

Properties of Axially-Loaded Self-Tapping Screws with Focus on Application in Hardwood

Forum Wood Building Nordic

“Advanced Processes for Enhanced Performance”

25th-27th September 2019 | Helsinki, FI

Reinhard Brandner

Graz University of Technology

Institute of Timber Engineering and Wood Technology | Graz | Austria

Content

- Introduction & Motivation
- Tests on Single Screws
- Tests on Groups of Screws
- Conclusions

Introduction & Motivation

Introduction & Motivation

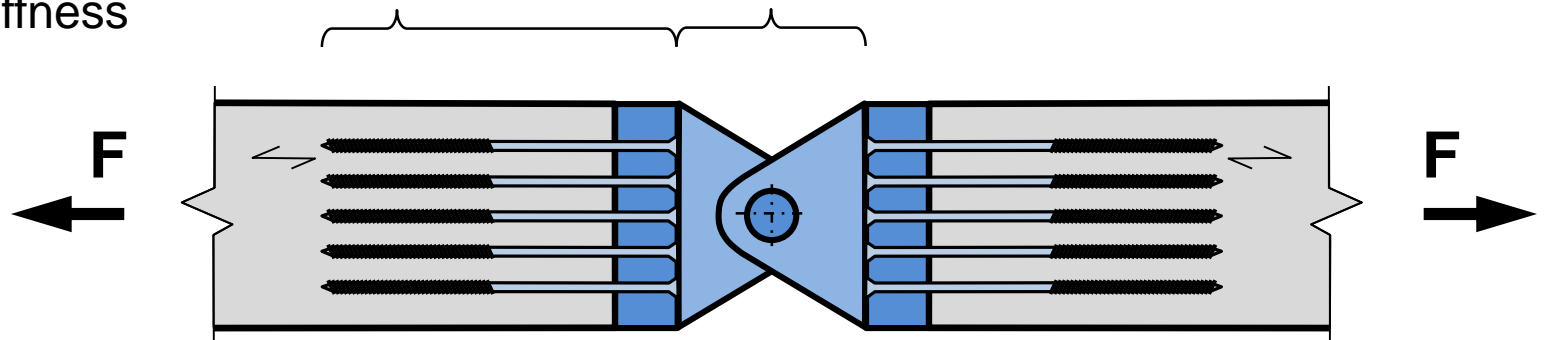
- **increasing availability** of hardwood !
 - **high performing** hardwood products optimal for linear & spatial light-weight framed structures !
- high performance needs to be maintained also at the joints !
- **economic & efficient joint solutions required !**

pre-assembled steel-timber joint

- high capacity
- high stiffness

steel-steel site-joint

- high ductility



Introduction & Motivation

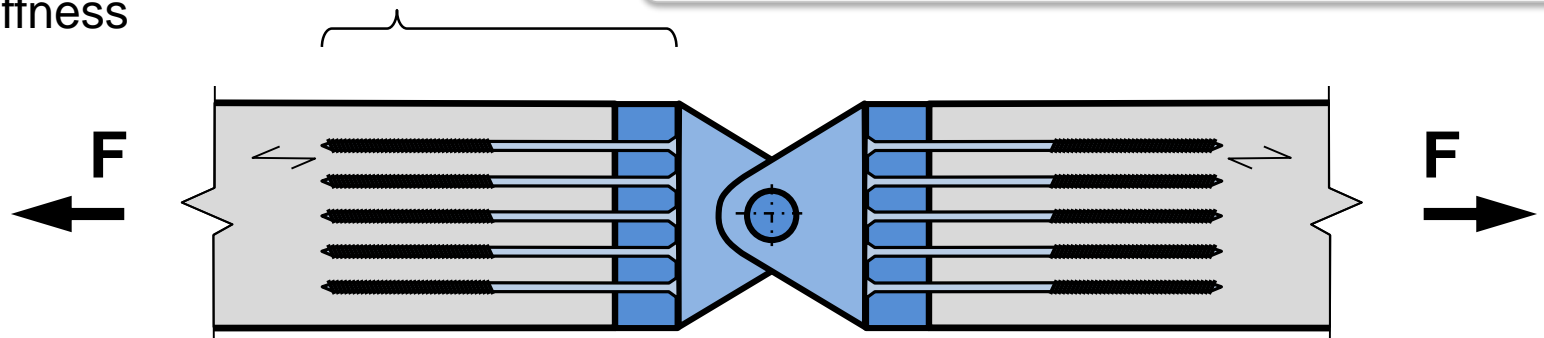
- **increasing availability** of hardwood !
 - **high performing** hardwood products optimal for linear & spatial light-weight framed structures !
- high performance needs to be maintained also at the joints !
- **economic & efficient joint solutions required !**

pre-assembled steel-timber joint

- high capacity
- high stiffness

FOCUS steel-timber joint

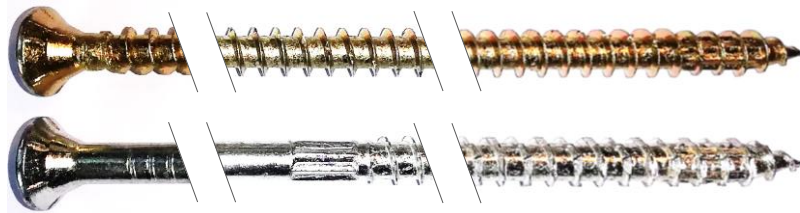
- high capacity
- withdrawal & screw tension failure modes
- prevention of brittle group failure modes
→ geometric constraints



