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DUCTILITY OF WOOD CONNECTIONS WITH SDS SCREWS OR RING NAILS AND ANGLE BRACKETS

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ABSTRACT: Mechanical connections in wood structures typically consist of structural members connected with combination of cold-formed thin-walled steel angle brackets and fasteners in forms of nails or screws. Design of these steel connectors is typically based on short-term monotonic load bearing capacities. Observations from experimental testing indicate that their failure modes and resistance to a cyclic loading should be checked carefully to prevent the thread of sudden collapse of structures using these connections. This paper presents the experimental results of connections of CLT elements connected together by angle brackets and subjected to the external cyclic loading. Special focus is made on connections using heavy duty screws as fasteners. Results of experimental testing are compared to results of testing of similar connections using ring nails as fasteners. In addition, numerical simulations are made with aim to predict the failure modes and the load bearing capacities of experimentally tested connections.

KEYWORDS: Timber connections, angle brackets, screws, numerical simulation, full-scale tests, Python scripting.

1 INTRODUCTION

Since its invention in Europe, cross-laminated timber (CLT) has become a widely used construction material which has started to attract the global attention [1]. Due to the brittle nature of wood, CLT structures rely on metal connections to achieve required ductility and energy dissipation [2]. When designed properly with steel connectors and CLT elements, the structure can exhibit superior seismic performance by leveraging the high strength-to-weight ratio of wood members and the high ductility of steel components [3]. A good understanding of connections in CLT structures is needed to better predict the performance of the structures and avoid unexpected failures, e.g., caused by the out-of-plane movements under wind and seismic loads [4]. Some scholars [5-10] already used advanced modelling techniques in Abaqus® to predict the performance of structures connected by the steel components, ring nails or screws. Therefore, it is the aim of this paper to continue developing similar numerical models and try to use them to predict the performance of the experimentally tested connections of CLT structures.

2 EXPERIMENTAL TESTING

A number of CLT connections made of steel angle bracket connectors and screws has been extensively tested. Three test setups were made to achieve mechanical loading of the connections in pull-out, shear, and rocking (see Figure 1). Applied force as well as displacement at chosen locations of tested connections was recorded too. In each test-setup, various connections differing by used type of Simpson Strong-Tie® angle brackets (HGA10KT, ABR9020, ABR105) were used. As fasteners, Simpson Strong-Tie® heavy duty SDS screws were used.

Figure 1: Experimental setup of CLT connection made of ABR9020 bracket and SDS screws subjected to rocking.

These test-setups are identical to those previously used in [11]. However, the type of used fasteners varies between these two studies. Therefore, the influence of using screws instead of ring nails on the obtained mechanical properties of the tested connections, could be compared. The special attention was paid on load bearing capacity, measured

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deformations (at the location of the red dot in figures 4-6), ductility and energy dissipations.

Table 1: *Overview of used fasteners in connections.*

Connector	Screw/Nail Type
HGA10KT	SDS25112 + SDS25300
HGA10KT	CNA4-60
ABR 105	SD10212
ABR 105	CNA4-60
ABR 9020	SD10212
ABR 9020	CNA4-60

CNA4-60 is an angular ring shank nail with 60 mm in length and 4.0 mm in diameter.

SD10212 is a screw with 63.5 mm (2.5 inch) in length, 25.4 mm (1.0 inch) long threaded part with 4.10 mm (0.161 inch) shank size.

SDS25112 is a screw with 38.1 mm (1.5 inch) in length, 25.4 mm (1.0 inch) long threaded part with 6.35 mm (0.25 inch) of outer diameter and 4.70 mm (0,185 inch) inner diameter.

SDS25300 is a screw with 76.2 mm (3.0 inch) in length, 50.8 mm (2.0 inch) long threaded part with 6.35 mm (0.25 inch) of outer diameter and 4.70 mm (0,185 inch) inner diameter.

All four types of listed fasteners were tested both in the axial (withdrawal) direction, as shown in Figure 2 and lateral (shear) direction (as shown in Figure 3). These experimentally obtained mechanical properties (force to displacement curves) of the fasteners were used later during the numerical modelling.

