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SHEAR RESISTANCE AND FAILURE MODES OF EDGEWISE MULTIPLE TAB-AND-SLOT JOINT (MTSJ) CONNECTION WITH DOVETAIL DESIGN FOR THIN LVL SPRUCE PLYWOOD KERTO-Q PANELS

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ABSTRACT: The objective of this study is to experimentally analyse effects of geometry variations of Multiple Tab and Slot Joint (MTSJ) connection with dovetail design on shear mechanical behaviour. Direct shear test was performed on angular ($\varphi = 90°$) MTSJ connection made of Kerto-Q 21mm-thick spruce plywood laminated veneer lumber (LVL) panels. Connection was examined in its configuration of three tabs/slots per edge. Nine different geometries of MTSJ connection were tested. In order to provide better understanding of mechanical behaviour of the connection, results were compared with finger joint (F) connection. Two characteristic failure modes were observed. Influence of three theta angles which define geometry of MTSJ connection was analysed concerning shear strength and stiffness. Connection showed very ductile shear behaviour with relatively high stiffness. It has been shown that by increasing θ_3 angle above 30°, shear strength decreases. On the other hand, the highest influence on shear stiffness is due to θ_2 and θ_3 rotations.

KEYWORDS: shear, multiple tab-and-slot joint connection, structural wooden panels, laminated veneer lumber, dovetail joint.

1 INTRODUCTION

The use of structural wooden panels as a building material has become more and more widespread during the last years. Thanks to the new developments in computer design and digital fabrication, timber construction industry is experiencing significant innovations in fabrication technology and structural applications. The possibility of discretising structural surfaces with 2D panel elements presents an interesting new challenge in timber construction industry. Therefore structural systems such as folded plate structures and plate shell structures build out of discrete panel elements present efficient systems for spanning large distances. Pre-fabrication of discrete elements and their on-site assembly provides more cost-effective way of construction so such structural systems have great potential for commercial use. Moreover, they provide an integral way of construction as they can act both as load-bearing structure and cladding at the same time, which makes them advantageous over other structural systems. Since panels need to be connected along their edges, due to limited panel thickness design of connection detail presents a challenging task.

Connections serve as essential load-bearing elements as they transfer forces between the components of structure and maintain integrity of the system. In plate shells and folded surface structures, connections nearly always weaken structure as they disturb material continuity. On the other hand efficient edgewise connection ensures structural interaction of members and thus sufficient structural stiffness. The most commonly used method for jointing thin timber panels is by using metal fasteners. According to EC5 the minimal distance from the screw to the edge of the panel is 4d (d-diameter of screw) [1]. This constrain can consequently require thicker panels with regard to connection detail design rather than load-bearing capacity of the structure.

Very recent re-discovery of integral mechanical attachments with the possibility of creating all-in-one joining with connections generated during the cutting process presents promising connecting solution for thin timber panels [2] and [3]. The Multiple Tab-and-Slot Joint (MTSJ) connection has been developed for edgewise joining of structural wooden panels inspired by historic woodworking techniques where dovetail and finger joints are the oldest known connecting methods.

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The main advantage of using these form-fitting joints is that, in addition to their load bearing function (connector feature), they also integrate features for the fast and precise positioning of thin elements (locator feature). Locator features constrain the relative movements of parts to only one possible assembly direction which is crucial for the fast and precise assembly. Moreover, these joints do not impose any constraints on the panel thickness.

Mechanical behaviour of panel connections is rarely addressed in the existing literature. Finger joint connection for timber panels integrated in robotically fabricated lightweight timber plate systems was presented in [4], [5] and [6]. Connection was tested with different setups on lateral, normal and shear force transmission and very good results were achieved for the shear strength [4]. The application of finger joint connection with crossing screws was successfully applied to segmental plate shell [6]. In this research finger joint connectors were used to resist decisive in-plane shear forces, whereas the smaller axial forces and out-of-plane shear forces were still taken up by crossing screws. It has been shown that by application of finger join more forces are attracted to flow through the connection in the form of in-plane shears instead of axial forces.

