Scotch pine | 8 | 1321(A) | 1291(A) |
| Ash wood | | 2629(A) | 1399(B) |

Letters in parenthesis indicate statistical difference

On the other hand, the average static bending strength values of the 6-staple L-shape joints produced from the ash wood control samples were statistically higher than those of the heat treated ash wood joints in the same number of staple. The same relation was observed between the average static bending strength values of the 8-staple L-shape joints produced from the control ash wood and heat treated ash wood. This can be explained as increasing the wood density in joints produced from control samples increased the static bending strength compared to the joints produced from heat treated wood samples. Kalayci (2019) observed the joints constructed from beech wood with the highest density, indicated the highest average shear force values compared to the ones manufactured from alder and Scotch pine, while the joints constructed from Scotch pine with the lowest density indicated the lowest shear force. Demirel and Zhang (2014) observed that L-shaped joints constructed from OSB-III with the highest density showed significantly higher ultimate moment resistance loads than L-shaped joints constructed from OSB-I and OSB-II joints with lower densities.

**Number of staple effect**

Table 5 shows the number of staple effect on L-shape joints. As shown in Table 4, the average static bending strength values of L-shape joints with 8-staple produced from both control and heat treated Scotch pine and ash wood samples were statistically higher than those with 6-staple. As the number of staples increased, the average static bending strength values of the L-shape joints increased. Demirel and Zhang (2014) investigated that increasing number of staples from 8 to 12 in L-shape OSB joints significantly increased the average maximum bending strength.

**Table 5:** Number of staple effect on average static bending strength values of L-shape joints.

| Treatment | Wood specie | Number of staple | |
|---|---|---|---|
| | | 6 | 8 |
| Control | Scotch pine | 1010(A) | 1321(B) |
| | Ash wood | 1917(A) | 2629(B) |
| Heat treated | Scotch pine | 941(A) | 1291(B) |
| | Ash wood | 1303(A) | 1399(A) |

Letters in parenthesis indicate statistical difference

Here, no significant difference was observed between the average bending strength values of the 6-staple L-shape joints made of heat treated ash wood and the average bending strength values of the 8-staple L-shape joints made of heat treated ash wood. The reason for this is that heat treatment in ash wood may break the mechanical structure of the joint elements, and therefore; it is thought that there is no statistical difference between the 8 and 6-staple joints. As the heat treatment weakens the mechanical structure of the wood material, the increase in the number of staples could make weaker or more fragile the wood material to be destroyed. Boonstra *et al.* (2007) examined the effect of heat treatment on the mechanical properties of the wood material and observed that the bending resistance of the wood material decreased after heat treatment. It has been determined from previous studies that the reason for the decrease in bending resistance after heat treatment is due to the degradation in hemicellulose (Kass *et al*. 1970), (LeVan *et al.* 1990), (Winandy 1995). Again, some studies stated that heat treatment reduces the bending resistance of wood material (Bengtsson *et al.* 2002, Santos 2000). Kaygın *et al*. (2009) found a decrease in some mechanical properties such as bending resistance in pawlonia wood as a result of heat treatment.

**Wood specie effect**

Table 6 shows the wood specie effect on average maximum static bending strength values of L-shape joints. As shown in Table 6, the average static bending strength values of the 6-staple and 8-staple L-shape joints produced from both heat treated and control ash wood were statistically higher than those produced from Scotch pine. The reason for this is that the density of the ash wood is higher than the density of the Scotch pine. Demirel and Zhang (2014) investigated the static bending strength values of L-shape furniture joints produced from OSB material of different densities (OSB-I, OSB-II, OSB-III) and consequently, the L-shape joint produced from OSB-III with the highest density indicated the highest maximum bending strength compared to those produced from OSB-II and OSB-I with lower and the lowest densities, respectively.

