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INFLUENCE OF THE SPECIMEN PREPARATION ON THE EMBEDMENT STRENGTH OF SELF-TAPPING SCREWS

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ABSTRACT: Due to their simple application and their wide-ranging applicability, self-tapping timber screws are either used for various types of connections or reinforcements in timber constructions. Apart from axial loading, self-tapping timber screws can be also loaded lateral, whereas the embedment strength f_h is one of the major parameters in the design process. The experimental determination of the embedment strength f_h, following EN 383, demands test procedures with thin timber specimen, whereas during the screw-application initial crack forming under specific conditions occur. As this has an unwanted and negative influence on f_h, a new way of specimen preparation was developed, with which initial crack formation can be excluded. Besides the presentation of this new method, the contribution also contains an experimental verification, which may lead to a significant modification of the current design model of f_h of self-tapping screws.

KEYWORDS: embedment strength, self-tapping screws, initial checks, novel preparation method, RILEM TC TPT

1 INTRODUCTION

Due to their versatile applicability and their simple installation without pre-drilling, self-tapping timber screws are frequently applied in contemporary timber constructions. Thereby, they are either loaded in axial or in lateral direction or in a combination of both. In the latter cases, their design according to Eurocode 5 [1] bases on the European Yield Model (EYM), where their yield moment M_y and the timber member's embedment strength f_h serve as main material properties. With regard to the embedment strength, there are two alternatives for a related calculation; one given in the present version of Eurocode 5 (where rules for nails and dowels are adopted for self-tapping screws in dependence of the size of their thread diameter) and one, which was specifically developed for self-tapping screws (c. f. Blaß et al. [2]) and is anchored in the majority of European Technical Assessments (ETAs) of self-tapping timber screws.

Comparing both approaches, especially the way how they consider the load-to-grain angle α, which is exclusively done by the Eurocode 5 approach, leads to a significant overestimation of experimentally determined f_h while for the ETA-approach (basing on Blaß et al. [2]) a high agreement between test results and model prediction was found, c. f. Gstettner [3]. In fact, this is surprisingly since the impact of the load-to-grain-angle α represents timber's well-known orthotropic material behaviour, established and successfully verified for f_h of other dowel-type fasteners such as dowels or bolts. The reason for the deviating behaviour, found for self-tapping screws, is discussed in Section 2.

2 RESEARCH ISSUE

Following the regulations according to EN 383 [4], aiming to avoid fastener's bending and to test a realistic application scenario, Gstettner [3] conducted screw embedment tests with a specimen-thickness $t = 2\,d$ without pre-drilling in advance. Thereby, the embedment strength f_h of several different screw types with their individual tip-characteristics applied in solid timber specimen with varying load-to-grain-angle (α), as well as the fastener axis-to-grain angle (ε), see Figure 1, was determined.