Tests on Single Screws

Steel Capacities of Single Screws: Benchmark

torque ($M_{\text{tor,max}}$) & tensile capacity ($F_{\text{tens,max}}$) of screws



ST1 RAPID ®

ST2 RAPID ® Hardwood

| d [mm] | d ₁ [mm] |
|-----------|------------------------|
| 8.0 | 5.20 |
| 8.1 | 6.08 |

ETA-12/0373 (2017) Schmid Schrauben Hainfeld GmbH

| screw type | max. tensile capacity | | max. torque | |
|------------|-----------------------|---------------------------------|-------------|--------------------------------|
| | no. [-] | $F_{\text{tens,max,mean}}$ [kN] | no. [-] | $M_{\text{tor,max,mean}}$ [Nm] |
| ST1 | 10 | 26.8 (100 %) | 10 | 28.8 (100 %) |
| ST2 | 10 | 36.5 (+ 36 %) | 10 | 43.8 (+ 52 %) |

Tests on Single Screws

withdrawal capacity ($F_{ax,max}$)

AIM: $F_{ax,max} \rightarrow f$ { density ρ ; wood anatomy group; thread-grain angle α ; application condition }

common par.

- $\alpha = 0^\circ, 90^\circ$ (rad.)
- BE, BB
- ST1, ST2
- $\cong 20$ spec. each
- $l_{ef} = 50$ mm

G01: wood anatomy

- SW: Norway spruce (NS-A, NS-B, NS-C)
- RP: sweet chestnut (SC), oak (OA), ash (AS)
- DP: black poplar (BP), birch (BI), beech (BE)

G02: thread-grain angle

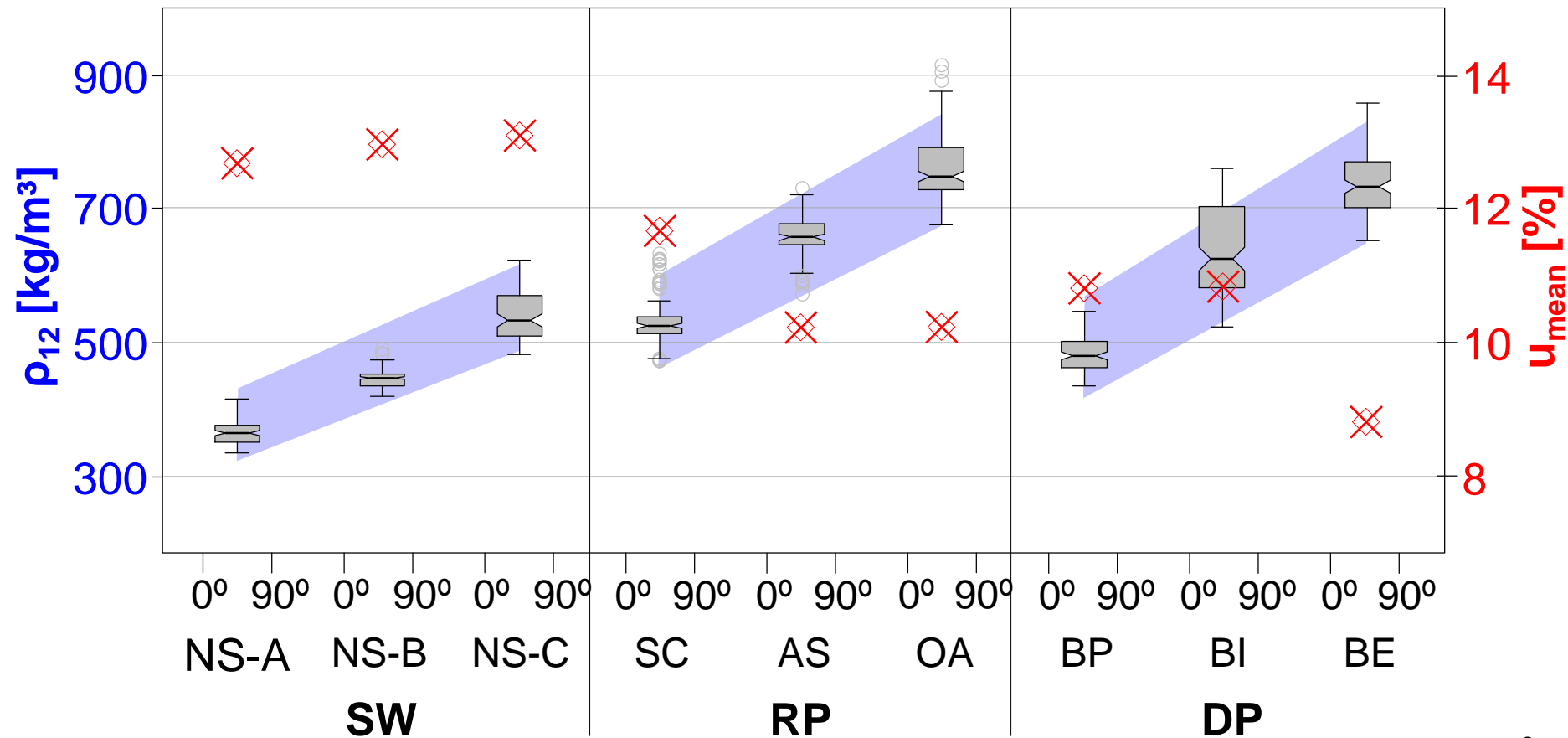
- $\alpha = 0^\circ, 15^\circ, 30^\circ, 45^\circ, 90^\circ$