The application of MTSJ connection for timber panels is quite new. Semi-rigid behaviour of this connection with dovetail design has been analysed both experimentally and numerically on box-beam samples for spruce plywood Kerto-Q LVL in [7]. Influence of tab length has been examined where connection showed promising stiffness results in shear.

The goal of this study is to experimentally analyse effects of geometry variations of MTSJ connection with dovetail design on shear strength and stiffness.

1.1 Multiple Tab-and-Slot Joint Connection (MTSJ)

Multiple Tab and Slot Joint (MTSJ) connection consists of teeth (tabs) and hollows (slots) as shown in Figure 1. The term “multiple” refers to the repeated number of tabs/slots alongside the edge, being larger than one.

Geometry of MTSJ connection is obtained by three successive rotations (denoted by three theta angles ($\theta_1, \theta_2, \theta_3$), following the convention of the Bryant’s angles as detailed described in [3] and [8].

Three rotations define two important guidelines of the connection: insertion vector and vector normal to the locking face. Each of the two connected panels (F_0 and F_1) has its normal (n_0 and n_1). Therefore joints main axes are defined as: $u_1 = n_0 \times n_1$; $u_2 = n_0$ and $u_3 = u_1 \times u_2$. First rotation is around the axis of the connection u_1 for an angle θ_1 which results in defining new connection axes $(u_1^{'} = u_1, u_2^{'}, u_3^{'})$. Second rotation is around newly obtained $u_2^{'}$ for an angle θ_2 which results in defining new connection axes $(u_1^{''}, u_2^{''} = u_2^{'}, u_3^{''})$. This rotation defines orientation of the locking faces in reference to the panel F_0. Finally, last rotation is around newly obtained $u_3^{''}$ for an angle θ_3 which results in defining insertion vector. This rotation defines inclination of the tabs/slots in reference to the panel F_0.

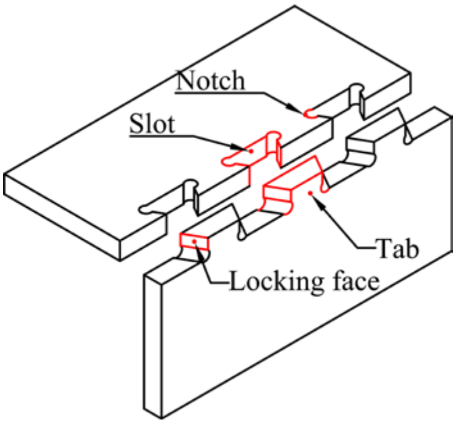

Figure 1: *Description of MTSJ connection*

MTSJ connection is one degree of freedom (1DOF) connection meaning that the two panels can be assembled only along the single direction defined by vector of insertion. The relative positioning as well as the load-transfer between the two connected panels are defined by the geometry of the MTSJ connection. In total, ten parameters define MTSJ connection as shown in Table 1 [8]. Depending on the chosen parameters (dihedral angle between the two panels as well as the tool inclination limits of the CNC cutting machine), possible combinations of the rotation angles can be defined

Table 1: *MTSJ connection parameters*

Parameters	Symbol	Unit
Insertion angle (1)	θ_1	°deg
Insertion angle (2)	θ_2	°deg
Tab angle	θ_3	°deg
Dihedral angle	φ	°deg
Tab length	L_t	mm
Panel thickness	T_p	mm
Panel Specific Gravity	ρ_k	kg/m3
Angle edge to grain	α	°deg
Notch 12mm	r	t or b
Tool angle T241	β	°deg

2 MATERIALS AND METHODS

2.1 Specimens Material

Specimens were constructed of Metsä Wood spruce plywood Kerto-Q laminated veneer lumber (LVL) panels with spruce ply orientation I-III-I (0-90-0-0-0-90-0). Panels used in this study have thickness of 21mm with the specific gravity 480kg/m^3 [9].

