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Effect of Metal-Plate Connector on Tension Properties of Metal-Plate Connected Dahurian Larch Lumber Joints

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Abstract

This paper investigated the tensile behavior of metal-plate connected Dahurian larch (*Larix gmelini* (Rupr.) Rupr) lumber joints. Relationships between the ultimate load and metal-plate connector (MPC) length, width, and area were analyzed for AA loading (i.e. load parallel to the grain, MPC length parallel to the load direction) and EA loading (i.e. load parallel to the grain, MPC length orthogonal to the load direction). Failure modes were studies for both AA and AE loading conditions. It was found that the tensile strength of the joint increased as the size of the connector increased. Tooth withdrawals, MPC breakage and wood breakage were all failure modes observed for the AA loading case. However, tooth withdrawal was the only failure mode observed in the EA loading case.

Keywords: MPC joint, ultimate tension load, MPC size, failure mode

1. Introduction

Metal-plate connected lumber joints can be considered as semi-rigid (i.e. neither pinned nor completely rigid). Therefore, the deformations of the joint may have a substantial contribution to the overall deformation of the structure. Many studies (e.g. Gupta & Gebremedhin, 1990; Sasaki & Hayashi, 1982; Lau, 1987; Kent et al., 1997; Riley & Gebremdhim, 1999) analyzed the mechanical properties of semi-rigid joints in the metal-plate connected wood trusses. The average tensile strength of metal-plate connected truss joints fabricated by No.2 Southern pine lumber and 20-gage punched metal plates was found to be 27 kN, and a combination of wood and teeth failure modes was observed.

A variety of failure modes may occur at the connections in a truss system. For example, shear or tension in the steel elements, tooth withdraw, and wood failure. It has been proven that specimens including short metal-plate connectors usually fail under plate yielding while longer plates fail because of tooth withdrawal. An effective way to avoid metal-plate connector tearing and withdrawal ia to increase the contact area between connector and trusses, and keep the plate length longer than width (see, for example, Riley & Gebremedhin, 1999; Lau, 1987; O'Regan et al., 1998).

Dahurian larch is a popular species in the northeast region of China. It is used for wood frame construction because of its high strength, good decay resistance and abundance in resources. The physical and mechanical properties of Chinese larch had been extensively analyzed in terms of bending, compression, tension etc. Chen et al. (2001) tested small specimens (20×20 mm^2 cross section) of clear Chinese larch following the GB1927-1943-91 standard, "Testing methods for physical and mechanical properties of woods": the modulus of rupture (MOR), the modulus of elasticity (MOE) and the ultimate compression strength (UCS) were found to be 139.0-188.7 MPa, 4.5-5.0 GPa, and 42.3-61.1 MPa, respectively. Wang et al. (2009) tested full-size specimens (38×89 mm^2 cross section) of Chinese larch following the GB /T 50329-2002 "Standard for methods testing of timber structure". The MOR, MOE, 5% percentile UCS and ultimate tension strength (UTS) were found to be 62.3 MPa, 13.7 GPa, 26.4-31.4 MPa, and 14.4-22.4 MPa respectively. Currently, no much data is available on the mechanical behavior of MPC joints for Chinese larch. Gupta (1996) evaluated strength properties of three connections on different materials. It was found that the average ultimate load of MPC joints of Russian dahurian larch (the same family as Chinese larch) was obtained as 37 kN, which was higher than that of southern pine (28 kN) and Douglas-fir (33 kN). Joints always failed in the withdrawal mode. Latterly, Wei et al. (2013) completed tension tests of Chinese larch MPC joints of four types, including AA and EA, and tfound that the ultimate tension load was reduced by 18.9% from AA to EA. Its failure modes were analyzed, and the load-deflection curves by Foschi 3-parameter model were developed.

The present study aims to: (i) determine the strength and failure mode of Dahurian larch MPC joints subjected to tensile loading; (ii) assess the relationship between the connector dimensions and the ultimate axial load of the joint; (iii) analyze the relationship between the joint size and the failure modes. The MPC joints including plate-connectors of various sizes were tested in both the AA and EA loading modes. The ultimate tensile loads, failure modes, and relationship between MPC size and mechanical properties were analyzed separately for each specimen type.

2. Experimental

All lumbers were processed with a local sawmill. The modulus of elasticity (MOE), air density and moisture content (MC) of each specimen were determined before fabricating the joints in according to the procedures described in GB50329-2002, GB/T1933-1991, and GB/T1931-1991 standards. In order to determine the MOE, the wood piece was placed flat-wise between the two supports spaced by 1620 mm, while the distance between loading points was 810 mm. Displacement was measured at the mid span by a linear variable differential transducer (LVDT) and then recorded by a computer. The average MOE, air density and MC determined in these experiments were 13.8 GPa, 650 kg/m^3 and 12%, respectively.