G03: predrilling

- nPD, 5.5, 6.0, 6.5, 7.0 mm

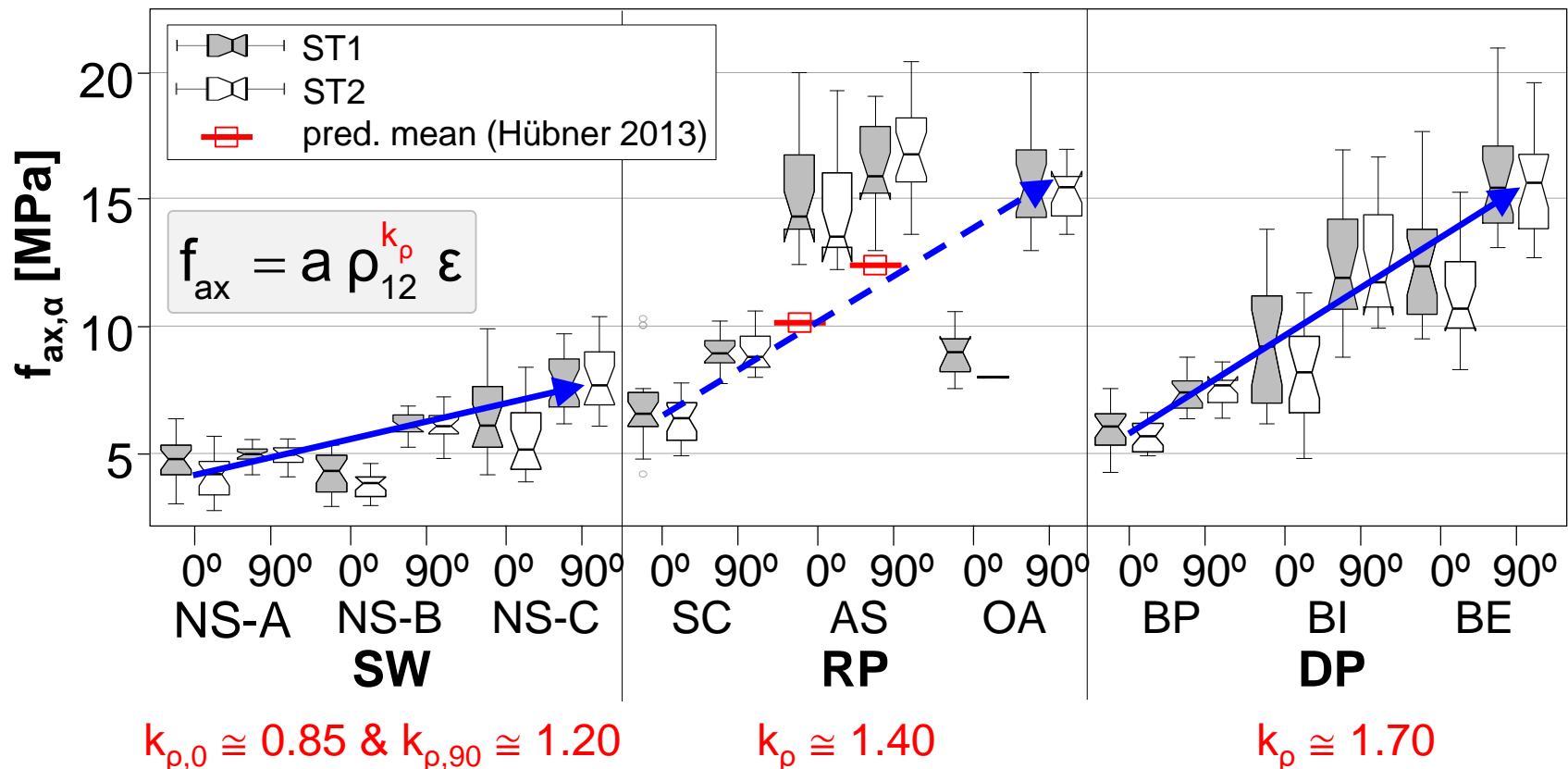
G01 – Wood Anatomy: Density & Moisture

- apart from BE, moisture content $u_{\text{mean}} \cong 12 \pm 2 \%$
- density ρ_{12} within & between wood anatomy groups well distributed