Kerto-Q is produced from 3mm thick rotary-peeled veneers of Norway spruce glued together to form a continuous sheet. The lay-up of the cross-section of 21mm panels consists of cross-bonded veneers. This means that four-fifth (80%) of veneer is parallel grained and one-fifth (20%) is glued crosswise. This way structure improves the lateral bending strength and stiffness of the panel, thus increasing the shear strength and provides good solution when high shear strength is one of the requirements. In following, parallel grained layers will be denoted as “0” and perpendicular grained as “90”.

2.2 Description of the specimens

All specimens are constructed as L-shaped containing two panel elements (F_0 and F_1) connected with MTSJ connection with dovetail design. All specimens (including both elements) have parallel grain orientation in reference to direction of load. Series of specimens with grain orientation are shown in Figure 2. Grain direction is defined as the direction of majority of veneers. In total thirteen different series of specimens were tested with five replicates of each one. Nine series are:

- D1-D9 - MTSJ connection with dovetail design having nine different geometries in relation to different theta angles according to Table 2.

Considering the constrains that selected dihedral angle between the parts is $\varphi = 90°$ and tool inclination angle is $\beta = 30°$, possible combinations of theta angles are determined and given in Table 2. The angles were chosen as extreme values of each of the three ($\theta_1, \theta_2, \theta_3$) where the remaining two angles are then determined according the algorithm described at [9].

Table 2: *Combinations of theta angles*

	θ_1	θ_2	θ_3
D1	0	0	±10
D2	0	30	±10
D3	0	0	±30
D4	45	0	±10
D5	45	31	±10
D6	45	0	±38
D7	90	0	±10
D8	90	30	±10
D9	90	0	±30

For comparison reasons remaining four series are:

- F - Finger joint connection which can be considered as MTSJ connection having all theta angles equals to zero;
- FS - Finger joint with addition of screws. 3x Würth ASSY screws (4mm x 60mm) were put through the each tab of one panel (F_0 or F_1) to the slot of the another one;
- G - Glued connection where two panels with same outer dimensions are glued alongside the edge;
- S - Screwed connection where two panels are connected with 3x Würth ASSY screws (4mm x 60mm) on the same position as in the series FS;

In all series D1-D9, F and FS the chosen tab length in the axis of the connection is 50mm. All specimens consist of three tabs/slots per edge.

Specimens were cut with MAKA 5-axis CNC machining robot. Considering the cutting process inside corners cannot be sharp so “notches” are imposed on the interior corners of the connection as shown in Figure 1. There are two possible geometries of notches, bisector and tangential. In this test we choose bisector type as more material consuming and thus with less reduction of shear surface. Presence of notches influences the effective force-resisting (shear) area as it reduces shear surface in some series of specimens.

