Study on the effect of shear stiffness and strength by screw angle and timber grain direction

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ABSTRACT: This paper compares the test results by using self-tapping screws and setting the screw insertion angle and timber grain direction as parameters. Previous studies have investigated the effect of screw angle on load-deformation performance and stiffness. However, no data has been accumulated on the behavior of inclined screws driven in different grain directions. In this paper, experimental studies on inclined screws driven in different grain directions are conducted, and regression equations are obtained from the obtained numerical values. The results were compared against a regression equation proposed in the literature. As a result of the comparison, it was found that a highly accurate regression could not be obtained for certain angles, and this problem was solved by introducing a new reduction factor.

KEYWORDS: self-tapping screws, full threaded screws, inclined screw

1 – INTRODUCTION

Previous research[1] has reported that the shear stiffness of screw joints increases depending on the screw angle. However, these experiments were conducted with loading direction parallel to grain direction. The direction of the timber grain affects the strength of joints using screws. Therefore, we conducted an experiment to verify the effect of differences in grain direction on the shear stiffness and strength of joints with inclined screws. The shear stiffness of a timber-to-timber joint with screws is known to increase with the influence of screw angle. However, grain direction and screw length influence this shear stiffness, too. Therefore, in this study, we unified the screw insertion length and timber species, and conducted tests with only the grain direction and screw insertion angle as variables

.2 – BACKGROUND

It is known that the shear stiffness increases depending on the angle at which the screw is driven diagonally, but it is not only the screw angle that determines the load-deformation characteristics of timber joints, but also the direction of the timber fibers, species, and density, and shape of the screw, which is determined under the influence of various factors such as the amount of screwing. Therefore, in this study, we unified the shape, length, and amount of timber species, and conducted tests with only the grain direction and screw angle as parameters.

3 – EXPERIMENTAL SETUP

Full-thread screws (200 mm long, 8 mm diameter) were inserted at an angle of 30°, 45°, and 60° into the cedar lumber in each grain direction. The embedded length of the screw

was approximately equal 員 the main and side members (as shown in Table 1, and Fig. 1).

4 – RESULTS

Typical load-displacement curves are shown in Fig. 2. When the grain direction of the side member is 0°, the stiffness increases as the screw angle approaches 90°. When the grain direction of the side member is 90°, the stiffness increases,

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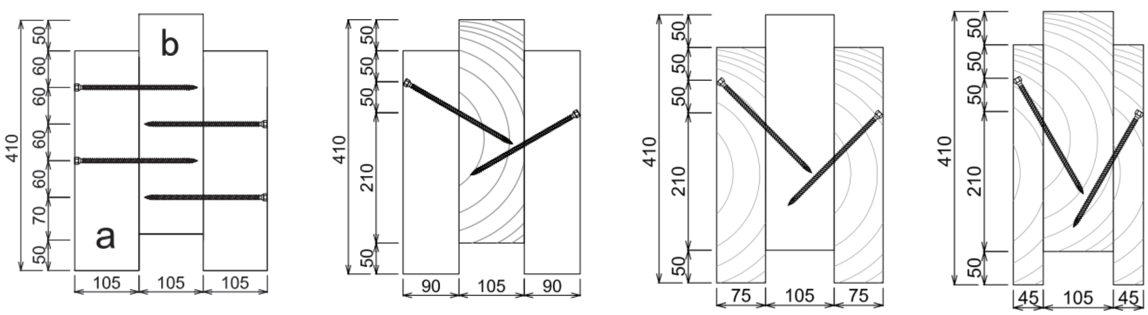
https://doi.org/10.52202/080513-0511

Table 1. Overview of test samples

Sample name*	Timber	Screw angle	a Thickness	b Thickness	a Insertion length	b Insertion length	a Grain direction	b Grain direction	n
0° - 0° (0°)	Cedar	0°	105mm	105mm	105mm	95mm	0°	0°	6
0° -90° (0°)							0°	90°	
90° - 0° (0°)							90°	0°	
90° -90° (0°)							90°	90°	
0° - 0° (30°)		30°	90mm		104mm	96mm	0°	0°	
0° -90° (30°)							0°	90°	
90° - 0° (30°)							90°	0°	
90° -90° (30°)							90°	90°	
0° - 0° (45°)		45°	75mm		106mm	94mm	0°	0°	
0° -90° (45°)							0°	90°	
90° - 0° (45°)							90°	0°	
90° -90° (45°)							90°	90°	
0° - 0° (60°)		60°	45mm		90mm	110mm	0°	0°	
0° -90° (60°)							0°	90°	
90° - 0° (60°)							90°	0°	
90° -90° (60°)							90°	90°	