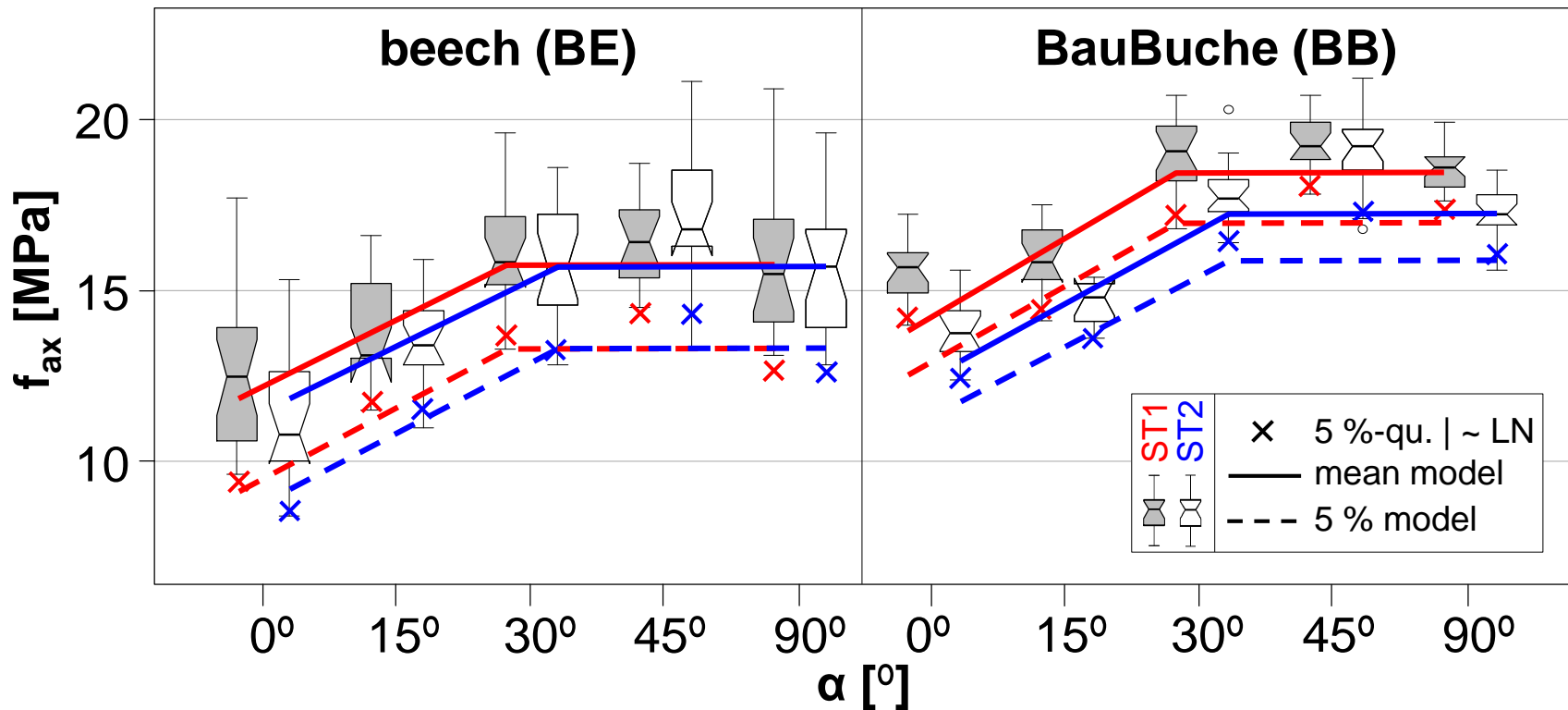
G01 – Wood Anatomy: Withdrawal Strength

- OA below (splitting !) & AS above expectation !
- at $\alpha = 90^\circ$, ST2 similar; at $\alpha = 0^\circ$, 10 % below ST1 !
- f_{ax} vs. ρ_{12} comparable with prev. outcomes & higher than regulated !
(e.g. Newlin & Gahagan 1938; McLain 1997; Schneider 1999; Hübner 2013; a. o.)