**Table 6:** Wood type effect on average static bending strength values of L-shape joints.

| Treatment | Number of staple | Wood specie | |
|---|---|---|---|
| | | Scotch pine | Ash wood |
| Control | 6 | 1010(A) | 1917(B) |
| | 8 | 1321(A) | 2629(B) |
| Heat treated | 6 | 941(A) | 1303(B) |
| | 8 | 1291(A) | 1399(A) |

Letters in parenthesis indicate statistical difference

In Table 6, the average maximum bending strength values of the 8-staple L-shape joints made of heat treated ash wood are mathematically higher than those of the 8-staple L-shape joints made of heat treated Scotch pine woods, but no statistical difference was observed. When looking into Table 6, it is clearly seen that heat treated joints show less strength values compared to the control joints. The reason could be that heat treatment made wood structure weaker and therefore no statistical difference was observed in ash wood joints with 8-staple.

**Failure modes for the joints under static bending loading**

As a result of the static loading, almost all of the joints were failed with the small gap between small and large members due to staple leg static shear, and the small member was generally broken from the upper hole side. In some samples, cracks were observed in large members, and very rarely cracks were observed in the gusset plates of the joints. Figure 5 shows some failure mostly observed under static bending loading.

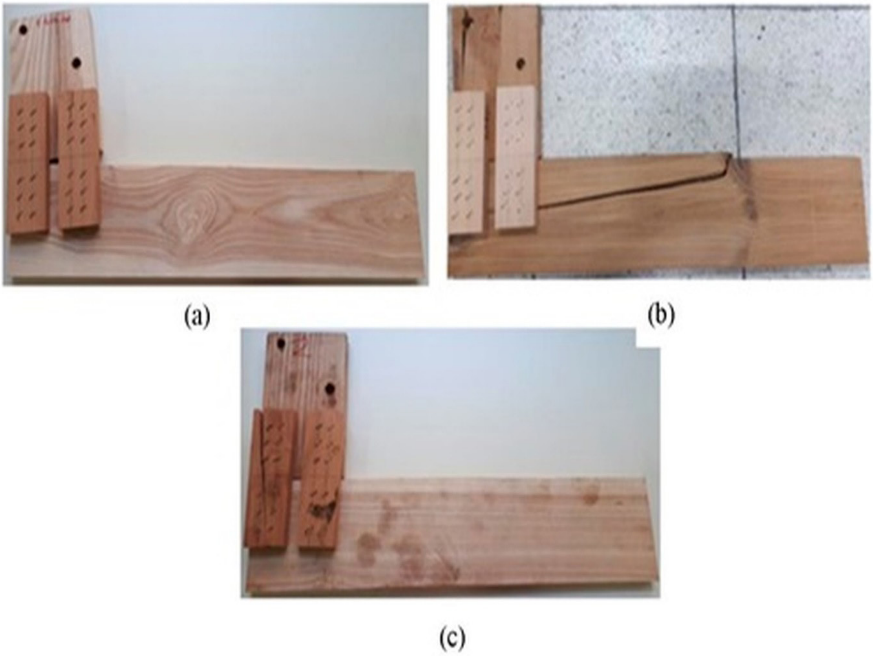


**Figure 5:** Failure modes of the joints under static bending loading: (a) little amount of the staples came out of the large member, (b) the small member crack from the upper hole side and cracks in large member, and (c) cracks in the gusset plate.

### Cyclic fatigue loading

As shown in Table 7, it can be generally said that, according to the GSA, all L-shape joints are included in the light acceptance level but 8-staple L-shape joint produced from control ash wood joints which are included in the medium acceptance level. The most important conclusion to be drawn for this study is that the L-shape joints produced from the control and heat treated wood species passed the same loading step and failed in the same loading step. This mean that unlike static loading even if a material is heat treated, it can withstand the same fatigue loading with control samples under long time loading duration. In other words, a heat treated wood can withstand in the same loading level as the same wood without heat treatment under fatigue load. However, this situation is different under static loading. This study, perhaps, made an important contribution to the literature due to such a result. Only, heat treated ash wood L-shape joints with 8-staple failed one level behind the control ash wood joints with the same staple number. The only difference between the control joint and heat treated joints under fatigue load is that heat treated joints survived with less number of cycles under the same fatigue load level. Ratnasingam and Ioras (2013) found that heat treated samples had significantly lower fatigue strength compared to the control rubber wood samples.