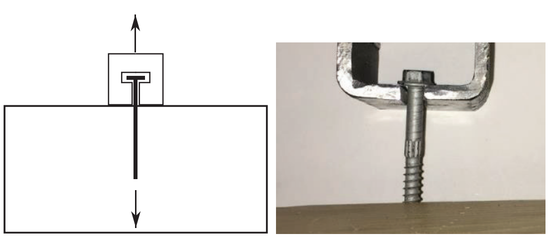

Figure 2: *Experimental setup of axially loaded fastener: schematic (left) and during tests (right).*

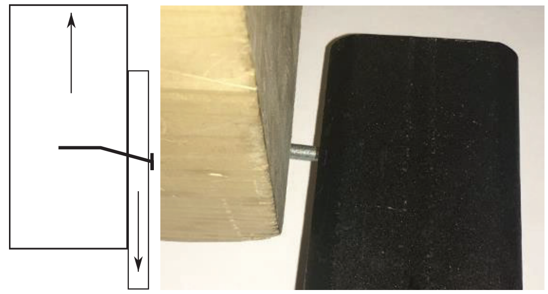

Figure 3: *Experimental setup of laterally loaded fastener: schematic (left) and during tests (right).*

The rocking test-setup consists of two CLT blocks (200x135x300 mm^3) fixed to the floor and one CLT block (105x300x150 mm^3) placed between them. A 3 mm gap between the blocks is designed to avoid friction between the CLT members. The load is applied at the top of the intermediate CLT panel at a distance of 205 mm from the shear plane, as shown in Figure 4. This eccentricity was chosen to ensure large bending load on the connection together with limited shear force action in relation to its shear load carrying capacity. A loading protocol with the maximal magnitude of displacement equal to 50 mm was used.

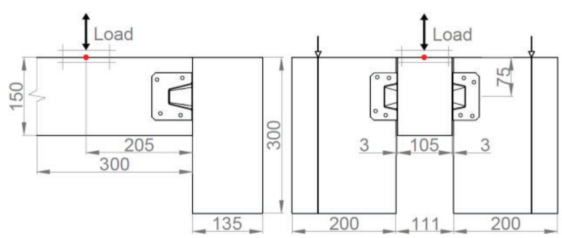

Figure 4: *Side and front view of the experimental setup of HGA10KT brackets for rocking test.*

The shear test setup consists of two CLT blocks (200x135x300 mm^3) fixed to the floor and one CLT block between them (105x320x300 mm^3). A 3 mm gap between the blocks is designed to avoid friction when the external load is applied.
The load is applied at the top of the intermediate CLT panel to act in the shear plane of the connection as shown in Figure 5. A loading protocol was used with a maximum displacement of 35 mm.

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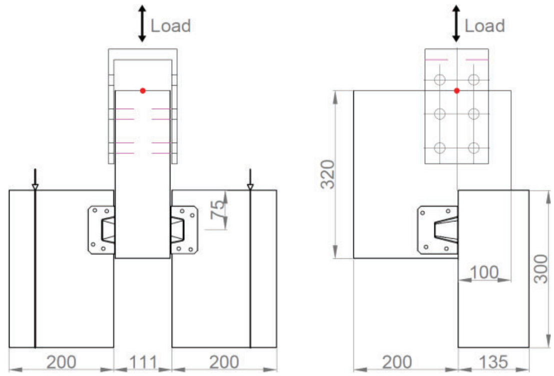

Figure 5: *Front and side view of the experimental setup of HGA10KT brackets for shear test.*

Pull-out test setup was made of one horizontal CLT block ($105x150x600\ mm^3$) fixed to the floor and one vertical CLT block ($105x320x150\ mm^3$). The load is applied at the top of the vertical CLT block as shown in Figure 6. A loading protocol was used with a maximum displacement of 50 mm.