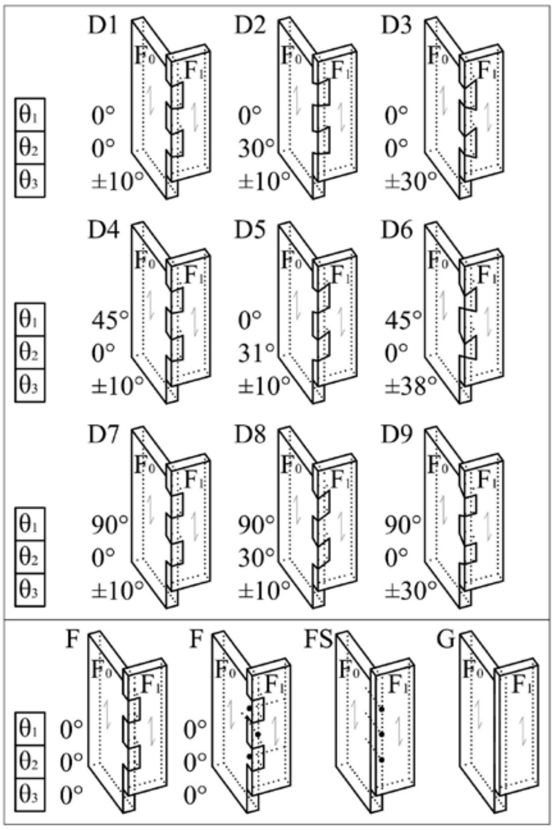

Figure 2: *Series of specimens*

2.3 Method of testing

Direct shear test was performed and specimens were subjected to uniaxial compression. Designed setup consists of two vertical steel brackets and wooden specimen is clamped between those brackets as shown in Figure 3. One of the brackets is fixed while the other one is free and movable. Wooden specimen is tightened between the brackets using three $\phi 10$ bolts. Entire set-up is further fixed for the 15mm thick steel base plate which is clamped for the stable base. Panel F_0 was fixed in all replicates and load was applied to the panel F_1. Steel "cap" covers the top of the panel F_1 in order to secure proper load distribution and avoid destruction of timber specimens due to the pressure of steel head from the cylinder. The "cap" is designed the way so to ensure application of load exactly in the axis of the connection.

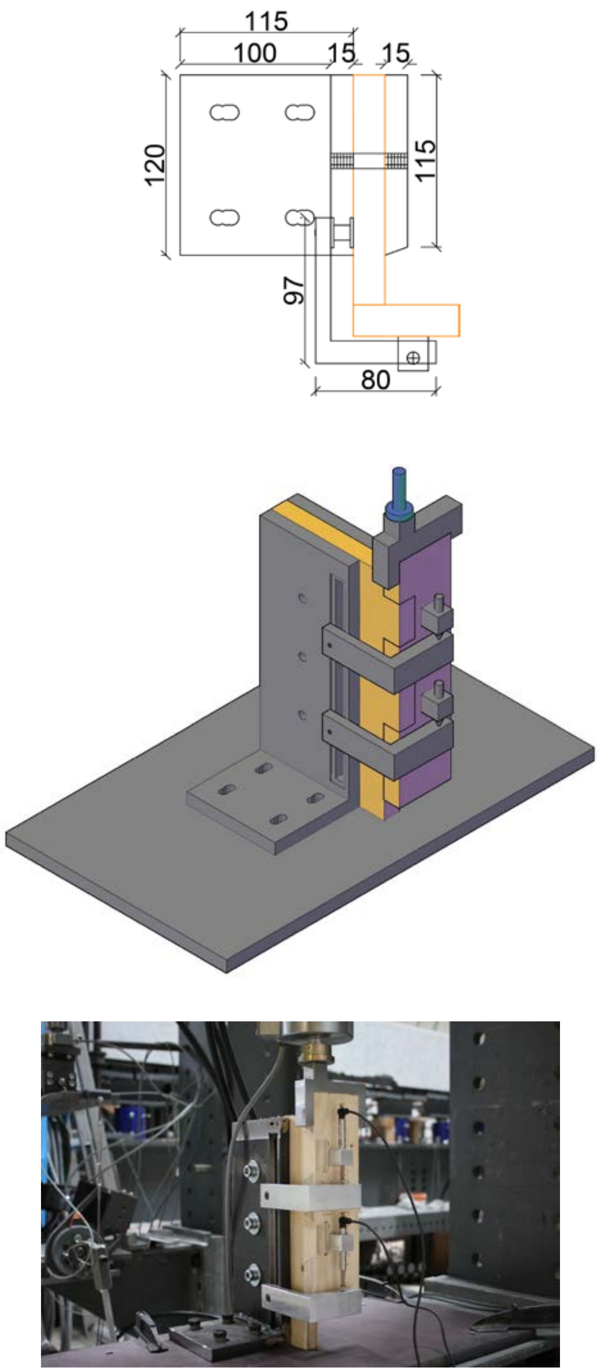

Figure 3: *Designed setup for shear test*

The loading direction was parallel to the grain for both fixed and movable panel. Load was applied vertically in the axis of the connection using 20kN cylinder and measured by 50kN HBM C2 load cell transducer. The relative slip between the fixed and movable member was measured on two positions (at each of the tabs) using two Linear Variable Differential Transformers (LVDT) sensors. The relative slip was further taken in the analysis as the average value from the two displacement transducers.