**Table 7:** The loading levels at which the L-shape joints succeed as a result of the fatigue test.

| Wood specie | Number of staple | Passed load level | Failed load level |
|---|---|---|---|
| Control Scotch pine | 6 | 45,4 | 56,75 |
| | 8 | 56,75 | 68,1 |
| Control ash wood | 6 | 45,4 | 56,75 |
| | 8 | 68,1 | 79,45 |
| Heat treated Scotch pine | 6 | 45,4 | 56,75 |
| | 8 | 56,75 | 68,1 |
| Heat treated ash wood | 6 | 45,4 | 56,75 |
| | 8 | 56,75 | 68,1 |

### Failure modes for the joints under cyclic fatigue loading

The failure modes were generally observed as the staple leg fatigue shear more than the ones under static bending loading. Also staple breakage was observed in joints compared to the joints under static bending loading as shown in Figure 6c. In the study of Zhang *et al.* (2006) on fatigue performances of T-shape metal-plate-connected joints in furniture grade pine plywood, joints failed mainly due to tooth fatigue shear at the roots. Some joints showed cracking and splitting in the large member while some showed them in the small member. Particularly, fragmentation of members was more observed in heat treated joints. Figure 6 shows failure modes mostly observed under cyclic fatigue loading.

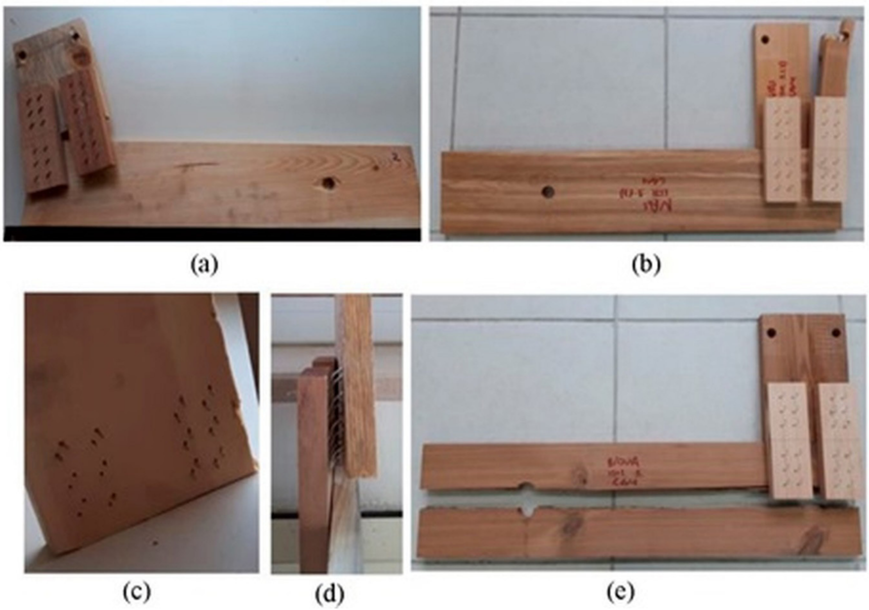


**Figure 6:** Failure modes of the joints under repeated fatigue loading: (a) staple leg fatigue shear, front view, (b) small member rupture, (c) staple rupture, (d) staple leg fatigue shear, side view, and (e) large member rupture.

### Ratio of static bending test to fatigue test

Table 8 indicated the ratios of the static bending values of the L-shape joints to the final passed fatigue load levels of the same joints. In the studies of Zhang *et al*. 2001, Zhang *et al*. 2004, Zhang *et al*. 2006, Wang *et al.* 2007a, Wang 2007b, Demirel 2012, it was seen that the ratio of static loading values to passed fatigue loading values for L-shape joints varied between 1,6 and 3. In this study, the general ratio is 2,85 and it is in the same range as literature studies.

**Table 8:** The ratios of the static bending values of the L-shape joints to the final passed fatigue load levels of L-shape joints.

| Bending test values (kg) | Number of staple | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 6 | | | | 8 | | | |
| | Control Scotch pine | Heat treated Scotch pine | Control ash wood | Heat treated ash wood | Control Scotch pine | Heat treated Scotch pine | Control ash wood | Heat treated ash wood |
| Static bending test load values | 103 | 96 | 195 | 133 | 135 | 132 | 268 | 143 |
| Fatigue test passed load values | 45,4 | 45,4 | 45,4 | 45,4 | 56,75 | 56,75 | 68,1 | 56,75 |
| Ratio | 2,27 | 2,11 | 4,3 | 2,93 | 2,38 | 2,33 | 3,94 | 2,52 |
| General ratio | | | | | | | | 2,85 |

Also, as shown in Table 8, the ratio of static loading results to fatigue loading results for L-shape joints produced from heat treated samples is lower than those of the control samples and closer to the average within the range specified in the literature. In other words, L-shape joints produced from heat treated wood yielded a better ratio between 1,6 and 3 and close to 2 compared to the control joints.