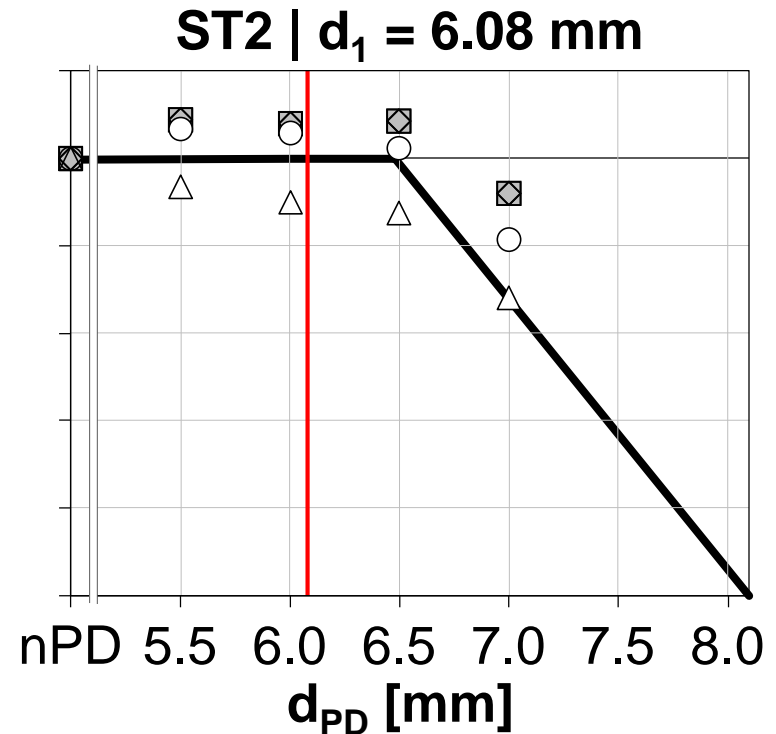
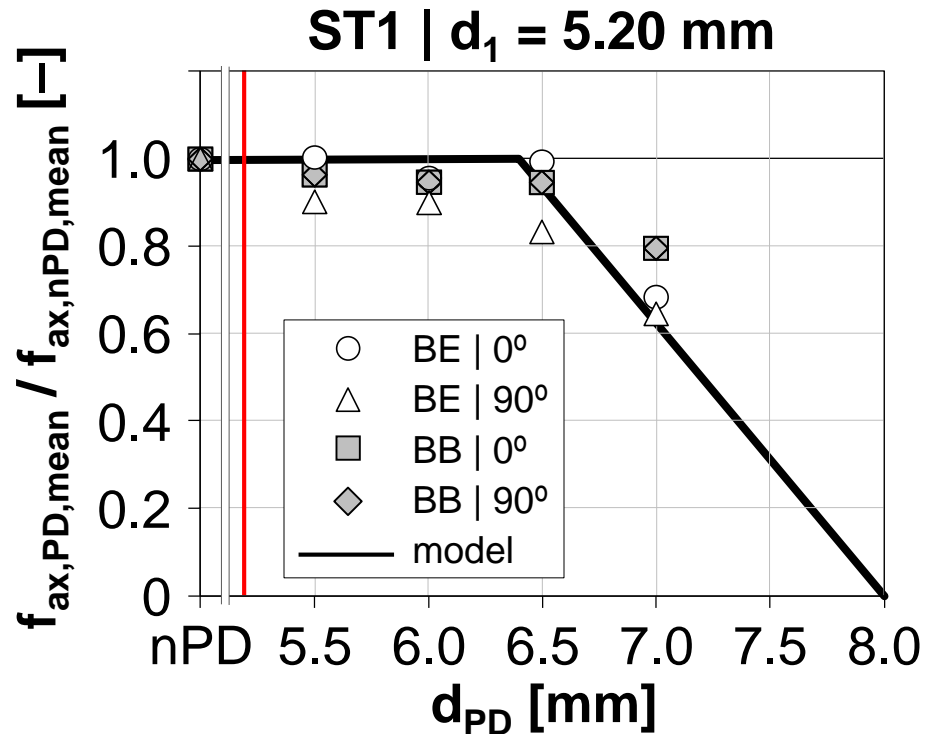
G02 – Thread-Grain Angle α

- bi-linear model with inflexion at $\alpha = 30^\circ$ proposed ! (see also Hübner 2013)
- $f_{ax,0,05} / f_{ax,90,05} = 0.70$ comparable with prev. findings !



G03 – Predrilling

- $d_{PD} \leq 6.5$ mm allows to maintain withdrawal properties at nPD !
→ proposal: $d_{PD,max} = \min \{ 0.8 d; d - 1.5 \text{ mm} \}$
- predrilling eliminates differences between ST2 & ST1 at $\alpha < 30^\circ$!