Figure 1. Experimental set up utilized in the tensile tests performed on MPC join

The Gannail-GN20 MPC obtained from a local supplier was used in this study. The plate thickness was 1.0 mm, the tooth length was 9.5 mm, a dn the tooth density was 8/in.^{2}. For the AA loading mode, MPCs with the following dimensions (width×length) were considered: 40×75 mm^2, 50×50 mm^2, 50×75 mm^2, 50×100 mm^2, 50×125 mm^2, 50×150 mm^2, 75×100 mm^2, 75×125 mm^2 and 75×150 mm^2. The MPCs' dimensions considered for the EA loading mode were: 50×50 mm^2, 75×40 mm^2, 75×50 mm^2 and 75×75 mm^2.

In order to minimize the variations in MOE, density and MC of connected pieces, each joint assembly was fabricated from a single piece of lumber cut in two halves then re-jointed by two MPCs applied by a hydraulic press. Three replicates were used in order to obtain statistically significant data.

Tension tests were carried on with a 50 kN universal testing machine at about 1 mm/minute loading speed and the specimens were failed in about 5 minutes. The load was applied by a hydraulic cylinder and load and deformation data were collected by a data acquisition system until failure. Two holes of diameter 20 mm were predrilled across the specimen width at 100 mm from both ends of the MPC jointed specimen. Two steel bars were inserted into the holes to transfer the tensile load to the specimen. The experimental set-up utilized in the tensile tests is shown in Figure 1.

Table1. Experimental results of the tensile tests performed on MPC joints

Orientation	MPC size（L.×W.）（mm）	Specimen number	Ultimate load (kN)	Failure mode
	40×75	1	10.77	Tooth withdrawal
		2	10.83	Tooth withdrawal
		3	13.85	Tooth withdrawal
	50×50	1	8.41	Tooth withdrawal
		2	6.17	Tooth withdrawal
		3	10.87	Tooth withdrawal
	50×75	1	12.02	Tooth withdrawal
		2	13.93	Tooth withdrawal
		3	14.47	Tooth withdrawal
	50×100	1	17.9	Tooth withdrawal
AA Orientation		2	31.52	Tooth withdrawal
		3	25.95	Tooth withdrawal
	50×125	1	21.33	Broken MPC
		2	17.43	Broken MPC
		3	21.33	Broken MPC
	50×150	1	25.11	Broken MPC
		2	23.41	Broken MPC
		3	-	-
	75×100	1	24.07	Tooth withdrawal
		2	25.58	Tooth withdrawal
		3	31.62	Tooth withdrawal
	75×125	1	33.18	Broken MPC
		2	32.45	Broken wood
		3	11.77	Broken wood
	75×150	1	43.97	Broken wood
		2	38.96	Broken MPC
		3	-	-
	50×50	1	8.05	Tooth withdrawal
		2	7.1	Tooth withdrawal
		3	-	-
	75×40	1	7.4	Tooth withdrawal
		2	9.27	Tooth withdrawal
EA Orientation		3	-	-
	75×50	1	11.47	Tooth withdrawal
		2	12.01	Tooth withdrawal
		3	15.38	Tooth withdrawal
	75×75	1	18.28	Tooth withdrawal
		2	17.32	Tooth withdrawal
		3	25.4	Tooth withdrawal

3. Results and Discussion

3.1 Relationship Between MPC Joint Tensile Strength and Joint Size

Experimental results gathered for the tested MPC joints are shown in Table 1. It can be seen that the ultimate tensile load was in the range of 8.41-43.97 kN for the AA loading mode and 7.4-25.4 kN for the EA loading mode. The tooth withdrawal, plate breakage and wood rupture are the three main failure modes observed for the AA specimens, while only the tooth withdrawal was seen for the EA loading mode.

The dimensions of the metal plate connector greatly affect the mechanical properties of MPC joints, especially the strength and stiffness. The requirements on MPC size given in some standards (TPI 1995, TPI 2002, GB50005-2003) indicate that no failure should occur regardless of the plate width and length. The dimensions of the MPC element should be determined considering the size of lumbers and the joints to be realized. Larger plates allow the fraction of load supported by each tooth to be reduced. However, increasing the length of the plate will increase the costs and material waste, and might not necessarily improve the overall tensile strength of the joint. Triche and Suddarth (1998) found that the bearing capacity of teeth decreased by 39% in spite of tripling the MPC length.