## CONCLUSIONS

In this study, static bending and fatigue bending performance of L-shape furniture joints produced from control and heat treated Scotch pine and ash wood were evaluated and compared.

The results showed that the average maximum static bending strength values of the 6-staple and 8-staple L-shape joints produced from heat treated Scotch pine were mathematically lower than those produced from the control Scotch pine samples, but this value did not make a statistical difference. On the other hand, it was observed that the static bending strength values of 6 staple and 8-staple L-shape joints produced from heat treated ash wood joints were significantly lower than the control ash wood joints. The reason of this could be using a wood material with higher density such as ash wood which has higher density than Scotch pine.

The increase in the number of staples under static bending was observed to increase the bending resistance values in both control and heat treated samples. However, the bending resistance of 8-staple L-shape joints obtained from control ash wood samples did not significantly higher than the one of 6-staple L-shape joint obtained from heat treated ash wood.

Under the static bending loading, the joints produced from higher density ash wood generally showed statistically higher bending values than the joints made of lower density Scotch pine. However, there was no significant difference between the 8-staple joints produced from these two heat treated wood species.

After the static bending loading, a slight gap between the small member and the large member were observed in almost all of the joints due to staple leg shear. Cracking was observed in the upper hole of the small member in the most of joints due to the location of the hole.

Under cyclic fatigue loading, whether controlled or heat treated, almost all joints were able to withstand the same loading level, that is, even if the control samples resisted more in terms of loading cycles, they failed under the same load or service level. Only, a loading step of 8-staple joints produced from control ash samples, compared to those with heat treatment, completed the fatigue test at the highest level. In other words, control samples of the ash wood joints gave more durable results than heat treated ones. However, the joints produced from all other control and heat treated samples indicated the same strength that can be used in the same service area. Therefore, it is an important result of this study that heat treated joints can be used in the same place with L-shape joints produced the control samples as a result of fatigue loading. At the end of this study, it can be said that the loss in mechanical properties under fatigue loading may be negligible compared to the one under static bending loading.

After cyclic fatigue loading, the L-shape joints mostly indicated staple leg fatigue shear mode which was more than staple leg static shear under static loading. Unlike the joints under static bending, the staples showed rupture under fatigue loading. Some joint members were destroyed under fatigue loading, especially the heat treated ones.

The overall ratio obtained as a result of static bending and repeated fatigue bending loadings for L-shape joints produced from control and heat treated ash wood and Scotch pine was determined as 2;85. Additionally, this ratio for the L-shape joints produced from heat treated samples yielded closer results to the ratios obtained in literature studies compared to those produced from control samples.

## REFERENCES

**Ahajji, A.; Diouf, P.; Aloui, F.; Elbakali, I.; Perrin, D.; Merlin, A.; George, B. 2009.** Influence of heat treatment on antioxidant properties and colour stability of beech and spruce wood and their extractives. *Wood Sci Technol* 43(1-2): 69-83. https://dx.doi.org/10.1007/s00226-008-0208-3.

**ASTM International. 2010.** Standard test method for mechanical fasteners in wood. American Society for Testing and Materials. ASTM D 1761. 2010. ASTM International: West Conshohocken, PA, USA.

**Boonstra, M.; Acker, J.V.; Tjeerdsma, B.F.; Kegel, E.F. 2007.** Strength properties of thermally modified softwoods and its relation to polymeric structural wood constituents. *Ann For Sci* 64(7): 679-690. https://dx.doi.org/10.1051/forest:2007048

**Boonstra, M. 2008.** A two-stage thermal modification of wood. PhD Thesis, University Henri Poincaré, Nancy 1., France.