* ①° -② ° (③°)、①a Grain direction、②b Grain direction、③Screw angle



0° -0° (0°) 0° -90° (30°) 90° -0° (45°) 90° -90° (60°)

Figure 1, Examples of test samples (dimensions in mm)

but the increase is not as significant as when the grain direction of the side member is 0°. In particular, the stiffness does not increase for screw angle larger than 30°, when the side and main members have a grain direction of 90°. In conclusion, when using diagonal screwing to increase shear stiffness, it is necessary to pay attention to the direction of the grains, and to the direction of the screw head. Figs.3 to 6 show the load capacity of each test specimen for each specification. From Fig.3, when the screw angle is vertical, there is no big difference in the graph outline. In shear joints using 8-mm full thread screws (hereinafter φ8 screws), it can be said that the grain direction has little effect on the yield strength in vertical joints. Fig.4 shows the graph when the screw angle is 30°.The initial stiffness is larger compared to the graph in Fig. 3, and this feature is especially noticeable in the 0°-0° specification. Fig.5 shows the graph when the screw angle is 45°.Both the initial slope and maximum capacity (P_{max}) tend to have stable numerical values. Since it is easy to construct and has the effect of increasing stiffness, diagonal screwing is quite convenient. Fig.6 shows the graph when the screw angle is 60°. The tendency of initial stiffness related the screw angle is like that for screw angle of 30° and 45°, but P_{max} tends to be lower overall.

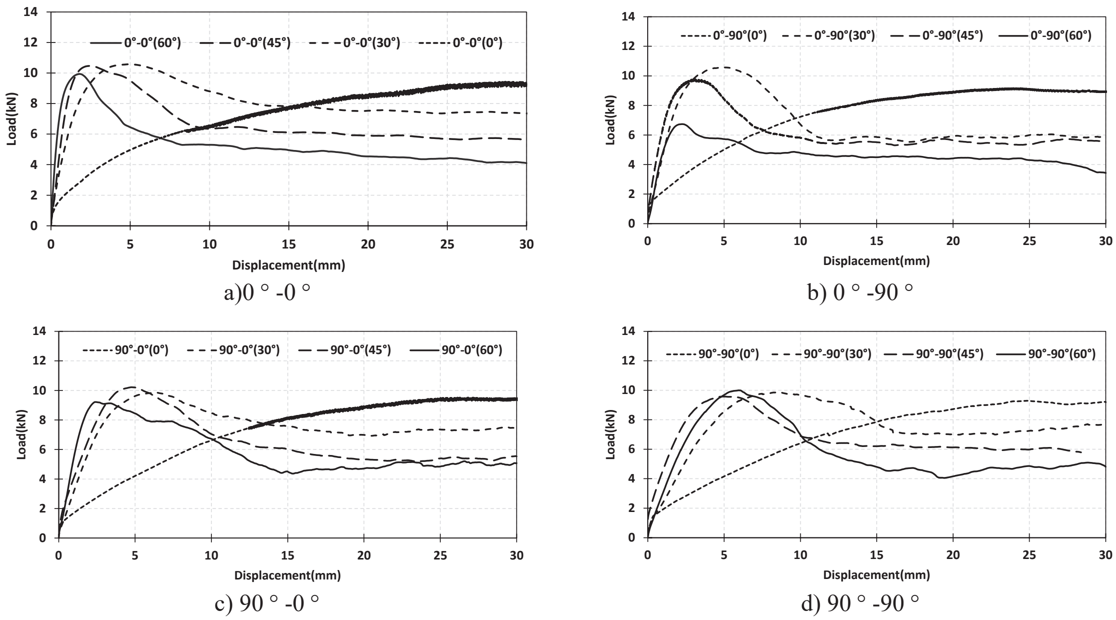


Figure 2, Typical load-displacement curves.

