Nailed timber joints with a thick interlayer

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1. Introduction

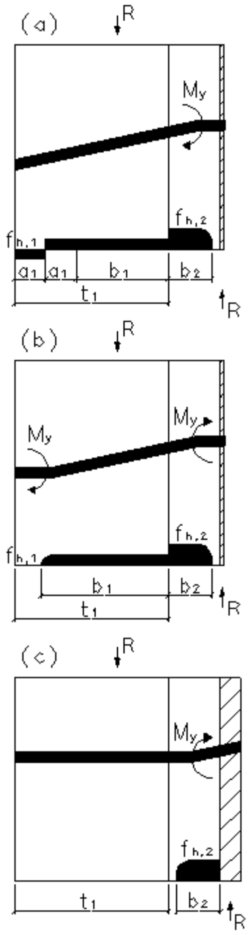
A new solution for joining timber floors to walls was sought by a domestic housing producer. Based on industrial requirements, the solution incorporated the use of a thick interlayer of plywood between a steel plate and the timber stud in a nailed connection. For this particular design, no prediction formula for the resistance is available.
In this paper, the prediction formulas for nailed timber joints with a thick interlayer are derived. The theoretical derivation was compared to experiments. A grand total of 18 experiments with varying geometry and materials were performed. The results show that the derived prediction formula is useful for predicting the ultimate load for nailed joints with a thick interlayer but the rope effect needs to be clarified in accordance with the proposal for [3].

Keywords: nailed joints, thick interlayer, Johansen theory.

2. Theoretical models

Five potential failure modes for rigid connected thin interlayer to timber were presented by [2] for thin and thick steel plates. In the present study three new failure mechanisms for thick interlayers are presented (*Figure 1*), two for thin and one for thick steel plates. The load carrying capacity of single-shear timber-to-steel joints with thick interlayer was derived according to Johansen theory.
A rigid connection between timber and the interlayer is assumed in the formulas. The parameters that govern the occurrence of a specific failure mode are the nail pointside penetration depth t_1, the thickness of the interlayer and the embedding strength ratio $\beta = f_{h,2}/f_{h,1}$.
Failure mechanism (a) can only occur for $t_1<6d$ or $t_1<8d$ that is the required minimum penetration depth [3] for smooth or annular ringed shank nails respectively. The β value does not effect this failure mode. Retaining t_1 higher than required minimum [3] is sufficient to avoid the appearance of failure mode (a). The appearance of failure mechanism (b) is expected in the case of $\beta<1$ and t_1

larger than 0.5*l* where *l* is the nail length. The coefficient 0.5 was found from a parameter study on the new failure mechanisms and those presented by [2] and [3]. Consideration of cases for β>1 leads to solutions according to [3] or those developed by [2].
The failure mechanism (c), valid for a thick steel plate, can be obtained for all combinations of β and t_1. Failure mechanism (c) was found to be independent of the location of the plastic hinge within, or at the interface, the interlayer.



Thin steel plate

Failure mechanism t_1<6d or t_1<8d

$$R = 2 f_{h,1} d b_1, \qquad b_1 = \sqrt{\frac{\beta}{6+\beta}\left(t_1^2 + \frac{t_1^2\beta}{6+\beta} + \frac{4M_y}{f_{h,1}d}\right)} - \frac{t_1\beta}{6+\beta} \qquad (a)$$

Thin steel plate

Failure mechanism β<1 and t_1>0.5*l*

$$R = 2 f_{h,1} d b_1, \qquad b_1 = 2\sqrt{\frac{M_y}{f_{h,1}d}\cdot\frac{\beta}{3+\beta}} \qquad (b)$$

Thick steel plate

Failure mechanism for all combinations of β and t_1

$$R = f_{h,2} d b_2, \qquad b_2 = \sqrt{\frac{2M_y}{f_{h,2}d}} \qquad (c)$$

Figure 1 Assumed failure mechanisms: (a, b) Thin steel plate with thick interlayer, (c) Thick steel plate with thick interlayer