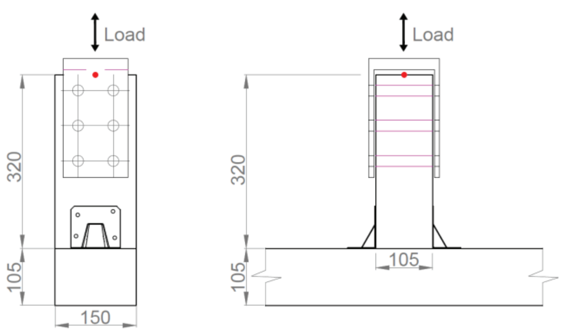

Figure 6: *Front and side view of the experimental setup HGA10KT brackets for pull-out test.*

3 NUMERICAL SIMULATIONS

Realistic numerical models (Figure 7) were assembled in the Abaqus® software, by using the same scripts as were used in [11]. Timber beams, where no contact occurred between the angle brackets and the wood, were simulated with beam elements. Some parts of the timber beams in close vicinity of angle brackets were simulated with shell elements. Shell elements were also used for the angle brackets. The Abaqus® wire elements connecting one point of mesh of beam part and one point of mesh in angle bracket part with assigned "uniaxial behaviour" represented each fastener in the model. This approach was chosen because it allows to define the re-loading path of the wires simulating fasteners in the Abaqus® software.

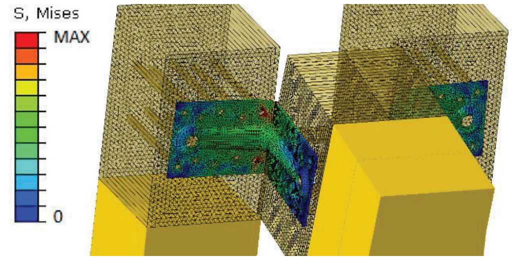

Figure 7: *Numerical simulation of CLT connection made of ABR9020 bracket and SDS screws subjected to rocking.*

Parametric modelling with Python scripting was used to create the model geometry and properties of the connections. This approach allows fast modification of beam dimensions, fastener properties and type of angle brackets, needed to cover a large number of possible combinations of possibly used angle brackets and fasteners. In addition, it allows to define the "uniaxial behaviour" directly to Abaqus® keywords.

4 RESULTS AND DISCUSSION

The presented load-displacement curves for both individual fastener joints and angle bracket connections bring a direct comparison between the nails and screws as well as between the experimentally and numerically obtained results.

4.1 FASTENERS

The presented force to displacement curves in Figure 8 show that the 60 mm long ring nails have very similar withdrawal resistance as only 38.1 mm long screws. In addition, screws are stiffer but less ductile. Other two tested screws (76.2 and 63.5 milometers long) have the same initial stiffness like the 38.1 mm long ones but they vary significantly in their strength.

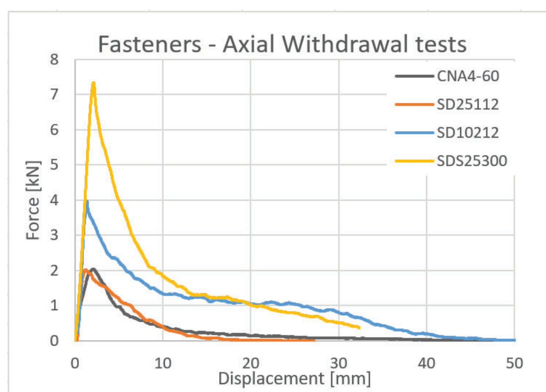

Figure 8: *Representative mechanical behaviour of three types of screws and one type of nail subjected to the withdrawal test.*

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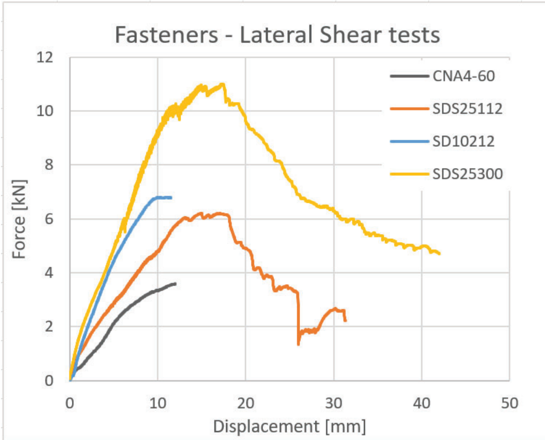

Figure 9: *Representative mechanical behaviour of three types of screws and one type of nail subjected to lateral shear test.*

The presented force to displacement curves in Figure 9 show that ring nails are both less stiff and weaker in term of the lateral resistance. 38.1 mm long screws have similar lateral resistance as 63.5 mm long screws because the shorter ones have thicker shank compared to the longer ones (4.1 mm compared to 4.7 mm). As expected, the longest screws with the thickest shank are both the stiffest and strongest.