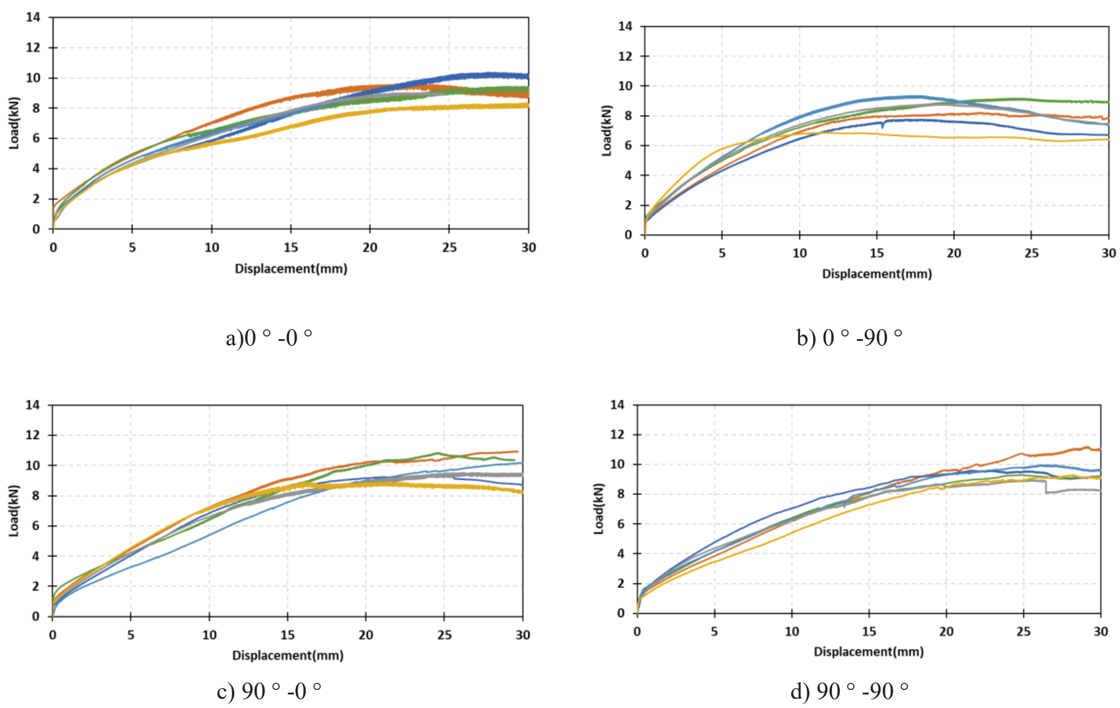
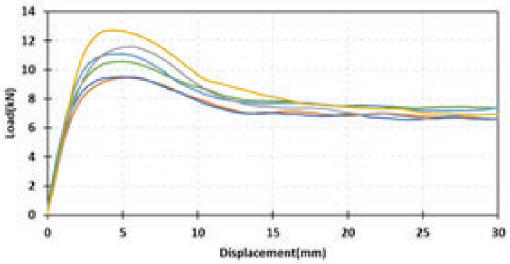
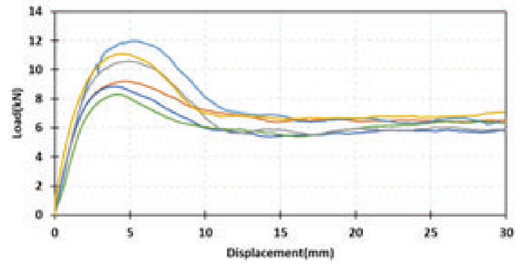


Figure 3. All load-displacement curves (screw angle=0 °)