3. Experimental study

3.1 Shear tests with timber-to-steel joints with thick interlayer

The load carrying capacity and the deformation behaviour of single shear timber-to-steel joints with thick interlayer were determined in short-term tests. A 23 mm thick plywood interlayers were placed between a timber stud and a steel plate for the first test series (embedding strength of interlayer $f_{h,2}$ was higher than embedding strength of timber $f_{h,1}$, β>1). A 22 mm particleboard interlayers were used for the second series with beech studs ($f_{h,1}$>$f_{h,2}$ and β<1). Interlayers were nailed to the timber with eleven 75x2.8 pre-drilled nails. In the first series one pre-drilled ringed shank nail 80x6, was used together with 3 and 6 mm steel plates. In total 10 tests were performed, 5 for each thickness of a steel plate. In the second series, one pre-drilled nail 75x4 was used with 2 and 4 mm steel plates. Here 8 tests were carried out, 4 for each thickness of the steel plate. *Figure 2* shows the test set-up. The results of both tests series are presented in *Table 1* and load-displacement curves showing typical behaviour from each test are shown in *Figure 3* together with a picture showing the deformed nail of one test specimen.

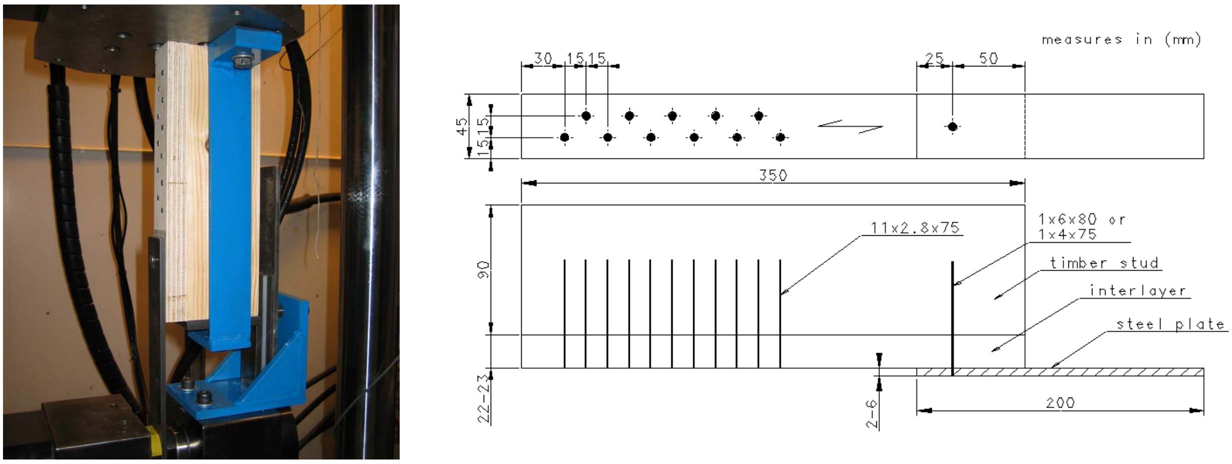


Figure 2 Test set-up of the single shear timber-interlayer-steel plate joints

3.2 Embedding strength tests

The embedding strength of spruce, beech, plywood and particle board were determined according to [4]. Compression tests parallel to the grain for timbers and to the outer layers of plywood and particleboard were performed. Ringed shank nails diameters of 4 mm and 6 mm were used and were pre-drilled with diameters 3.2 mm and 4.8 mm respectively. In total 17 tests were performed, 5 for spruce and particleboard, 4 for beech and 3 for plywood. The mean values of the embedding strength, f_h, were 43.1 MPa for spruce and 48.8 MPa for plywood for nails with a diameter of 6 mm. 91.9 MPa for beech and 55.4 MPa for particleboard for nails with a diameter of 4 mm.

4. Experimental results

To verify the tests results theoretically, the average f_h values for timber and interlayer taken from the embedding tests were used. The theoretical values presented in *Table 1*, confirmed the occurrence of failure mechanism (c), which emerges as a minimum value calculated from formulas presented in this study and developed by [2] and [3]. For the first tests series, *Table 1*, of spruce with plywood as interlayer two failure mechanisms occurred. For the thick steel plate, one plastic hinge formed within the interlayer (failure mechanism (c)); for the thin steel plate two plastic hinges formed. The formation of the second plastic hinge at the interface between interlayer and steel plate exclude the use of failure mechanism (a). This phenomenon was most probably caused by the large deformation in the nail. For the second test series of beech with particleboard as interlayer, failure mechanism (c) occurred for both thin and thick steel plates. The possible explanation for this is probably because the specimens were examined after the tests were completed, when the deformation is around 15 mm, *Figure 3*. However the second tests series results suggest that the failure mechanism (c) could also be considered for thin steel plates.