Load and displacements were recorded and averaged data from five replicates of each specimen are presented graphically. In total 65 samples were tested. All specimens were tested until the failure.

3 RESULTS AND DISCUSSION

3.1 Failure Mode

For proper design of connections it is important to understand load path within the connection and failure modes which can occur. Failure modes depend on the connection geometry, as well as the material and its associated failure modes. The failures of the MTSJ connection specimens can be classified into two failure modes:

a. Failure of the first and second tab
b. Failure of the first and third tab

First, second and third tab are denoted counting from the top to the bottom of the specimen and belonging to the panels F_0, F_1, F_0 in alternating order.

Figure 4 shows characteristic failures of MTSJ connection. In all tested samples, and at each of the tabs, failure occurs in layers oriented parallel to the grain. Therefore, it is very obvious splitting of the layers on the glued contact between second (90) and third (0) layer as well as between fifth (0) and sixth (90) layer. Also, first (0) and seventh (0) layer (two outer) quite often split from the second (0)/sixth (0) layer from the same reason.

First failure mode is characteristic for the connections D2, D3, D5, D6, D8 and D9. In this failure mode, after the application of load, cracks appear on the first tab. With further increase of load, load is redistributed to the third tab. However, third tab resists further loading while in the same time makes thrust on the second tab. Therefore, failure occurs in the second tab caused by this thrust. For all series of specimens characterized by this failure mode it is characteristic that they have more extreme angles comparing to those exhibiting second failure mode.

Second failure mode appears in connections D1, D4 and D7. This failure mode is also characteristic for the connections F and FS. All series of specimens with this failure mode are characterized by small values of rotation which determines inclination of tabs. In this type of failure, load-distribution is as expected. After application of load, primarily first tab is loaded. With more increase of load first cracks appear on this tab and load is further distributed to the third tab. After the application of critical load failure occurs in both, first and third tab.

a)

b)

Figure 4: *Characteristic failures – load parallel to the grain: a) first failure mode, b) second failure mode*

Concerning glued specimens, characteristic failure happens in first layer by diagonal split as shown on Figure 5.

Figure 5*: Characteristic failure of glued specimens*

3.2 Replicate comparison

Five replicates of each of the thirteen series of specimens were tested in shear. Between the replicates we did not observe any large imbalances in stiffness and ultimate load values. Therefore, average curves are considered to be relevant, and will be observed for the further analysis and comparison between the specimens.

3.3 Envelop load-slip curves

Figure 6 shows the envelope load-slip average curves obtained from experimental results of tested specimens D1-D9, F, FS, S and G that were loaded parallel to the grain. Ultimate load and ultimate shear strength values are presented in the Table 3. Only glued connection showed highly brittle failure. All other connections showed certain amount of softening after the failure. Hardening occurred in D8 and D2 connections. Screwed connection has significantly lower resistance comparing to all other connections. FS connection has weaker performances compared to F connection. This could be explained in relation to the re-distribution of the load between two connectors (finger joint and screws). Since connection accomplished by screws has significantly lower performances in shear, presence of screws will weaken the overall resistance of this “composite” connection for the percentage of their impact on shear load-transfer.