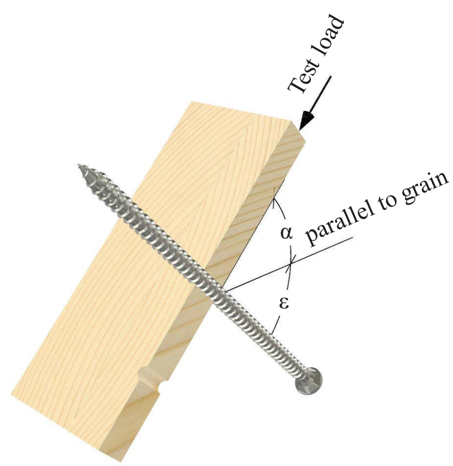

__Figure 1:__ Definition of the load-to-grain (α) and axis-to-grain angle (ε)

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In addition, to investigate an impact of the timber density on f_h, tests with three different timber-density classes of softwood were executed. In the frame of this campaign and especially for specific variations {α =var. | ε = 90°}, initial crack forming due the material displacement in the frame of screw insertion was observed. Thereby, the crack size and length were found to depend on the tip features of the screw. Results of some preliminary insertion tests indicate that RAPID® screws (8.0 x 220 mm, d_i = 5,2 mm), equipped with a tip-compressor and a half cut in combination with a low insertion speed, lead to crack formation in a tolerable amount. A related example is shown in Figure 2 (top). Even though this specific form of application was chosen, the crack formation due to the small specimen thickness according to EN 383 [4] still had a negative impact on screws loaded parallel to grain (α = 0° | ε = 90°). One consequence was that α did not influence the size of f_h at all. This observation is equal to the one made by Blaß et al. [2], with significant consequences for the regulation in currently valid ETAs of self-tapping screws, but stands in clear contrast to timber's orthotropic characteristics, as e.g. expressed by the Hankinson-formula, which rules the increase of f_h with decreasing α for laterally loaded dowels in EN 1995-1-1 [1].
To conclude: the challenge of the current determination of f_h for self-tapping screws is, that its empirical background bases on tests with comparatively thin specimens (aim: avoid fastener's bending during testing), which do not fulfil the minimum thickness requirements according to ETA and thus have a significantly negative impact on the initial crack formation. As pre-drilling turned out to be not a suitable alternative (note: pre-drilling leads to a differently pronounced densification of the timber surrounding the screw), the aim of the present investigation was to find a way of test specimen preparation, leading to a required specimen thickness according to EN 383 [4] on the one hand and avoiding initial crack formation as a consequence of a too thin specimen thickness on the other. The successful result of this finding process in form of a new specimen preparation method is shown in Figure 2 (bottom).

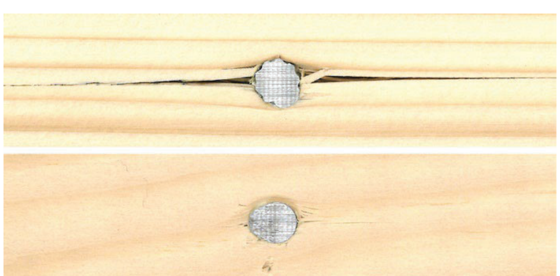

Figure 2: *Influence of the timber-specimen preparation on the embedment strength (f_h); (top) without- (bottom) with special specimen preparation*

The following sections comprise an explanation of this new method, the experimental programme to verify its impact on f_h as well as the gained test results and the proposals to modify the present approaches for determining f_h.

3 MATERIALS AND METHODS

3.1 OVERVIEW OF THE TEST PROGRAM

Inspired by the test program of Gstettner [3] an additional program in order to determine the influence of the specimen preparation process on the embedment strength (f_h), especially for α = 0°and ε = 90° was carried out. Next to a variation of the inner thread diameter (d_i) and the tip features, also the influence on the embedment strength (f_h) of three different application cases AC = {h | m | t} was investigated. Within each single test series, a minimum number of n = 18 tests was planned. The test program is shown in Table 1.

Table 1: *Overview of the test program, including the planned number of tests (n) within the test series*

⇩ Screw Type	AC ⇨	(h)	(m)	(t)
StarDrive	6.0 x 160	n = 18	18	18
RAPID®	8.0 x 220	18	18	18
RAPID®	8.0 x 240	18	18	18
RAPID®hardwood	8.0 x 320	18	18	18

3.2 MATERIALS

3.2.1 Timber Specimen

Due to its widely use in timber engineering and its status as a reference material in fastener testing, see EAD 130118-01-0603 2019 [5], pre-graded and kiln-dried structural timber lamellas with strength grade C24 acc. EN 338 [6] were used as a test material. They comprised a mix of Norway Spruce (*Picea Abies, Pinaceae*) and European Fir (*Abies Alba, Pinaceae*). Due to their similar mechanical properties, both wood species are treated as one assortment in practise. Within those lamellas, sections, free from any local growth characteristics (knots, pitch pockets, etc.) were used to gain high-quality preliminary timber specimen (t_{pre} = 40 mm), which were thereafter conditioned at 20 °C and 65 % relative humidity in order to reach an equilibrium moisture content u = 12 % according to SC 1 [1].
The dimensions $\{l_{(\alpha,\varepsilon,d)} \mid w_{(\alpha,\varepsilon,d)} \mid t_{(\lambda,d)}\}$ of the finished solid timber specimen are based on the regulations of EN 383 [4] for bolts and dowels, applicated in solid timber or wood-based panels, depending on the axis-to-grain angle α = {0° | 90°}, the nominal fastener diameter (d), as well as the slenderness (λ) as an ratio between the specimen-thickness (t) and the nominal fastener diameter (d). For specimen with {α = 0° | ε = 90°}, i. e. the load is applicated parallel to grain, while screw insertion is perpendicular to grain, EN 383 [4] proposes a specimen width $w_{(\alpha=0,d)} = 2\,a_1$, a length $l_{(\alpha=0,d)} = l_1 + l_2$ and a corresponding thickness $t = \lambda \cdot d$. To avoid fastener bending and to ensure embedding as a failure mode solely, λ was defined with 2. To prevent the specimen from further in-grain splitting during test execution, initiated throughout the screw application, additional 2 d were added to the distance to the loaded end (l_1). It is worth mentioning, that this setting was equal to the one by

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Gstettner [3], enabling comparability to his investigations without this special form of specimen preparation. The final dimensions of the specimen are given in Table 2.