Generic Model for Withdrawal Strength of Single Self-Tapping Screws

SW & HW $k_{ax,05} = \begin{cases} 1.0 & 30^\circ \leq \alpha \leq 90^\circ \\ 0.70 k_{gap,05} + \alpha \frac{1 - 0.70 k_{gap,05}}{30} & 0^\circ \leq \alpha \leq 30^\circ \end{cases}$

$k_{gap,05} = \begin{cases} 0.90 & \text{CLT narrow face} \\ 1.00 & \text{else} \end{cases}$

$f_{ax,05} = f_{ax,ref,05} k_{ax,05} k_{sys,05} \left(\frac{\rho_{05}}{\rho_{ref,05}} \right)^{k_p}$

$k_p = \begin{cases} 1.10 & \text{SW \& } 15^\circ \leq \alpha \leq 90^\circ \\ 1.25 - 0.05 d & \text{SW \& } 0^\circ < \alpha < 15^\circ \\ 1.40 & \text{RP \& } 0^\circ \leq \alpha \leq 90^\circ \\ 1.70 & \text{DP \& } 0^\circ \leq \alpha \leq 90^\circ \end{cases}$

$f_{ax,ref,05} = \begin{cases} 0.0130 \rho_{ref,05}^{1.10} d^{-0.33} & \text{SW} \\ 0.0029 \rho_{ref,05}^{1.40} d^{-0.33} & \text{RP} \\ 0.0004 \rho_{ref,05}^{1.70} d^{-0.33} & \text{DP} \end{cases}$

$k_{sys,05} = \begin{cases} 1.0 & \text{structural timber; } n = 1 \\ 1.10 & \text{CLT side face; } n \geq 3 \\ 1.13 & \text{GLT; } n \geq 5 \end{cases}$

Tests on Groups of Screws

Aim & Fixed Parameters

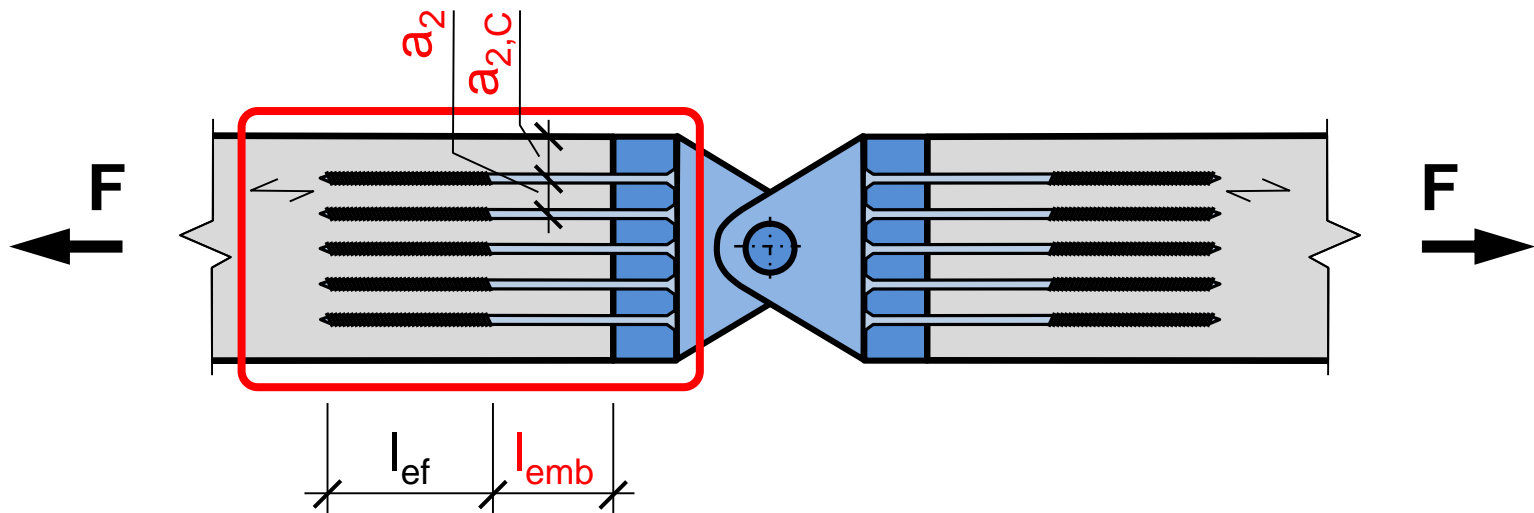
AIM

geometric conditions for end-grain joints | $n_{ef,mean} = n$

→ f { min. edge-dist. $a_{2,C}$; spacing a_2 ; thread emb. length l_{emb} }

fixed parameters

- ST2
- BE & BB
- $\alpha = 0^\circ$



Insertion & Withdrawal Tests

→ a_2 & $a_{2,C}$ & l_{emb} without splitting

→ a_2 & $a_{2,C}$ halved when predrilled !

→ thread embedment $l_{emb} = 2$ d reduces a_2 (– 1 d) !