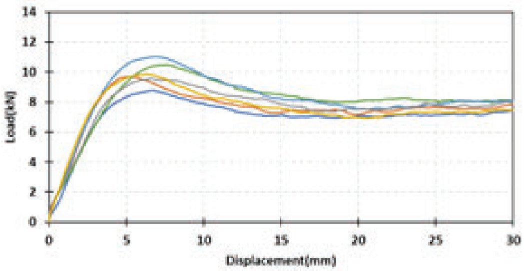
https://doi.org/10.52202/080513-0511



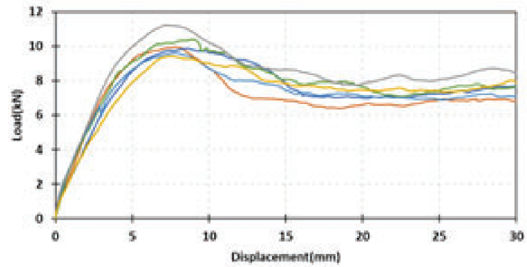
a)0° -0°



b) 0° -90°

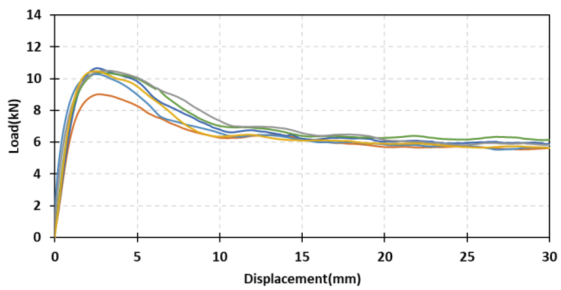


c) 90°-0°

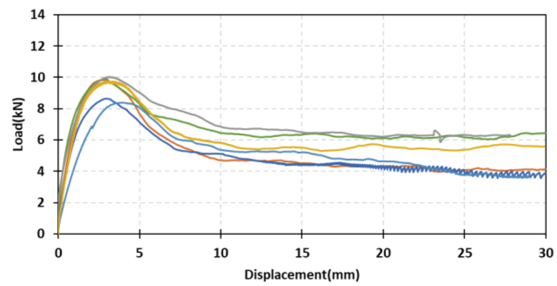


d) 90°-90°

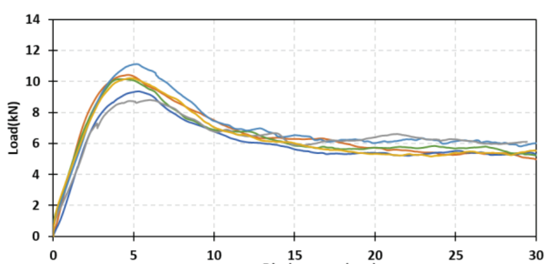
Figure 4, All load-displacement curves (screw angle=30 °)