Table 2: *Dimensions of the finalised timber specimens*

	EN 383 [4]	Gstettner [3]
a_1 (unloaded edge)	$\geq 3\ d$	$7\ d$
l_1 (loaded end)	$\geq 10\ d$	$(10 + 2)\ d$
l_2 (unloaded end)	$\geq 10\ d$	$10\ d$
t (thickness)	$(1.5 \div 4)\ d$	$2\ d$

In general, the new and improved specimen preparation process is based on the assumption, that the initial cracking mainly depends on the specimen thickness, see section 2. In order to enable screw insertion in a timber specimen with sufficient (practical) thickness to prevent initial cracking (t_{pre} = 40 mm) and to enable screw testing with the desired thickness according to EN 383 [4] ($t = \lambda \cdot d$), four major steps (A ÷ D), independent of the screw insertion {h | m | t}, were executed. Apart from a pre-drilling with a drill bit ($d_d = d + 2$ mm), which simplifies the removing of the slab (A) and the application of the self-tapping screw without predrilling thereafter (B), several circular saw cuts were carried out (C). For a perfect alignment of the self-tapping screw a specific template was used. To prevent the saw blade hitting the fastener, a safety distance was essential; the remaining wood material was removed with a chisel to complete the specimen preparation procedure (D), see Figure 3.

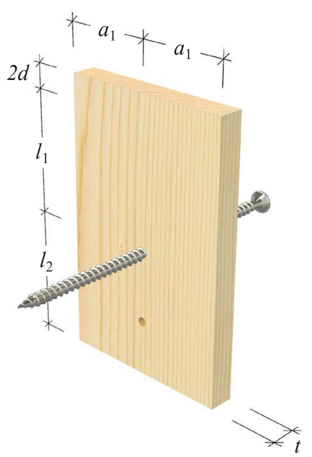

Figure 3: *Specimen dimensions, inspired by EN 383 [4]*

In order to cover the determination of the embedment strength f_h and to test a realistic application scenario of self-tapping screws without predrilling for three different cases {h | m | t}, different specimen application cases were carried out, see Figure 4. Whereas within case (h) the initial crack appears head-sided, i. e. the slab is removed on the side of the tip (see Figure 4, step A, highlighted **in blue**), both slabs are cut off for case (m), i. e. no initial crack occurs on both sides and for case (t) the initial crack occurs tip-sided, therefore the slab is head-sided removed (see Figure 4, step A, highlighted **in green**).

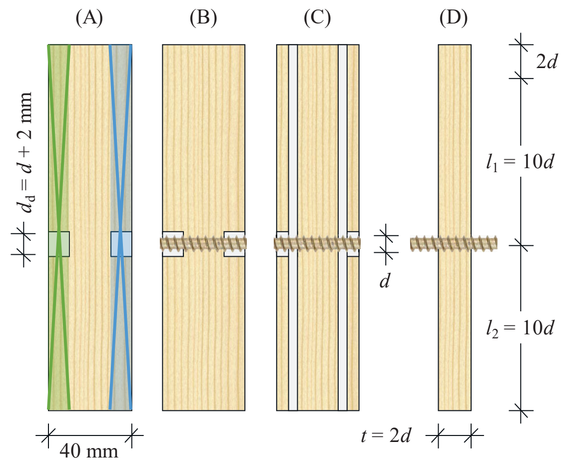

Figure 4: *Manufacturing process of the specimen*

3.2.2 Self-tapping screws

A self-tapping screw can be characterized as a hardened and coated carbon-steel rod, which consists of a head-part (h) including the drive, a middle member (m) with its thread and/or shank, as well as the tip (t), which are mostly equipped with varying features (*tf*). In the frame of the present investigation, four different screw types (ST1 ÷ ST4) according to ETA-12/0373 [7] were investigated, see Table 3 and Figure 5.

