Rotational Stiffness at Ridges of Timber Folded-plate Structures

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Summary

Folded plate structures propose an efficient design employing thin Laminated Veneer Lumber panels. Inspired by the Japanese furniture joining technique, the Multiple Tab-and-Slot Joint was developed for multi-assembly of timber panels with non-parallel edges, as a solution requiring no adhesive or metal joints. As the global analysis of our origami structures reveals that the rotational stiffness at ridges affects the global behaviour, we propose an experimental and numerical study of this linear interlocking connection. Its geometry is governed by three angles that orient the contact faces. Nine combinations of these angles were tested with two different bending set-ups: closing or opening the fold formed by two panels and measuring the rotational slip. The non-linear behaviour has been conjointly reproduced numerically using the finite element method and the continuum damage mechanic.

Keywords: semi-rigid, connection, moment-rotation, folded-plate, timber

1. The Multiple Tab-and-Slot Joint as structural panel connection

When a folded plate structure is uniformly and vertically loaded, slab and plate action induce transverse and longitudinal action in the folds. At ridges, bending moment M_j forces perpendicular to ridge N_j, Q_j and force along ridge T_j typically arise. We limit our study to the behaviour under bending moment. Thereafter, we will seek to understand how the geometry, especially the angles directing the normal to the locking face, impacts on this semi-rigidity.

The ridge (or valley) connection employed here is a one-degree-of-freedom connection (for the purpose of assembly) where tabs are inserted in slots. ”Multiple” refers to interlocked tab and slot, which are reiterated along the common edge of two connected panels. The geometry of the connection defines the relative positioning of the panels by three angles and allows a certain degree of load-transfer between them. The assembly of the two panels is directed along a vector of insertion. The locking faces of each part belong to the same contact plane after insertion.

2. Experimental study

Eleven series of two 21mm-LVL-Kerto-Q panels with spruce ply (0-90-0-0-0-90-0) are assembled with eleven particular sequences of joint elements. Geometrical properties of the experimental specimens are gathered for clarity in fig.1, nevertheless no glue has been added during the assembly process of samples (a) to (j).
Four identical specimens of each sample were tested using a dedicated folding machine. Rotation and loads are recorded by averaging values of two inclinometers and summing data from cell loads, respectively. This method is applied both for closing (S01) and opening (S02) the joint. A total of 88 specimens have been tested.

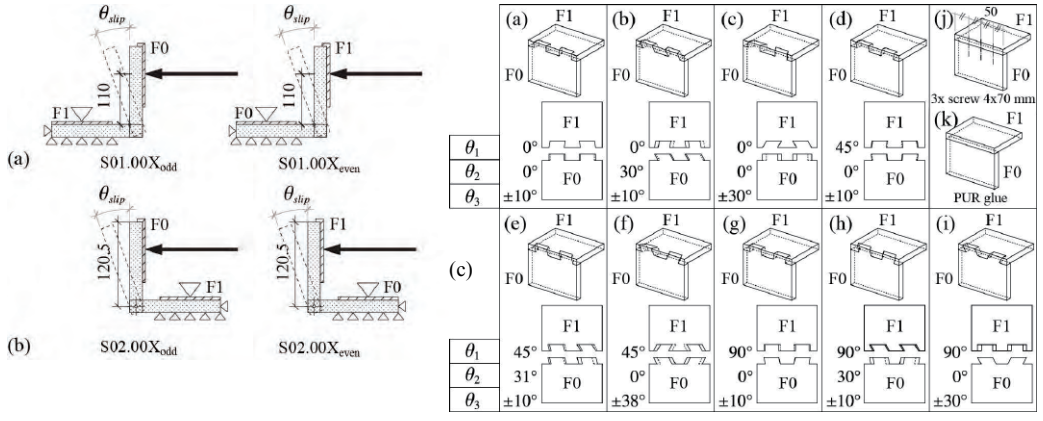

Fig. 1: Bending test (a) "Closing" mode, (b) "Opening" mode (c) sample geometries

3. Numerical model

The LVL Kerto-Q material is implemented as multi-layered. As through-thickness stress cannot be ignored the model uses linear hexahedral elements with reduced integration (C3D8R). Each of the seven layers will have its own orientation (0-90-0-0-0-90-0). The Coulomb friction coefficient is set to 0.3. In order to approach the non-linear behaviour of the joint, we used a wood model based on the Continuum Damage Mechanics (CDM), generously provided by C.SANDHASS. It consists mainly in penalization of the elastic moduli.

4. Results and discussion

In fig.2, it is worth noting that the numerical model matches well the experimental curves of the samples (a) under closing. Despite the asymmetry of the joint, we cannot observe any large difference during pushing on F0 or F1. Moreover, the MTSJ in this configuration behave as semi-rigid. Others results are presented in the full version.

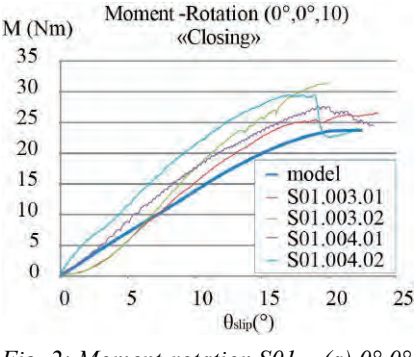

Fig. 2: Moment-rotation S01 – (a) 0°,0°,±10°

5. Conclusions

These first tests on rotational stiffness of MTSJ with nejiri arigata design show a ductile behaviour with a relative low stiffness compare to screw and glue. The joints were tested in their minimal configuration with two and one tabs per panel. The influence of the tab angle θ_3 is significant and its combination with the others angles should be clarified by others analysis. Dovetail connection will be shortly tested whereas their application is of minor use in multi-edge assembly for folded plate structure. The numerical model based on Continuum Damage Mechanisms shows promising results although the material parameters and the boundary conditions have to be improved.