**Bengtsson, C.; Jermer, J.; Brem, F. 2002.** Bending strength of heattreated spruce and pine timber. In: Proceedings of international research group on wood protection IRG 33 - Cardiff, Wales, United Kingdom. May 2002.

**Candelier, K.; Dumarçay, S.; Pétrissans, A.; Desharnais, L.; Gérardin, P.; Pétrissans, M. 2013a**. Comparison of chemical composition and decay durability of heat treated wood cured under different inert atmospheres: Nitrogen or vacuum. *Polym Degrad Stab* 98(2): 677–681. https://dx.doi.org/10.1016/j.polymdegradstab.2012.10.022

**Candelier, K.; Dumarçay, S.; Pétrissans, A.; Gérardin, P.; Pétrissans, M. 2013b**.Comparison of mechanical properties of heat treated beech wood cured under nitrogen or vacuum. *Polym Degrad Stab* 98(9): 1762–1765. https://dx.doi.org/10.1016/j.polymdegradstab.2013.05.026

**Demirel, S. 2012.** Static and fatigue performance of oriented strandboard as upholstered furniture frame stock, PhD Thesis, Mississippi State University, Starkville, USA. http://sun.library.msstate.edu/ETD-db/theses/available/ etd-03212012-085200/unrestricted/Final.pdf

**Demirel, S.; Zhang, J. 2014.** Bending moment resistance of L-shaped two-gusset-plate furniture joints in oriented strandboard. *Wood Fiber Sci* 46(3): 356-367. https://wfs.swst.org/index.php/wfs/article/view/1078/1078

**Demirel, S.; Kalayci, G. 2020.** Measuring and estimating shear force of one stapled and one-row multi stapled wood joints. *Maderas-Cienc Tecnol* 22(3): 395-404. https://dx.doi.org/10.4067/S0718-221X2020005000313

**Eckelman, C.A.; Haviarova, E.; Zhu, H.; Gibson, H. 2001.** Considerations in the design and development of school furniture based on local resources. *For Prod* 51(6): 56-63.

**Gündüz, G.; Korkut, S.; Korkut, D.S. 2008.** The effects of heat treatment on physical and mechanical properties and surface roughness of Camiyani Black Pine wood. *Bioresour Technol* 99 (7): 2275-2280. https://dx.doi.org/10.1016/j.biortech.2007.05.015

**General Service Administration. GSA. 1998.** Upholstered furniture test method. SA FNAE-80-214A. General Services Administration: Washington, D.C., USA. https://www.gsa.gov/cdnstatic/Upholstered_Furniture_Test_Method.pdf

**Hannouz, S.; Collet, R.; Butaud, J.C.; Bleron, L.; Candelier, K. 2015.** Mechanical characterization of heat-treated ash wood in relation with structural timber standards. *PRO LIGNO* 11(2): 3-10. https://hal.archives-ouvertes.fr/hal-01162542/document

**Kalayci, G. 2019.** Investigation of lateral shear resistance of one and two row multi staple joints constructed from different wood species. Master Thesis. Karadeniz Technical University, Trabzon, Turkey. https://tez.yok.gov.tr/UlusalTezMerkezi/tezSorguSonucYeni.jsp

**Kass, A.; Wangaard, F.F.; Schroeder, H.A. 1970.** Chemical degradation of wood: the relationship between strength retention and pentosan content. *Wood Fiber* 2: 31-39. https://wfs.swst.org/index.php/wfs/article/viewFile/1942/1942

**Kaygin, B.; Gunduz, G.; Aydemir, D. 2009.** The effect of mass loss on mechanic propertiesof heat-treated paulownia wood. *Wood Res* 54(2): 101-108. https://acikerisim.bartin.edu.tr/bitstream/handle/11772/1778/A9.pdf?sequence=2&isAllowed=y.