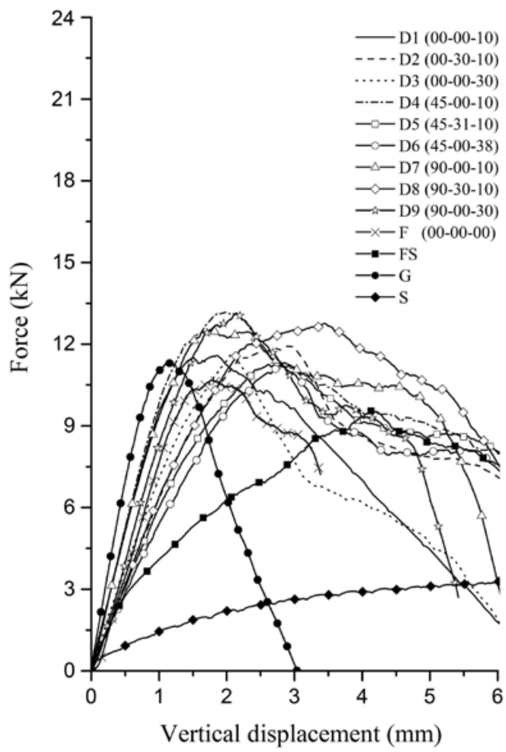

Figure 6*: Load-slip non-linear average curves for shear*

Comparing to F connection, all specimens (D1-D9) resisted higher ultimate load. D4 and D9 connections had ultimate loads 18% higher than F connection. Ultimate shear strength was calculated as a ratio between the mean ultimate load (mean is related to average of 5 replicates) and force-resisting area. Force-resisting area was measured from the 3D geometry of specimens prepared for fabrication process. This area is reduced in some series of specimens due to presence of notches imposed during the fabrication process. Although notches reduce force-resisting area in certain extent, their positive impact reflects in avoiding sharp corners which are places for possible concentration of stresses.

Table 3: *Ultimate load and shear resistance*

sample	θ_1-θ_2-θ_3	Mean Ultimate Force	Force-resisting area	Ultimate shear strength
	degree	kN	mm^2	N/mm^2
D1	00-00-10	11.59	2100	5.52
D2	00-30-10	11.92	2100	5.68
D3	00-00-30	11.6	2100	5.52
D4	45-00-10	13.18	2209.96	5.96
D5	45-31-10	11.26	2226.98	5.06
D6	45-00-38	11.22	2587.26	4.34
D7	90-00-10	12.53	2255.52	5.56
D8	90-30-10	12.76	2279.58	5.6
D9	90-00-30	13.13	2609.22	5.03
F	finger j.	10.68	2100	5.09
FS	f+3xscrew	9.54	2100	4.54
S	3xscrew	3.55		
G	PUR glue	11.31	4725	2.39

Except D5, D6 and D9 connections, all other specimens showed notably higher shear strength comparing to F connection. The highest shear strength showed D4 (45-00-10) connection. On the other hand, the lowest shear strength is characteristic for the connection D6 (45-00-38). Difference in their shear resistance is for about 27%. Concerning geometry of the two connections (D4 and D6), they differ only in θ_3 angle. Therefore difference in their shear strength is relevant. However, similar trend is not characteristic for the connection pairs D1 (00-00-10) - D3 (00-00-30); and D7 (90-00-10) - D9 (90-00-30). Despite their difference in only θ_3 angle they still have similar shear resistance between each other. However, D6 connection has the most extreme θ_3 angle comparing to all other mentioned pairs. Therefore it is obvious that by increasing θ_3 up to 30 degrees, resistance remains similar. But by increasing θ_3 more, up to 38 degrees, shear strength decreases significantly.

Influence of θ_1 angle on shear resistance can be analysed similar way. D1, D4 and D7 configurations differ only in θ_1 angle (θ_1=00/45/90). Maximum difference (between D1 and D4) in their shear resistance is for about 7%. Similar trend is obvious for the connections D2, D5 and D8 where maximum difference (between D2 and D5) is for about 11%. Therefore, no matter on the obvious difference in θ_1 rotation, resistance does not change significantly.

Shear resistance in reference to θ_2 angle can be seen if we compare configuration: D1 and D2; D4 and D5; D7 and D8. Maximum difference in their shear strength is between D4 and D5 connections for about 15%. Other two pairs differ up to 3% which is negligible.

3.4 Linear load-slip curves

The initial stiffness was calculated from the elastic range of the corresponding load-slip envelopes. Limits of the linear-elastic range were taken between 10% and 40% of the ultimate load. The curves are obtained using linear regression by averaging the linear fits of five replicates of each specimen. Therefore, corresponding linear curves are displayed in this range (10%-40%) and shown on Figure 7. The corresponding mean values of shear stiffness are given in Table 4.