Table 1 Verification of theoretical models with tests results. Density and moisture content of performed tests

Test		F_{max} [kN]		Density [kg/m^3]		Moisture content [%]	
		Tests results	Theoretical values	Timber	Interlayer	Timber	Interlayer
Mean values of 5 tests	Spruce-plywood joint-thin steel plate	9.34	**(a) excluded**	548	475	9.63	6.90
	Spruce-plywood joint-thick steel plate	6.70	**4.03 (c)**	551	474	9.35	6.91
Mean values of 4 tests	Beech-particleboard joint - thin steel plate	6.01	**2.06 (c)**	613	610	8.04	6.15
	Beech-particleboard joint - thick steel plate	5.50	**2.06 (c)**	589	605	8.06	6.02

The rope effect was not taken into account in the theoretical load-carrying capacities in *Table 1* therefore the tests results values are higher than the predicted by theoretical models. The load-carrying capacities reached during the both test series are higher by 1.65 - 2.9 compared to those calculated from equation (c). For long nails with threaded shanks the experimental load-carrying capacity was found to be up to 2.6-times the theoretical value according to Johansen theory [5]. In [3] the rope effect is presented as an additive contribution to the characteristic load-carrying capacity for timber-to-timber and panel-to-timber connections. This effect increases a connection capacity depending on different fastener. The value can vary from 15% for round nails to 100% for screws [3].

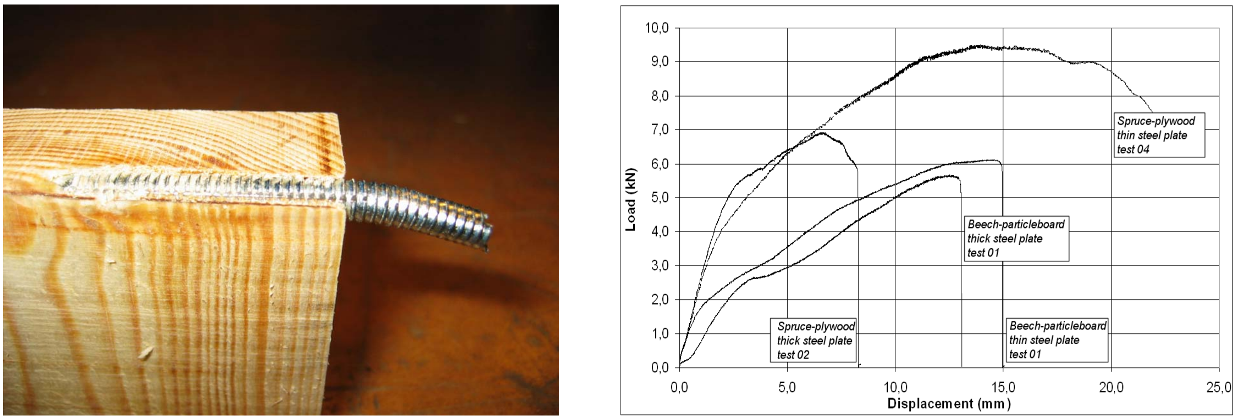


Figure 3 Opened specimen after test and load-displacement curves of average representative from each test series

5. Conclusion

The load carrying capacities of a single-shear timber-to-steel joint with thick interlayer based on Johansen theory were derived and conditions when different failure mechanisms can occur were presented. The case with interlayer rigidly connected to timber together with thin or thick steel plate was examined.

In the present study different materials and various geometric parameters were tested. The first test series was performed with $\beta>1$, to demonstrate failure mechanisms (a) and (c). Results obtained in the second test series for thick and thin steel plate attached to the interlayer and $\beta<1$ confirmed that β and pointside penetration length do not govern failure mechanism (c). The tests results also showed that the rope effect, which is not taken into account in the theoretical study, affects the connection capacity.

For further studies it is recommended to investigate the limit between “thin” and “thick” interlayer and the influence of nail deformation on the failure mechanisms especially when a thin steel plate is used (excluded failure mode in *Table 1*). Also, using thicker interlayers than in this study could better describe any effect of the distribution of the plastic hinge within the interlayer.

6. References

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