→ BB: a_2 in radial & tangential direction different ($a_{2,rad} = a_{2,tan} + 2$ d) !

→ a_2 & $a_{2,C}$ from insertion tests overall lower than from withdrawal tests !

| species / product | l_{emb} [d] | insertion tests | | | withdrawal tests | | |
|-------------------|---------------|-----------------|-------|-----------|------------------|-------|-----------|
| | | nPD | PD | | nPD | PD | |
| | | $a_{2,C}$ | a_2 | $a_{2,C}$ | a_2 | a_2 | $a_{2,C}$ |
| BE | 0 d | 2.5 d | → | 1.25 d | >> 5 d | → 3 d | >> 1.5 d |
| | 2 d | – | – | – | – | → 2 d | >> 1.5 d |
| BB (rad.) | 0 d | 3.75 d | → 2 d | 2 d | – | → 5 d | 3 d |
| | 2 d | – | – | – | – | → 4 d | 3 d |
| BB (tang.) | 0 d | 3.75 d | → 2 d | 2 d | – | → 3 d | 3 d |

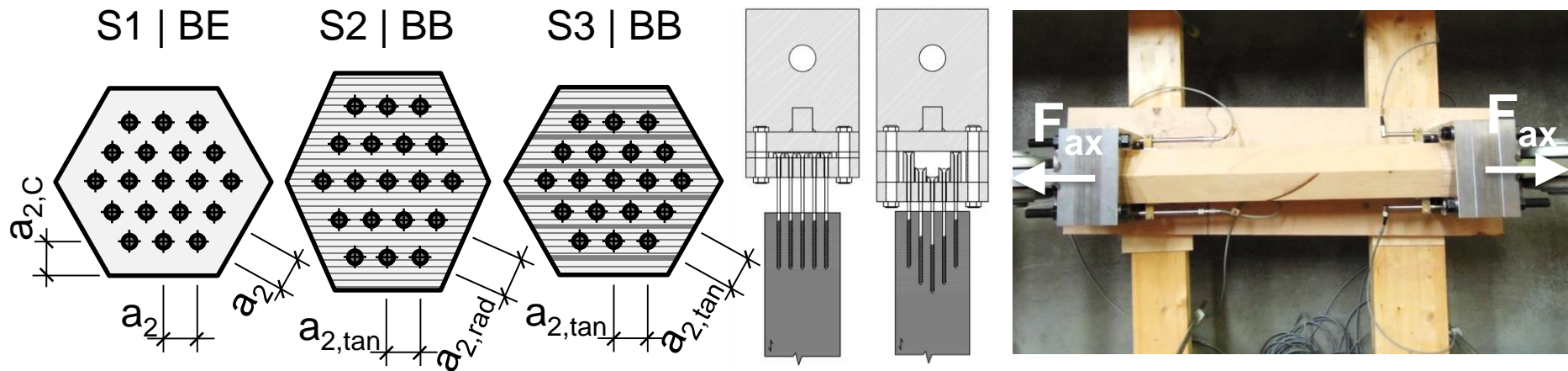
Tests on End-Grain Joints: Aim & Settings

investigations (pull-pull; $n = 19$; predrilled)

→ AIM: withdrawal without splitting

→ fixed parameters: $a_{2,C} = 3 d$; $l_{emb} \geq 2 d$; $a_{2,BE} = a_{2,BB,tan} = 3 d$; $a_{2,BB,rad} = 4 d$

→ varied parameters: (i) product, (ii) thread embedment (length & shape)



Tests on End-Grain Joints: Results



failure m.

split.

split.