**Kocaefe, D.; Poncsak, S.; Boluk, Y. 2008**. Effect of thermal treatment on the chemical composition and mechanical properties of birch and aspen. *Bioresources* 3(2): 517-537. https://ojs.cnr.ncsu.edu/index.php/BioRes/article/view/BioRes_03_2_Kocaefe_PB_ThermalTreatment_Birch_Aspen

**Kol, H.S.; Sefil, Y.; Keskin, S.A. 2015**. Effect of heat treatment on the mechanical properties, and dimensional stability of fir wood. In Proceedings of the 27th International Conference Research for Furniture Industry. Ankara, Turkey. September 2015, p.269-279

**LeVan, S.L.; Ross, R.J.; Winandy, J.E. 1990.** Effects of fire retardant chemicals on bending properties of wood at elevated temperatures. *Forest Products Laboratory* RP: 498. https://www.fpl.fs.fed.us/documnts/fplrp/fplrp498.pdf

**Metsa-Kortelainen, S.; Viitanen, H. 2009.** Decay resistance of sapwood and heartwood of untreated and thermally modified Scots pine and Norway spruce compared with some other wood species. *Wood Mater Sci Eng* 4(3-4): 105-114. https://www.tandfonline.com/doi/full/10.1080/17480270903326140?src=recsys

**Özçifçi, A.; Altun, S.; Yapıcı, F. 2009.** Effects of heat treatment on technological properties of wood. In 5th International Advanced Technologies Symposium (IATS’09) Karabuk. Turkey. May 13-15.

**Ratnasingam, J.; Perkins, M.; Reid, H. 1997.** Fatigue: its relevance to furniture. *Holz Roh Werkst* 55: 297-300. https://link.springer.com/content/pdf/10.1007/s001070050232.pdf

**Ratnasingam, J.; Ioras, F. 2011a.** Fatigue strength and design stress of oil palm wood for furniture application. *European Journal of Wood and Wood Products* 69(3): 507-509. https://dx.doi.org/10.1007/s00107-010-0476-0

**Ratnasingam, J.; Ioras, F. 2011b.** Bending and fatigue strength of mortise and tenon furniture joints made from oil palm lumber. *European Journal of Wood and Wood Products* 69(4): 677–679. https://dx.doi.org/10.1007/s00107-010-0501-3

**Ratnasingam, J.; Ioras, F. 2013.** Load-bearing characteristics of heat-treated rubberwood furniture components and joints. *European Journal of Wood and Wood Products* 71(2): 287-289. https://dx.doi.org/10.1007/s00107-013-0662-y

**Santos, J. 2000**. Mechanical behaviour of Eucalyptus wood modified by heat. *Wood Sci Technol* 34(1): 39-43. https://dx.doi.org/10.1007/s002260050006

**Wang, X.; Salenikovich, A.; Mohammad, M.; Echavarriar, C.; Zhang, J. 2007a.** Fatigue bending resistance of metal-plated joints constructed of oriented strandboard for upholstered furniture frames. *For Prod J* 57(11):59-63. https://www.diva-portal.org/smash/get/diva2:987692/FULLTEXT01.pdf

**Wang, X.; Salenikovich, A.; Mohammad, M.; Echavarriar, C.; Zhang, J. 2007b**. Moment capacity of oriented strandboard gusset-plate joints for upholstered furniture. Part 2: Fatigue load. *For Prod J* 57(7/8):46- 50.

**Winandy, J.E. 1995**. Effects of fire retardant treatments after 18 months of exposure at 150 ºF (66 ºC). Forest Products Labratory RN-0264. http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.566.2141&rep=rep1&type=pdf

**Yildiz, S.; Gezer, E.D.; Yildiz, U. C. 2006.** Mechanical and chemical behavior of spruce wood modified by heat. *Build Environ* 41(12): 1762-1766._https://dx.doi.org/10.1016/j.buildenv.2005.07.017

**Zhang, J.; Quin, F.; Tackett, B. 2001.** Bending fatigue life of two-pin dowel joints constructed of wood and wood composites. *For Prod J* 51(10):73-78. link.gale.com/apps/doc/A79899975/AONE?u=anon~b11c6da3&sid=googleScholar&xid=da582eb3

**Zhang, J.; Chen, B.; Daniewicz, S. R. 2004.** Fatigue performance of wood-based composites as upholstered furniture frame stock. *For Prod J* 55(6):53-59.

**Zhang, J.; Yu, Y.; Quin, F. 2006**. Bending fatigue life of metal-plate-connected joints in furniture-grade pine plywood. *For Prod J* 56 (11/12):62-66. link.gale.com/apps/doc/A157098559/AONE?u=anon~ccef0cd6&sid=googleScholar&xid=9b918f5b