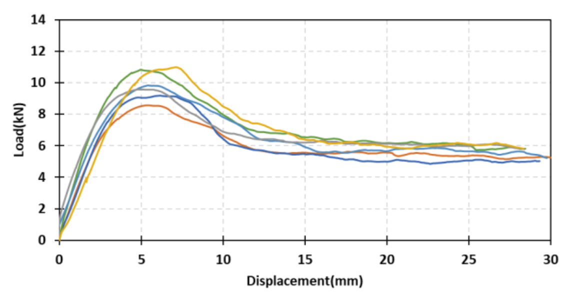
a)0° -0°



b) 0° -90°

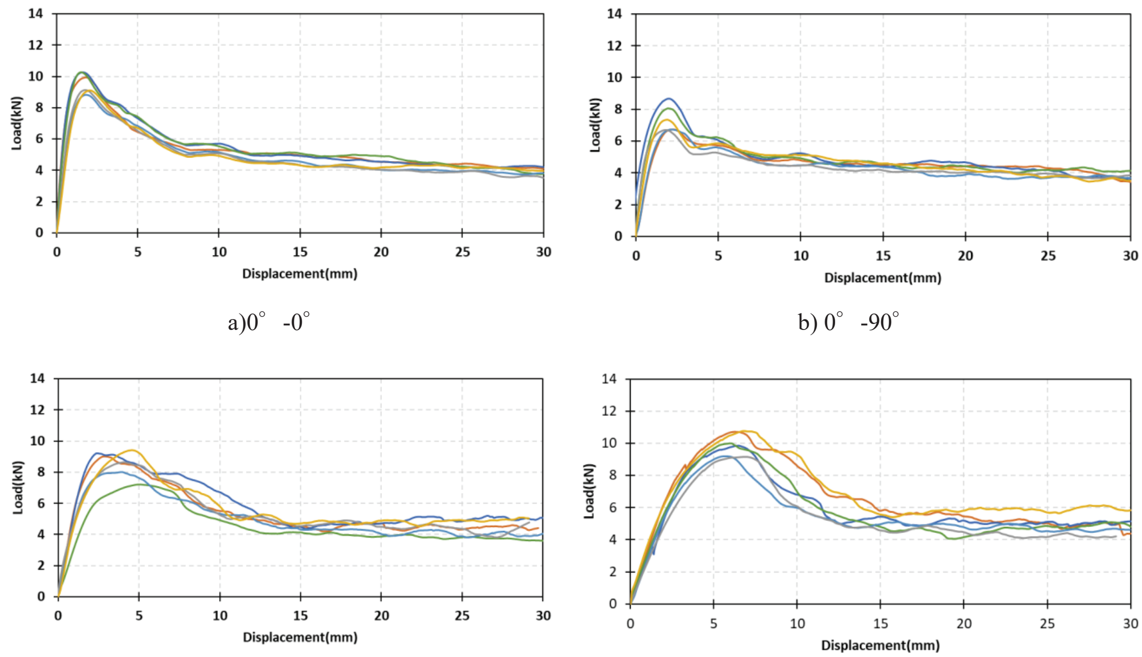


c) 90°-0°



d) 90°-90°

Figure 5, All load-displacement curves (screw angle=45 °)



a)0° -0° b) 0° -90°

c) 90°-0° d) 90°-90°

Figure 6, All load-displacement curves (screw angle=60 °)

5 – MATHEMATICAL FORMULA

Correlation between screw angle and shear stiffness shown in Fig. 7. When the grain direction of the side members is 0°, the stiffness increases as the screw angle approaches90°. When the grain direction of the side members is 90°, the stiffness increases, however the increase is slower than when the grain direction of the side members is 0°. These properties do not depend so much on the angle of the main member. In particular, the stiffness does not increase after a screw angle of 30° when the side and main members have a grain direction of 90°. Therefore, when using incline screwing to increase shear stiffness, it is necessary to pay attention to the grain direction of the side member. The influence on shear stiffness tends to be large, the influence on the maximum load tends to be small. These properties do not depend on the grain direction. In this case, shear stiffness in each grain direction can be easily estimated by using the regression Equation (1) to (4) obtained from Fig. 7 below. We propose the following formula:

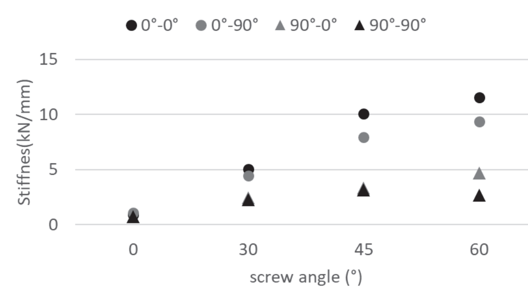


Figure7. *Correlation between screw angle and shear stiffness*

$$K_{0^\circ-0^\circ} = 0.19\theta + 0.6 \quad (1)$$

$$K_{0^\circ-90^\circ} = 0.14\theta + 0.9 \quad (2)$$

$$K_{90^\circ-0^\circ} = 0.065\theta + 0.6 \quad (3)$$

$$K_{90^\circ-90^\circ} = 0.05\theta + 0.74 \; (\theta \leq 30) \quad (4)$$

https://doi.org/10.52202/080513-0511

$K_{0^\circ-0^\circ}$ is shear stiffness when side members grain direction is 0° and main members grain direction is 0°(kN/mm)

$K_{0^\circ-90^\circ}$ is shear stiffness when side members grain direction is 0° and main members grain direction is 90°(kN/mm)

$K_{90^\circ-0^\circ}$ is shear stiffness when side members grain direction is 90° and main members grain direction is 0°(kN/mm)

$K_{90^\circ-90^\circ}$ is shear stiffness when side members grain direction is 90° and main members grain direction is 90°(kN/mm)