Table 3: *Thread specifications acc. to ETA-12/0373*

	d	d_i	P	l_t	tf
ST1	6.0 ±0.30	3.8 ±0.19	2.6 ±0.26	7.3 ±1.9	–
ST2	8.0 ±0.40	5.2 ±0.26	3.8 ±0.38	8.2 ±2.1	✓
ST3	8.0 ±0.40	5.2 ±0.26	3.8 ±0.38	8.2 ±2.1	✓
ST4	8.0 ±0.40	6.1 ±0.31	4.0 ±0.40	11.6 ±2.6	✓

Those differ once in their (nominal) outer thread diameter (d), inner thread diameter (d_i), thread pitch (p), tip-characteristics, including special tip-features (*tf*) and the coating; the latter responsible for corrosion-protection and added for easy application.

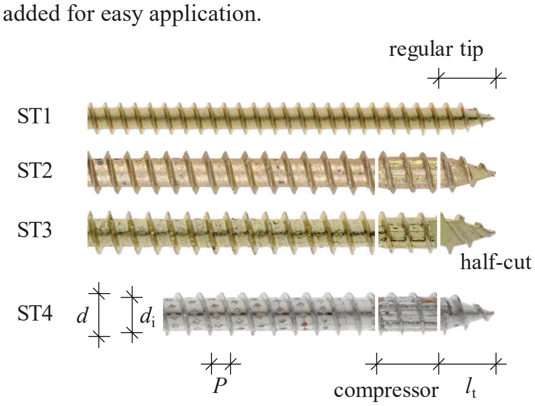

Figure 5: *Classification of self-tapping screws with their individual tip-characteristics (top to bottom: ST1 to ST4)*

Whereas the screw types ST1 ("StarDrive", $d_i = 3.8$ mm) and ST2 ÷ ST3 ("RAPID®", $d_i = 5.2$ mm) are designed for application in softwood, ST4 ("RAPID®hardwood") with $d_i = 6.1$ mm is especially, but non-exclusively seen for application in hardwood. ST2 to ST4 are equipped with a tip-compressor, which shall decrease the insertion moment. While the tip characteristic of ST3 provides a half-cut, all other screw types are designed with a regular tip (see Figure 5).

3.3 TEST–SETUP AND EXECUTION

In order to determine the embedment strength f_h of laterally loaded self-tapping screws, full-hole embedment tests following EN 383 [4] were carried out. The test setup consisted of two load-bearing steel brackets ①, which were connected rigidly with the universal test rig lignum_uni_275 ② (ZwickRoell GmbH & Co. KG), see Figure 6. The timber specimen with its already applicated screw was thereby embedded in steel clamps ③, in which the shape of the screw-thread had been removed by milling in order to guarantee a perfect bearing during testing. To minimize fastener bending, the distance between the steel brackets and the specimen was kept as low as possible; only to allow a free side-deformation of the timber specimen. While testing, the force transmission between the test rig and the timber specimen was realized throughout a custom-made adapter ④, which was made of beech plywood. The local displacement measurement was realised by two displacement transducers ⑤ (type WA-L), which were aligned symmetrically to the test axis. Thereby the interaction between the test specimen and the transducers was achieved by a dowel ⑥.

Figure 6: *Image of the test-setup ST1 with its single steel-components; configuration {α = 0° | ε = 90°}*

With regard to the test execution, all tests were performed acc. to EN 383 [4], but without the recommended hysteresis loop. The max. test load should be reached within 300 ±120 s and is defined as $F_{max,i} = \max\{F_{w=5,i} \mid F_{max,w<5,i}\}$.

3.4 POST-PROCESSING

The embedment strength $f_{h,i}$ was calculated acc. to EN 383 [4] by the following Equation (1).

$$f_{h,i} = \frac{F_{max,i}}{d \cdot t_{i,sp}} \quad \left[\frac{N}{mm^2}\right] \tag{1}$$

Thereby, the specimen thickness $t_{i,sp}$ was determined after the test execution of every single specimen.