4.2 CLT CONNECTIONS

The presented force to displacement curves in Figure 10 show that bigger angle brackets have higher load bearing capacity. In addition, connections with screws (dashed lines) have higher capacity than the similar ones with ring nails (full lines). The same colour is used for the same types of connectors (HGA10KT - blue, ABR9020 - orange, ABR105 - green) which were used in the tested CLT connections.

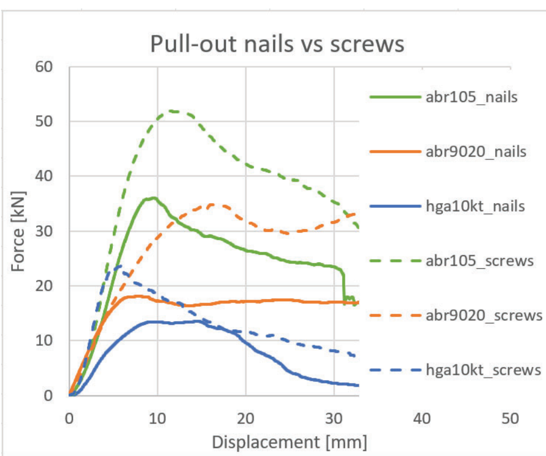

Figure 10: *Representative mechanical behaviour of three types of connections with nails and screws subjected to pull-out.*

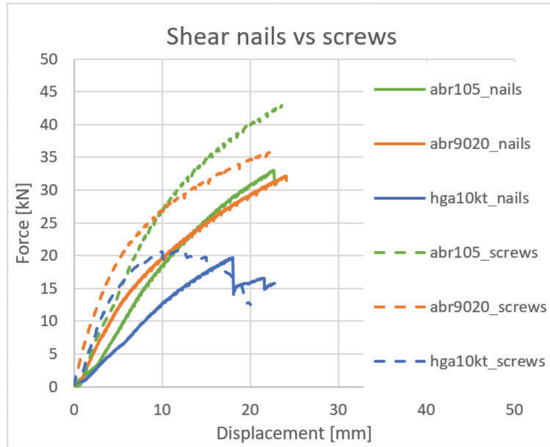

Figure 11: *Representative mechanical behaviour of three types of connections with nails and screws subjected to shear.*

The presented force to displacement curves in Figure 11 show that the size of the bracket does not have as significant influence on the load bearing capacity in shear as in case of the pull-out. Connections with screws (dashed lines) are generally stiffer than those with ring nails (full lines) but they do not have significantly higher capacity than the similar ones with ring nails. This indicates that not only fastener type contributes to the overall stiffness of the tested connections.

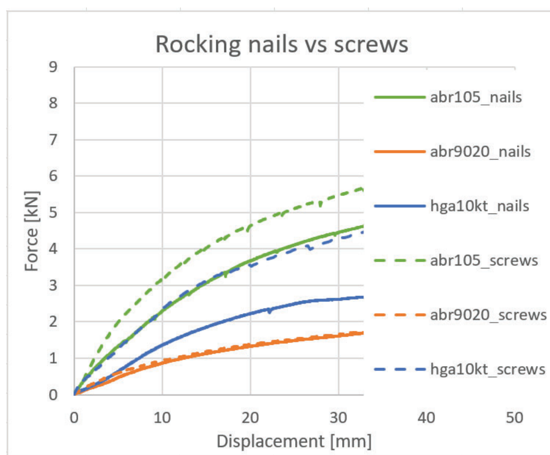

Figure 12: *Representative mechanical behaviour of three types of connections with nails and screws subjected to rocking.*

The presented force to displacement curves in Figure 12 show that the connections with the smallest bracket (HGA10kt) is stronger and stiffer that the medium size one (ABR9020). This might be caused by the influence of its relatively massive rib (compared to the one at the bigger angle bracket) on its stiffness. There is also no significant difference in stiffness nor capacity related to the used type of the fastener in case of the connection with ABR9020 bracket. Other two types of the brackets are stiffer and stronger with screws than with nails.