The ultimate tensile load determined for joints with 50 mm and 75 mm wide plates for the AA loading mode are presented in Figures 2 and 3, respectively. The plotted values were averaged from the experimental data reported in Table 1as 8.48, 13.4, 21.97, 20.03 and 24.26 kN, for the 50×50 mm^2, 50×75 mm^2, 50×100 mm^2, 50×125 mm^2 and 50×150 mm^2 plates, respectively. The ultimate tension load always increased with MPC size except for the joint realized with a 50×120 mm^2 plate. A linear relationship was found between the ultimate tension load and the MPC size with a coefficient of correlation R^2 of 0.865.

The average ultimate tensile loads for AA type joints were determined as 27.09 kN, 32.8 kN, and 41.47 kN, for the connectors with sizes of 75×100 mm^2, 75×125 mm^2 and 75×125 mm^2, respectively. A linear relationaship between the ultimate tension load and the plate length also presents in Figure 3. A better correlation was obtained compared to the 50 mm wide specimens (R^2: 0.99).

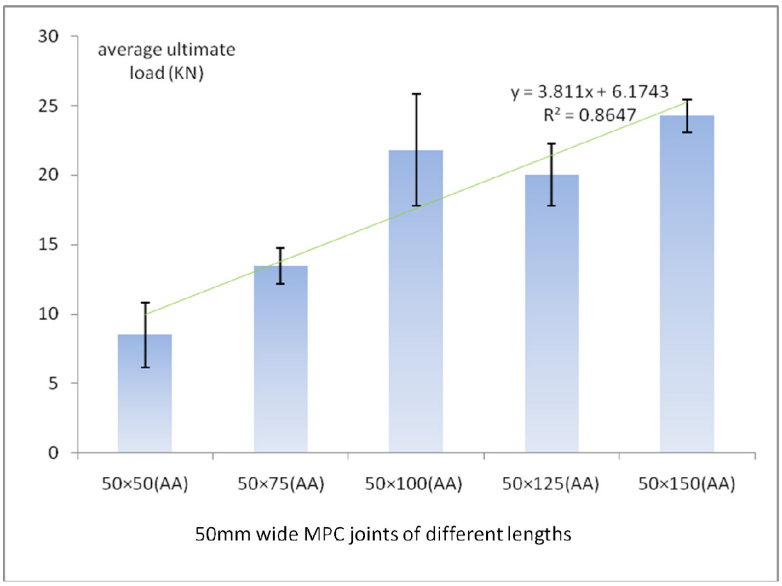

Figure 2. Ultimate tensile loads at different connector lengths for the 50 mm wide specimens loaded in AA mode

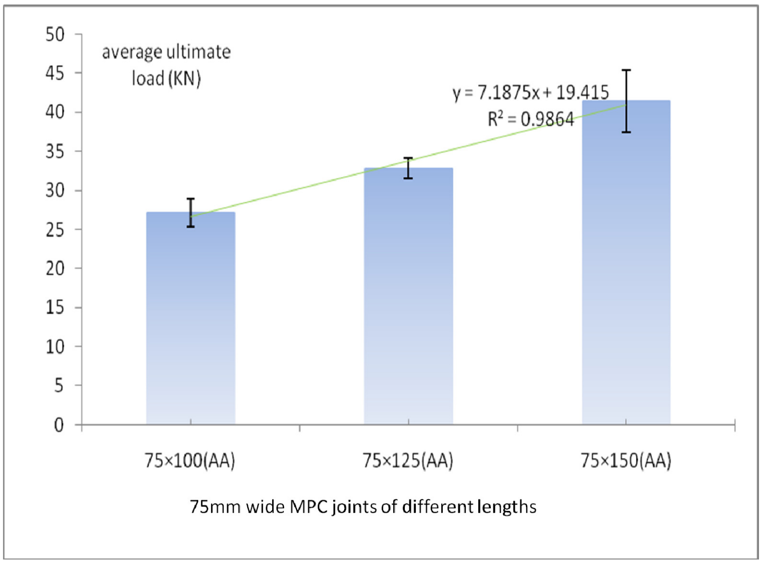

Figure 3. Ultimate tensile loads at different connector lengths for the 75 mm wide specimens loaded in AA mode

Figure 4 summarizes the experimental evidence gathered from the experimental tests carried out on the AA type specimens: (i) for a goven width of the connector, the ultimate tensile load increases with the plate length; (ii) for a given length of the connector, the ultimate tensile load of the joint becomed higher as the width increases.