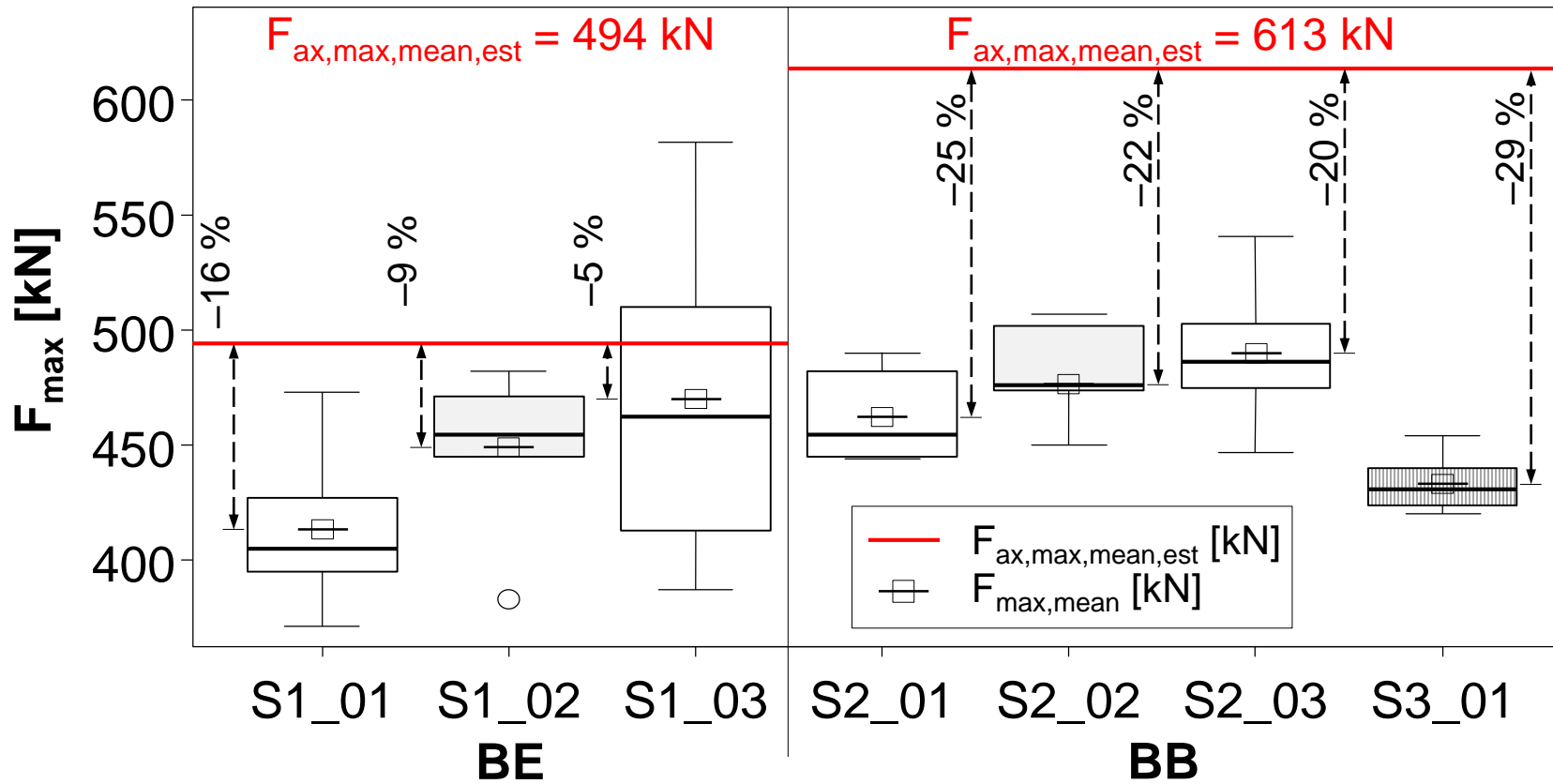
withdr.

split.

split.

spl./wi.

split.



Conclusions

Conclusions

▪ ST2 vs. ST1

- $M_{tor,max} + 52\%$ & $F_{tens,max} + 36\%$
- f_{ax} at $\alpha > 30^\circ$ similar, $\leq 30^\circ$ 10% lower
- optimised for hardwood but also highly efficient in softwood !

▪ generic model for f_{ax} in SW & HW !

- applicable for structural timber & struct. timber based products
- accounts for sign. higher f_{ax} in hardwood !

RAPID® Hardwood (ETA-12/0373)

RAPID® Hardwood
Ready for the future today

Schmid
schrauben hainfeld

Milling pockets

New friction part

Single thread

Compactor tip

Dimensions

Stocked sizes:
Ø 8 x 120mm
Ø 8 x 160mm (also washer head)
Ø 8 x 200mm
Ø 8 x 240mm
On request: Ø 8 x 60mm to
Ø 8 x 240mm

> No Pre-Drilling
> World first
> Made in AUSTRIA

BlueWin 700+

22 02/2019

Conclusions

- **predrilling has some excellent advantages !**
 - halved insertion moment already at $d_{PD} = d_1$
 - halved a_2 & $a_{2,C}$ for end-grain joints
 - higher f_{ax} at $\ll \alpha$
 - predrilling might become economical in industrial environments with automated pre-assembling of steel-timber joints !
- **end-grain joints in BE: $n_{ef,mean} = n$ achieved !**
 - application: predrilled
 - geometric requirements: $a_2 = a_{2,C} = 3 d$ & $l_{emb} = 10 d$

Thank You !

Acknowledgements

FFG BRIDGE 1 “**hardwood_SCREWS**” (No. 850748; 10/2015 – 06/2018)

- MA Matthias Pöll (2017)
- MA Tobias Reichinger (2017)
- MA Lothar Koppauer (2017) & MP Birgit Eckerstorfer (2017)

Ass.Prof. Priv.-Doz. Dipl.-Ing.(FH) Dr.techn. Reinhard Brandner

Graz University of Technology | Institute of Timber Engineering and Wood Technology

Inffeldgasse 24/I | 8010 Graz

p: +43 316 873 4605 | f: +43 316 873 104605

reinhard.brandner@tugraz.at