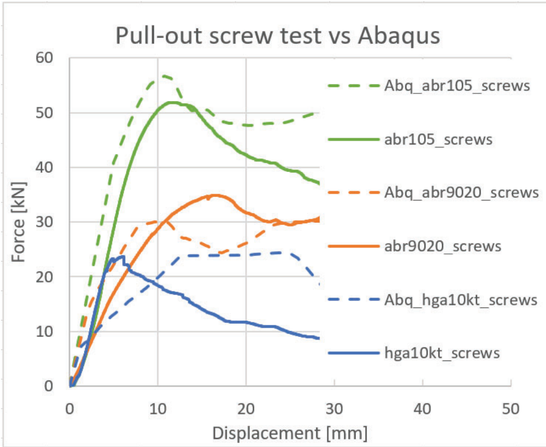

Figure 13: *Representative mechanical behaviour of three types of connections with screws subjected to pull-out compared to the results from simulations assembled in Abaqus (FEA).*

The presented force to displacement curves in Figure 13 show that there is the best agreement in case of the connection with the biggest (ABR105) angle bracket. The other simulations were relatively successful in predicting the stiffness of the connections in case of relatively small deformations and also in predicting of the load bearing capacities of the connections.

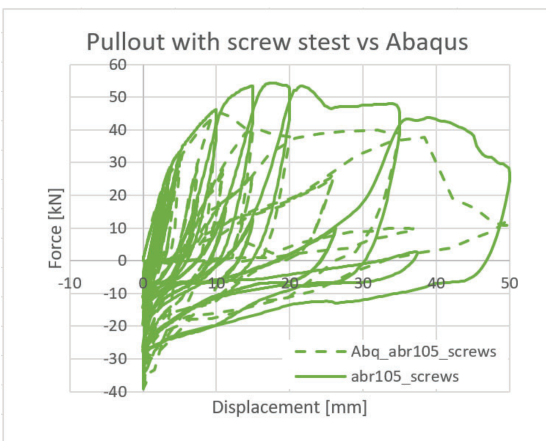

Figure 14: *Representative cyclic mechanical response of connection with angle bracket ABR105 and screws compared to the results from simulations assembled in Abaqus subjected to pull-out.*

The presented force to displacement curves Figure 14 shows the result of the most successful simulation of the mechanical response of the connection using ABR105 angle brackets and screws to the cyclic loading. There is better agreement between the numerical model and the results from the tests in case of the loading and unloading parts of the diagrams than in case of the re-loading ones.

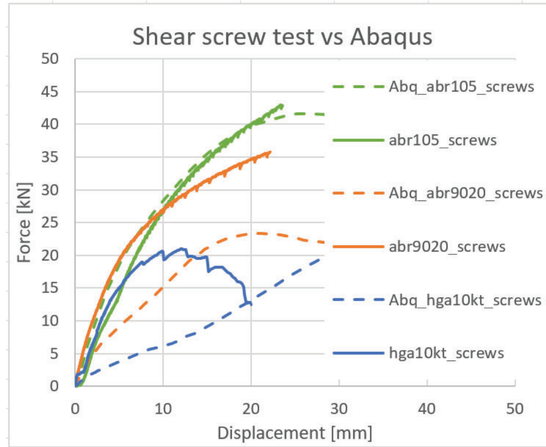

Figure 15: *Representative mechanical behaviour of three types of connections with screws subjected to shear compared to the results from simulations assembled in Abaqus (FEA).*

The presented force to displacement curves in Figure 15 show that there is the best agreement in case of the connection with the biggest (ABR105) angle bracket. The other simulations were relatively poor in predicting the mechanical behaviour of the tested connections.