As main indicators of strength and stiffness properties, the timber density $\rho_u = m_u / V_u$ acc. to ISO 3131 [8] and the moisture content $u = (m_u - m_0) / m_0$ acc. to EN 13183-1 [9] of each specimen were determined using a small piece of the test specimens, taken next to the applied screw (see Figure 3). Minor
deviations of the moisture content, influencing the wood density were adjusted by using Equation (2) acc. to EN 384 [10].

$$\rho_{12} = \rho_u \cdot (1 - 0.005 \cdot (u - u_{12})) \quad \left[\frac{kg}{m^3}\right] \tag{2}$$

whereas ρ_{12} is the moisture adopted timber density, ρ_u the timber density, determined immediately after testing, u the corresponding moisture content and $u_{12} = 12$ % the reference moisture content.
The embedment strength of every test series including a certain number of specimen n was subjected to an outlier adjustment ($\bar{n}$), see Gstettner [3].

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4 RESULTS AND DISCUSSION

4.1 TIMBER DENSITY | MOISTURE CONTENT

An overview of the main statistics for physical timber properties, such as the moisture content (u) and the wood density (ρ_{12}) is given in Table 4.

Table 4: *Main Statistics of physical timber properties*

	AC	$n = \bar{n}$	u_{mean}	$\rho_{12,mean}$	CoV[ρ]
		[-]	[%]	[kg/m³]	[%]
ST1	(h)	18	10.7	412	6.6
ST1	(m)	18	11.4	406	4.1
ST1	(t)	19	11.0	414	5.2
ST1	**–**	**18**	**13.3**	**406**	**4.03**
ST2	(h)	18	12.1	414	7.6
ST2	(m)	17	12.0	408	5.6
ST2	(t)	18	12.0	413	6.3
ST3	(h)	18	12.0	416	5.9
ST3	(m)	18	12.2	411	4.7
ST3	(t)	20	11.9	413	5.4
ST3	**–**	**19**	**12.7**	**417**	**5.61**
ST4	(h)	18	11.9	409	7.3
ST4	(m)	16	12.0	420	7.0
ST4	(t)	17	12.3	409	5.8
ST4	**–**	**19**	**13.3**	**412**	**4.58**

☐ research results of Gstettner [3]

For all test series, an average moisture content of $u = 12$ % (SC 1 acc. to EN 1995-1-1 [1]) was tried to reach. As a result, there are comparable moisture contents u_{mean} within the new series, while for the ones of Gstettner [3], higher moisture contents were observed. A longer storage of the new specimens under standard climate conditions (app. 2.2 years), led to a better converge to $u_{SC1} = 12$ %, as assumed. Regarding the timber density $\rho_{12,mean}$ a good match to $\rho_{mean,C24} = 420$ kg/m³ acc. to EN 338 [6] can be observed for all considered test series.

4.2 EMBEDMENT STRENGTH

In Table 5, the main statistics of f_h of the new test series are given in dependence of the screw type (ST1 to ST4) and compared with the reference ones of Gstettner [3]. Therefore, the ratio η according to Equation (3) is used to draw precise conclusions; here $f_{h,mean}$ is the average embedment strength of the test series with varying application cases {h | m | t} and screw types (ST1 ÷ ST4) while $f_{h,ref,mean}$ acts as a reference strength, taken from Gstettner [3].

$$\eta = \frac{f_{h,mean}}{f_{h,ref,mean}} \quad [-] \tag{3}$$

Table 5: *Main statistics of the embedment strength (all test series), including the research results of Gstettner [3]*

	AC	*d*	d_i	*tf*	$\bar{n}$	$f_{h,mean}$	CoV[f_h]	η
		[mm]	[mm]		[-]	[N/mm²]	[%]	[-]
ST1	(h)	6	3.8	–	16	19.89	10.8	1.26
ST1	(m)	6	3.8	–	16	17.94	13.0	1.16
ST1	(t)	6	3.8	–	17	17.36	15.0	1.12
ST1	**–**	**6**	**3.8**	**–**	**19**	**15.61**	**12.0**	**1.00**
ST2	(h)	8	5.2	✓	18	18.95	8.7	–
ST2	(m)	8	5.2	✓	15	19.77	7.5	–
ST2	(t)	8	5.2	✓	20	18.03	9.9	–
ST3	(h)	8	5.2	✓	19	22.53	12.0	1.11
ST3	(m)	8	5.2	✓	18	22.40	11.2	1.10
ST3	(t)	8	5.2	✓	17	21.47	11.6	1.05
ST3	**–**	**8**	**5.2**	**✓**	**19**	**20.44**	**10.51**	**1.00**
ST4	(h)	8	6.1	✓	17	16.37	14.1	1.17
ST4	(m)	8	6.1	✓	16	16.59	13.2	1.19
ST4	(t)	8	6.1	✓	17	15.27	16.4	1.09
ST4	**–**	**8**	**6.1**	**✓**	**17**	**13.67**	**7.17**	**1.00**