θ is screw angle (°)

In addition, we verified the mathematical formulation not only for stiffness but also for maximum strength and yield strength. Regarding the maximum strength of inclined screw connections, [1]Sakata et al. proposed the following formula:

$$Q_{js} = R_{ax} \cdot (\cos\theta + \mu_w \sin\theta)/(1-\mu_b) \quad (5)$$

Q_{js} is maximum shear strength of inclined screw connections (kN)

R_{ax} is maximum withdraw strength of screw (kN)

μw is friction coefficient of timber surface

μb is friction coefficient between screw and timber

Table 2 shows Q_{js} calculated from Equation (5) for screw angles of 30°, 45°, and 60° and ratio of experimental P_{max} to Q_{js}.

Table2. Ratio of P_{max} to the calculated value by Equation (5).

Screw angle	30°	45°	60°
Q_{js} (kN)	13.86	9.27	3.96
P_{max} (kN)	10.2	9.87	8.87
Q_{js}/P_{max}	**1.36**	**0.94**	**0.45**

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In the experiment, P_{max} was 9.5kN ±7%, regardless of the screw angle, and was similar for all θ values. On the other hand, according to Equation (5), Q_{js} is calculated to be larger as θ is smaller. Also, Q_{js} is calculated to be smaller as θ is larger.

To enhance the accuracy of the calculated values, a correction factor was determined through a parametric study. Equation (6), defined as the product of Q_{js} and this correction factor, we propose as an empirical formula for predicting the maximum shear strength of inclined screw joints.

$$Q_{js\theta} = Q_{js} \times 0.3e^{0.03\theta} \quad (6)$$

$Q_{js\theta}$ is the maximum shear strength of the parametrically adjusted inclined screw connection (kN).

e is Euler's number.

Table 3 shows Q_{js} calculated from Equation (6) for screw angles of 30°, 45°, and 60° and ratio of experimental P_{max} to Q_{js}.

Table3. Ratio of P_{max} to the calculated value by Equation (6).

Screw angle	30°	45°	60°
$Q_{js\theta}$ (kN)	10.23	10.73	7.18
P_{max} (kN)	10.2	9.87	8.87
$Q_{js\theta}/P_{max}$	**1.00**	**1.09**	**0.81**

Applying a correction factor enables the calculation of $Q_{js\theta}$ to values ranging from approximately -20% to +10% with respect to P_{max}.Although Equation (6) allows for a straightforward calculation of the maximum load, its application for determining the design load results in a complex formula. Therefore, to simplify the yield strength estimation, $Q_{js\theta}$ is multiplied by the ratio of the experimental shear yield strength (P_y) to P_{max}. The minimum value of this P_y/P_{max} ratio across the various fiber directions is then adopted as the reduction factor

Table4. Ratio of P_y to P_{max}.

Screw angle	30°	45°	60°
P_y(kN)	6.56	5.22	4.15
P_{max} (kN)	10.82	9.43	7.37
$Q_{js\theta}/P_{max}$	**0.61**	**0.55**	**0.56**

for the specific screw angle. These reduction factors are summarized in Table 4.

Adopting the lowest of these P_y/P_{max} values as a conservative reduction factor, Equation (7) is subsequently formulated for the calculation of the design load.

$$Q_{js\theta y} = 0.55 Q_{js\theta} \tag{7}$$

$Q_{js\theta y}$ is the design shear strength of the parametrically adjusted inclined screw connection (kN).

6 – CONCLUSION

This paper compared the test results by using screws and setting the screw insertion angle and timber grain direction as parameters. In conclusion, when using incline screwing to increase shear stiffness, it is necessary to pay attention to the grain direction and in particular to the grain direction of the side member. In addition, the influence of the screw insertion angle was found to be large, on shear stiffness whereas smaller, influence was noticed on the maximum capacity.

7 – REFERENCES

[1] Ryotaro Sakata, Masahiro Inayama, Kenji Aoki, Yusuke Nishino, Kazuki Ishimori “Study on the design method of built-up beams with inclined screw joints ,Part1：Single shear test of joints and estimation of its shear resistance“ (2018)

https://doi.org/10.52202/080513-0511