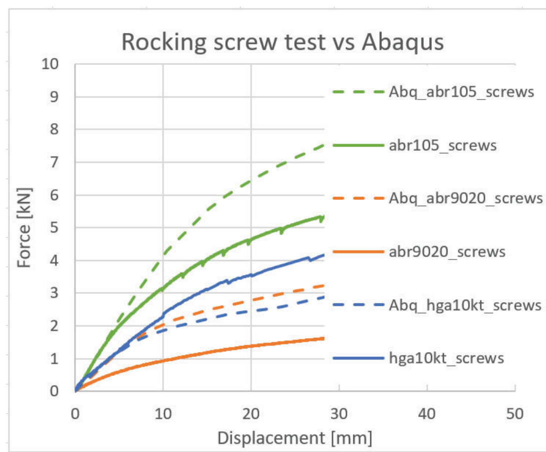

Figure 16: *Representative mechanical behaviour of three types of connections with screws subjected to shear compared to the results from simulations assembled in Abaqus (FEA).*

The presented force to displacement curves in Figure 16 show that there is the best agreement in case of the connection with the biggest (ABR105) angle bracket. However, all the simulations were relatively poor in predicting the mechanical behaviour of the tested connections.

5 CONCLUSIONS

Generally speaking, using screws instead of nails in studied connections lead to stiffer and stronger connections. On the other hand, using too strong screws

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may lead to a brittle failure of the connections subjected to the external loading.

The relatively simple numerical models which were quite successful in predicting the deformed shape and the load to displacement curves of the experimentally tested connections of all three studied types of angle brackets and setups, i.e.: pull-out, shear and rocking with ring nails were not so successful in case of screws. This might be caused by failure modes which include cracking the timber during testing, particularly in pull-out (Figure 17) and shear (Figure 18).

Figure 17: *Test specimen with HGA10kt angle bracket and screws after pull-out test.*

Figure 18: Test specimen with HGA10kt angle bracket and screws after shear test

Another factor which seems to be relatively important and is not included in the numerical model is the friction between the steel plate of the angle bracket and the surface of the timber. Therefore, it is the scope of the further research to develop the numerical model further to be able to predict the mechanical response of all the tested connections more accurately.

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REFERENCES

[1] Espinoza, O., Trujillo, V. R., Mallo, M. F. L., and Buehlmann, U.: Cross-laminated timber: Status and research needs in Europe. *BioResources*, 11(1), 281-295, 2016.

[2] G. D'Arenzo, G. Rinaldin, M. Fossetti, M. Fragiacomo: An innovative shear-tension angle bracket for Cross-Laminated Timber structures: Experimental tests and numerical modelling. *Eng Struct*, 197, p. 109434., 2019.

[3] M. Latour, G. Rizzano: Seismic behavior of cross-laminated timber panel buildings equipped with traditional and innovative connectors. *Arch Civ Mech Eng*, 17 (2) (2017), pp. 382-399, 2017.

[4] Rezvani, S., Zhou, L., & Ni, C.: Numerical analysis of in-and out-of-plane coupling effects on angle bracket connections in CLT structures. *Engineering Structures*, 250, 113494. 2022.

[5] Bedon C, Fragiacomo M.: Numerical analysis of timber-to-timber joints and composite beams with inclined self-tapping screws. *Composite Structures*. 207:13-28, 2019.

[6] Bedon C, Sciomenta M, Fragiacomo M. Correlation approach for the Push-Out and full-size bending short-term performances of timber-to-timber slabs with Self-Tapping Screws. *Engineering Structures*. 238:112232. 2021.

[7] Bedon C, Sciomenta M, Fragiacomo M. Mechanical characterization of timber-to-timber composite (TTC) joints with self-tapping screws in a standard push-out setup. *Applied Sciences*. 10(18):6534. 2020.

[8] Izzi M, Rinaldin G, Polastri A, Fragiacomo M. A hysteresis model for timber joints with dowel-type fasteners. *Engineering Structures*. 157:170-8. 2018.

[9] Izzi M, Rinaldin G, Fragiacomo M, Polastri A. Numerical modelling of steel-to-timber joints and connectors for CLT structures. *World Conference on Timber Engineering (2016)* (pp. 1-9). 2016

[10] Krawinkler, H., Parisi, F., Ibarra, L., Ayoub, A. and Medina, R.: Development of a Testing Protocol for Woodframe Structures, CUREE Publication No. W-02, 2001.

[11] Sejkot, P., A. Iqbal a S. Ormarsson. Finite-element modelling of connectors to achieve ductile connections in wood structures. *World Conference on Timber Engineering (WCTE 2021) Proceedings*. 3026-3032, 2021.