Effects of geometry variations of MTSJ connection on shear stiffness were further analysed. Nine (D1-D9) series of MTSJ connection were compared with F connection which is considered as MTSJ connection having geometry (00-00-00). Comparing to the F connection, from experimental results we can see that introduction of theta angles affects shear stiffness notably.

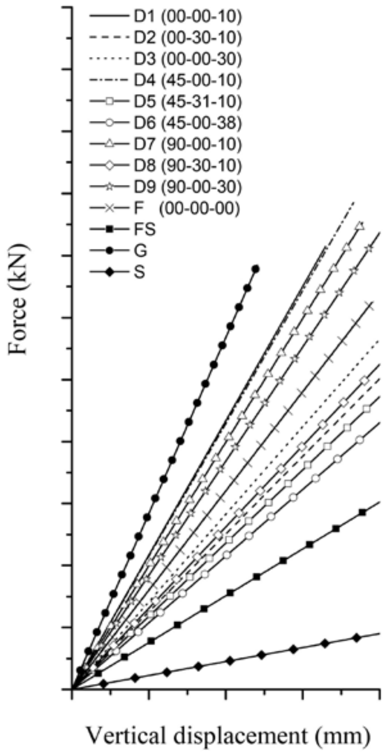

Figure 7*: Load-slip average linear curves for shear (between 10% and 40% of F_{max})*

By increasing θ_3 angle up to only 10 degrees as in D1 (00-00-10) connection, stiffness increases for about 26% comparing to F (00-00-00) connection. However, by further increase of θ_3 up to 30 degrees as in connection D3, shear stiffness decreases comparing to both D1 and F. In relation to F connection stiffness is lower for about

11% meaning that large θ_3 rotation has negative impact on shear stiffness of MTSJ connection.

Influence of the θ_1 angle can be analysed by comparing specimens D1, D4 and D7. Maximum difference in stiffness is between the specimens D1 and D7 for about 8%. Similar trend can be seen if we compare specimens D2, D5 and D8. Here maximum difference is between D5 and D8 connections for about 10%. However, difference in stiffness between the specimens D3 and D9 is larger and it is about 23%. Although most of the results indicate minor impact of θ_1 angle on shear stiffness, according to results in combination with other rotations its influence cannot be completely excluded.

Table 4: *Average stiffness*

sample	θ_1-θ_2-θ_3	Mean Stiffness (10%-40%)
	degree	kN
D1	00-00-10	10.83
D2	00-30-10	6.27
D3	00-00-30	7.07
D4	45-00-10	10.72
D5	45-31-10	5.90
D6	45-00-38	5.38
D7	90-00-10	9.98
D8	90-30-10	6.56
D9	90-00-30	9.21
F	finger j.	8.01
FS	f+3xscrew	3.78
S	3xscrew	1.13
G	PUR glue	14.19

Stiffness of the MTSJ connection in reference to θ_2 angle is analysed further. In order to examine influence of this angle following pairs are compared: D1 and D2; D4 and D5; D7 and D8. Differences in shear stiffness between the compared configurations are 27%, 44% and 34% respectively. This angle shows the highest imbalance in stiffness between the tested specimens.

4 CONCLUSIONS

Shear tests were conducted on Multiple Tab-and-Slot Joint (MTSJ) edgewise connection for Kerto-Q 21mm thick plywood LVL structural wooden panels. Nine different geometries of MTSJ connection with dovetail design (D1-D9) were tested experimentally. For comparison reasons four additional series of specimens were tested (F, FS, S, G). All specimens have following characteristics:

- Tab length $L_t = 50mm$
- Panel thickness $T_p = 21mm$
- Dihedral angle $\varphi = 90°$

Connection was examined in its configuration of three tabs/slots per connection. In total, thirteen different series of specimens with five replicates of each one were tested and results were analysed and compared. Ultimate strength and stiffness characteristics associated with different geometries of MTSJ dovetail connection were observed and compared with reference specimens. The current study has the goal to investigate effects of geometry variations of MTSJ dovetail connection on shear mechanical behaviour. The obtained results can be summarized as follow:

1. Two representative failure modes were observed:
   a. Failure of the first and second tab
   b. Failure of the first and third tab

   First failure mode is characteristic for the connections D2, D3, D5, D6, D8 and D9. Specimens which exhibit this failure mode have the most extreme angles θ_2 and θ_3 which are the angles that determine orientation of locking faces and inclination of tabs/slots respectively. On the other hand, second failure mode is specific for the connections D1, D4, D7, F and FS. Those connections are characterized by small values of previously mentioned rotation.