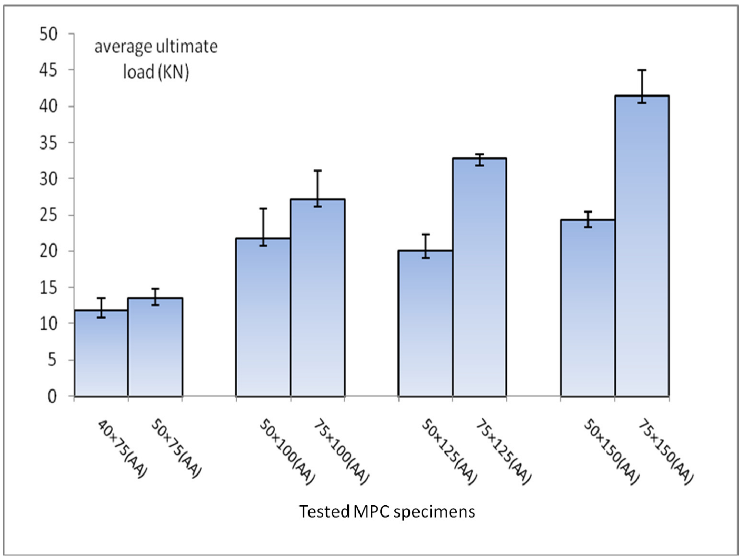

Figure 4. Comparison of the ultimate tensile loads for AA specimens with different plate widths

Figure 5 shows the average ultimate load determined for the 75mm width MPC joints tested under the EA loading mode: 8.34, 12.95 and 20.33 kN, respectively, for the joints including 75×40mm^2, 75×50mm^2 and 75×75mm^2 plates. It can be seen that strength of the joints with longer MPC plates (i.e. 75×50mm^2 and 75×75mm^2) increased by, respectively, 55.3% and 143.8% with respect to the 75×40mm^2 joint.

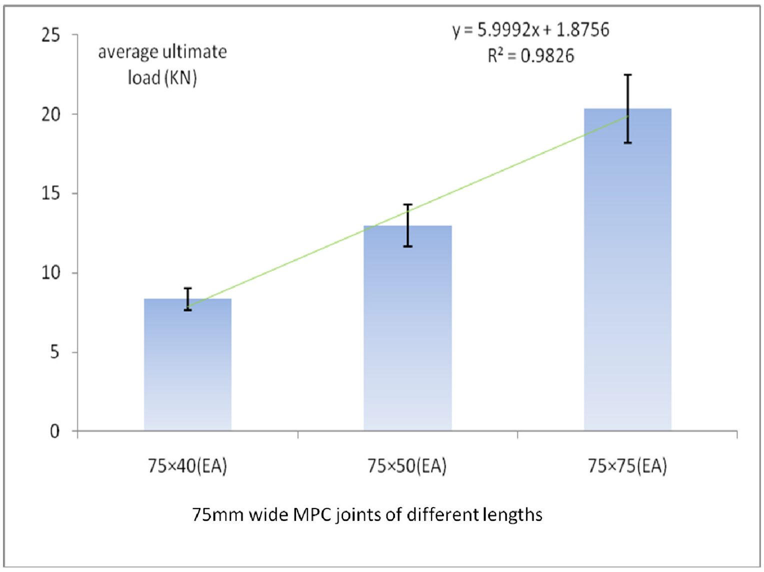

Figure 5. Ultimate tensile loads at different connector lengths for the 75 mm wide specimens loaded in EA mode

The MPC joints in the AA loading mode are stronger than that in the EA loading mode with the same joint dimensions. The ultimate tensile loads as a function of the MPC area are shown in Figure 6. It is seen from Figure 6 that the ultimate load increases linearly as the joint area increases. The R^2 values were determined as 0.73 and 0.83, for AA and EA specimens, respectively, with an average of 0.77.