☐ results of Gstettner [3]

First of all, the reference results of Gstettner [3] shall be discussed. In general, Gstettner [3] observed a regressive behaviour of the embedment strength f_h with an increasing screw diameter d. In addition, a significant reduction of the embedment strength was detected once for ST1 and also ST4, which was in fact not expected. It is assumed, that the initial crack forming during the screw application leads to this specific behaviour. ST4 is not equipped with a half-cut and has a higher inner thread diameter $d_i = 6.1$ mm, compared to ST3 ($d_i = 5.2$ mm). In case of ST1, there are no tip-features at all (see Figure 5).

Second and concentrating on the embedment strength as a consequence of the application cases {h | m | t} for all ST, significantly higher values of the embedment strength f_h compared to Gstettner [3] are given. The assumption of a positive effect on the embedment strength f_h by the new specimen preparation process is verified. This positive effect of the specimen preparation process on the embedment strength f_h is shown in Figure 7, exemplarily for ST1.

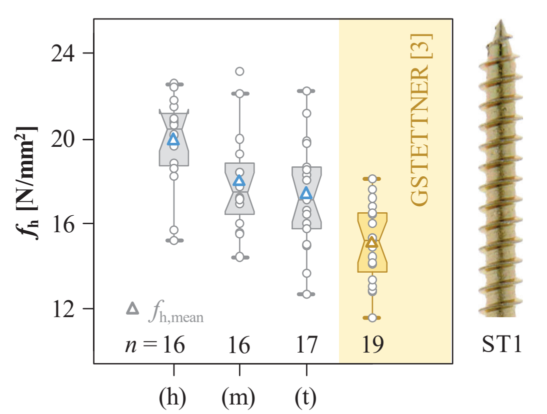

Figure 7: *Boxplot of f_h vs. application case for ST1, {d = 6 mm | d_i = 3.8 mm}*

Whereas the relative size of f_h for the application cases {h | m} of ST2 ÷ ST4 is almost equal, those of ST1 show a notable positive gap. With regard to the difference to the reference results and irrespective of the screw type, the application case (t) has the smallest increase of f_h compared to the results of Gstettner [3].

5 SUMMARY AND CONCLUSION

With focus on the lateral loading of self-tapping timber screws, an experimental research program was carried out to determine their embedment strength f_h. Thus, Gstettner [3] executed embedment tests using thin softwood specimen ($t = 2d$), following EN 383 [4]. Among others, a possible influence of the load-to-grain angle (α), screw axis-to-grain angle (ε), timber density (ρ) and several screw diameter (d) have been investigated. The outcomes of determining the embedment strength f_h for ST3, varying α are exemplarily shown in Figure 8.

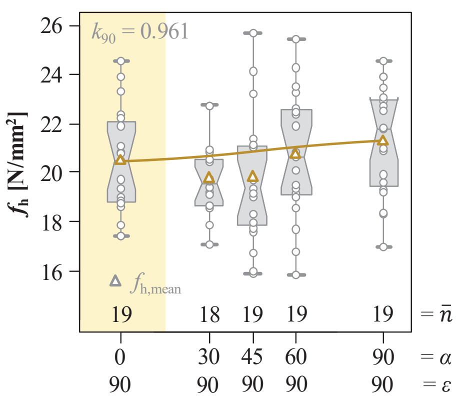

Figure 8: *Boxplot f_h vs. α for ST3, {d = 8 mm | d_i = 5.1 mm}*

Thereby, similar embedment strength (f_h) at a load-to grain angle α = 0°, compared to α = 90° was observed; which stands in a clear contrast to the general assumption of timber as orthotropic material. A negative impact of the specimen preparation and the application of the self-tapping screw without pre-drilling, especially for α = 0°, on the embedment strength (f_h) is assumed as a reason, see Gstettner [3]. Therefore, a new specimen-preparation process was developed, in order to disable an unwanted and negative influence of initial crack forming on the embedment strength. f_h, see section 3.2.1.