2. In comparison to F connection, which can be considered as MTSJ connection having all theta angles equals to zero, all nine series of MTSJ specimens (D1-D9) are able to withstand higher ultimate load. Except D5, D6 and D9 connections, all other specimens showed notably higher shear strength comparing to F connection. The highest shear strength showed D4 connection while the lowest shear strength is characteristic for the connection D6. Concerning three theta angles, it could be concluded that angles θ_1 and θ_2 do not have significant influence on shear resistance. On the other hand, by increasing θ_3 above 30 degrees, shear strength decreases significantly.

3. Introduction of theta angles affects shear stiffness notably comparing to F connection. Influence of θ_1 angle on shear stiffness is of minor importance, yet it cannot be completely excluded. The highest influence on shear stiffness is due to θ_2 and θ_3 rotations. By increasing θ_3 angle up to only 10 degrees as in D1 connection, stiffness increases for about 26% comparing to F connection. Difference in shear stiffness in reference to θ_2 rotation is up to 44% as between specimens D4 and D5.

In order to find the most optimal ranges for three rotations and their interactions, more combinations of angles should be examined and analysed.

REFERENCES

[1] EN 1995-1:2005. Eurocode 5: design of timber structures. Part 1–1. Common rules and rules for buildings. Brussels: CEN, European Committee for Standardization; 2005.

[2] Robeller C., Stitic A., Mayencourt P., and Weinand Y.: Interlocking Folded Plate – Integrated Mechanical Attachment for Structural Wood Panels. In P. Block, J. Knippers, N. J. Mitra, W. Wang, editors, *Advances in Architectural Geometry 2014*, pages 281-294. Springer International, Switzerland, 2015.

[3] Robeller, C., Integral Mechanical Attachment for Timber Folded Plate Structures. PhD Thesis, École polytechnique fédérale de Lausanne, 2015.

[4] Knippers, J., Menges, A., Gabler, M., La Magna, R., Waimer, F., Reichert S., Schwinn, T., From Nature to Fabrication: Biomimetic Design Principles for the Production of Complex Spatial Structures. In Springer Wien New York, pp. 107-122. Hesselgren, L. et al. (eds.), Advances in Architectural Geometry 2012.

[5] Krieg, O., Schwinn, T., Menges, A., Li, J.M., Knippers, J., Schmitt, A. and Schwieger, V., Biomimetic Lightweight Timber Plate Shells: Computational Integration of Robotic Fabrication, Architectural Geometry and Structural Design. In: Springer International Publishing Switzerland. Block P. et al. (eds.), Advances in Architectural Geometry 2014.

[6] Li J.M., Knippers J., Segmental Timber Plate Shell for the Landesgartenschau Exhibition Hall in Schwäbisch Gmünd—the Application of Finger Joints in Plate Structures. International Journal of Space Structures, Vol. 30, No. 2, 2015.

[7] Roche S., Robeller C., Humbert L. and Weinand Y., On the semi-rigidity of dovetail joints for the joinery of LVL panels, European Journal of Wood and Wood Products, 2015.

[8] Roche. S, Mattoni G. and Weinand Y., Rotational Stiffness at Ridges of Timber Folded-plate Structures. International Journal of Spatial Structures, Vol 30, No. 2, 2015.

[9] VTT certificate for structural laminated veneer lumber, No. 184-03, 24 March 2009, Certification body (S017, EN 45011) accredited by FINAS.

[10] Mattoni G., Folded Plate Structure, Design and Analysis of Woodworking Joints for Structural Timber Panels, Master Thesis, ENPC and EPFL, 2014.