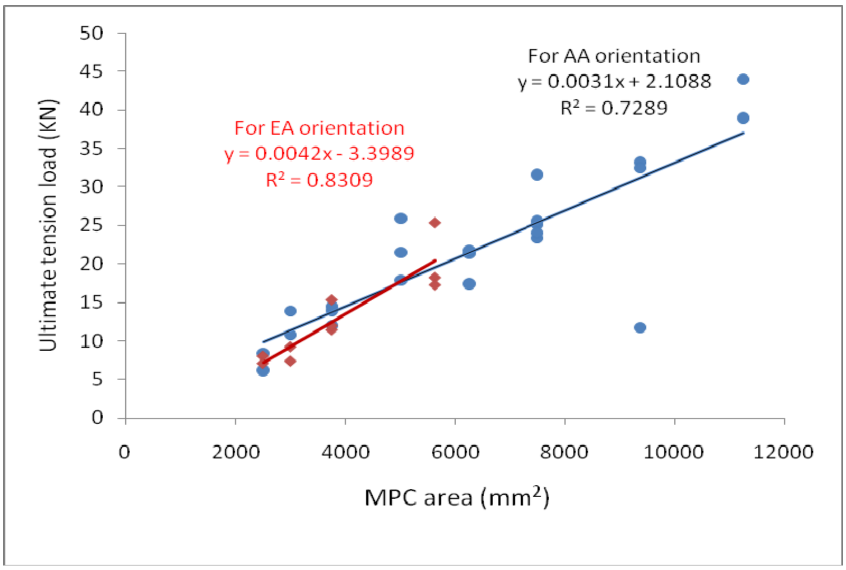

Figure 6. Relationship between the ultimate tensile load and the area of the metal plate connector

3.2 Relationship Between the Failure Modes of MPC Joints and the Joint Sizes

Figure 7 summarizes the failure modes observed in the experimental tests for the MPC joints. Tooth withdrawal, MPC breakage and wood rupture were the predominant failure modes. Tooth withdrawal was the most common failure mode for MPC plates shorter than 100 mm. Tooth withdrawal occurs when the teeth located on the plate edge cannot bear the axial tensile load transferred from the wood. Plate breakage is the most common failure mode for the MPC with a length of at least 100 mm and the plate width of smaller than 75 mm. In this case, the strength of MPC is not enough to bear large axial loads. Therefore, the MPC is more likely to fail when the connector slot is located at interface of the two pieces of wood.

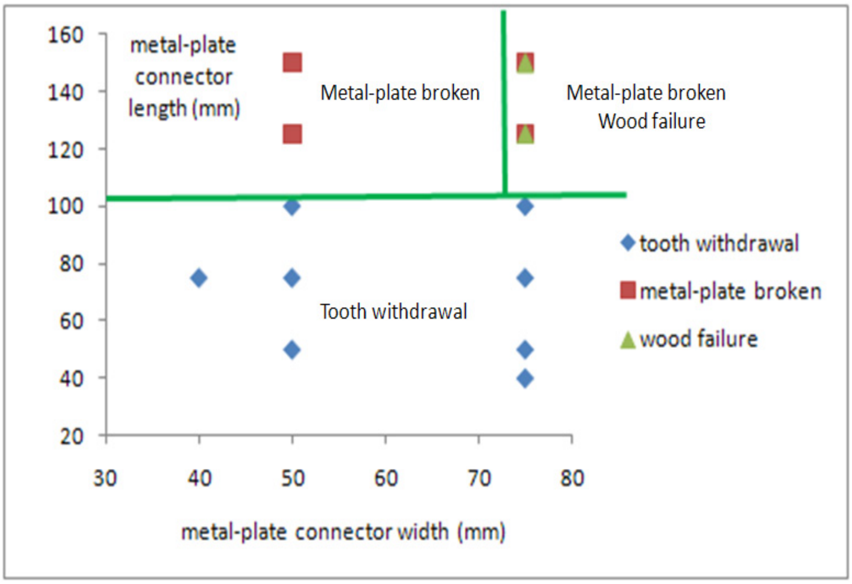

Figure 7. Failure modes observed for the Chinese larch MPC joints tested in this study

4. Conclusions

The relationship between the tensile strength of metal-plate connected Dahurian larch larch lumber joints and the size of the connector were analyzed. Two different loading modes (AA and EA) were considered.

The ultimate tensile loads were found in between 8.41 and 43.97 kN for AA specimens, and 7.4 and 25.4 kN for EA specimens. Increasing the size of the connector (i.e. the length of the plate for a fixed plate width and vice-versa) allows a higher ultimate tensile load to be obtained. The A linear relationship was found between the ultimate tensile load and the joints dimensions.

Tooth withdrawal, MPC breakage and wood rupture were the three failure modes observed for AA type joints, while tool withdrawal was the only failure mode for the EA type joints. Tooth withdrawal, MPC breakage and wood rupture occur in sequence as the axial tension load increases. The AA orientation is more appropriate for evalauting the axial tension properties of MPC joints.

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