Within this experimental research, executed after the one of Gstettner [3], three different application cases, using various self-tapping timber screw types have been investigated. Whereas in application case (h) the initial crack appears head-sided and within (t) tip-sided, no initial cracks occur within the application case (m). In fact, a remarkable impact of the new and improved specimen preparation process on the embedment strength f_h, i. e. independent of all application cases {h | m | t} and the screw types {ST1 ÷ ST4} was observed, see Table 5. With focus on the application cases (h) and (m), barley no difference of the embedment strength f_h was observed, whereas in the case (t), where the initial crack occurs tip-sided, f_h converges to the test results of Gstettner [3]. Furthermore, with focus on the different screw types with their individual tip-features and different inner thread diameters (d_i), a significant influence on the embedment strength f_h was observed.

On this basis the following proposals can be made: Since the new and approved specimen preparation process led to significant increased embedment strengths f_h, an implementation of the specimen preparation procedure in the current standards EAD 130118-01-0603 2019 [5] and EN 14592 [11] is recommended. Whereas Gstettner [3] proposes a $k_{90} \approx 1.0$, for self-tapping screws with their individual tip characteristics and inner thread diameters (d_i), following ETA-12/0373 [7] for practical purpose, a factor k_{90}, see equation (4) and (5), considering the increase of the embedment strength f_h due to this new and improved specimen preparation is recommended.

$$f_{h,\alpha} = (k_{90} \cdot \cos(\alpha)^2 + \sin(\alpha)^2) \cdot f_{h,90} \tag{4}$$

$$k_{90} = \begin{cases} 1.10 & \text{for timber member head-sided} \\ 1.20 & \text{for timber-member tip-sided} \end{cases} \tag{5}$$

Thereby, k_{90} for head-sided timber members is determined throughout a minimum (see Figure 9), comprising the application cases (h) and (t).

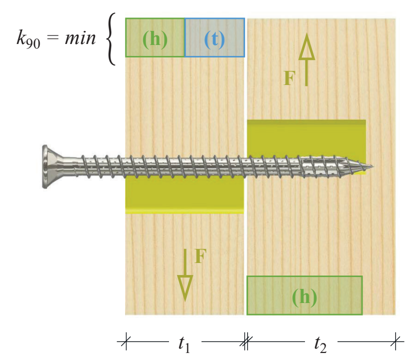

Figure 9: *Exemplary sketch of a timber-to-timber connection, executed with self-tapping screws*

It is worth mentioning, that the size of the embedment strength f_h was found to highly depend on the individual screw type, equipped with several tip-features and varying thread designs. Thus, a general applicability of k_{90}, shown in this contribution, can not be guaranteed. Therefore, further research work, also including a verification of α ≠ 0° is recommended, since it is assumed, that the initial crack forming does not influence at least specimen with α = 90°.

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REFERENCES

[1] EN 1995-1-1 +AC, A1, A2: Eurocode 5: Design of timber structures – Part 1-1: General – Common rules and rules for buildings. ASI, 2015-06.

[2] Blaß H.J, Bejtka I, Uibel T: Tragfähigkeit von Verbindungen mit selbstbohrenden Holzbauschrauben mit Vollgewinde. In: Karlsruher Bericht zum Ingenieurholzbau, 2006. (in German).

[3] Gstettner M: Experimentelle Untersuchung des Tragverhaltens lateral beanspruchter, selbstbohrender Holzbauschrauben, Master thesis, Institute of Timber Engineering and Wood Technology, Graz University of Technology, 2019. (in German).

[4] EN 383: Timber structures – Test methods – Determination of embedment strength and foundation values for dowel type fasteners, 2007-01.

[5] EAD 130118-00-0603: European Assessment Document – Screws for use in timber constructions. 2016-10.

[6] EN 338: Structural timber – Strength classes, 2016-06. ETA-12/0373: Screws for use in timber constructions. Vienna: OIB, 2016-04.

[7] ETA-12/0373: Screws for use in timber constructions. Vienna: OIB, 2022-03.

[8] ISO 3131: Wood – Determination of density for physical and mechanical tests, 1995-01.

[9] EN 13183-1: Moisture content of a piece of sawn timber – Part 1: Determination by oven dry method, 2002-02.

[10] EN 384: Structural Timber – Determination of characteristic values of mechanical properties and density, 2016-08.

[11] EN 14592: Timber structures – Dowel-type fasteners – Requirements, 2017-06.

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