CIB-W18/46-7-4

**INTERNATIONAL COUNCIL FOR RESEARCH AND INNOVATION IN BUILDING AND CONSTRUCTION**

**WORKING COMMISSION W18 - TIMBER STRUCTURES**

# WITHDRAWAL STRENGTH OF SELF-TAPPING SCREWS IN HARDWOODS

U Hübner

Association of the Austrian Wood Industries

AUSTRIA

**Keywords:** connection, screw, withdrawal strength, hardwood, beech, ash, Black Locust

---

Presented by U Hübner

A Frangi commented about the load duration behaviour and different COV as a function of diameter and asked if there were any physical reasons. U Hübner responded that with larger diameter screws reinforcing specimens against splitting perpendicular to grain was needed and that this was a very complicated failure mechanism with mixture of failure modes. Also it was very difficult to distinguish what governed at which angle. Also tests from Graz and Karlsruhe with screws installed parallel to grain and loaded at 70% of the short-term failure load indicated failure within 1 week. More research is needed.

F Lam commented that installation at less than 30 degree parallel to grain can be risky especially in cyclic moisture conditions.

J Munch Andersen commented that in terms of comparison with code equations it would be better to compare with softwood.

J W van de Kuilen commented that the density of hardwood can range from 100 kg/m³ to 1200 kg/m³ and received clarification of the density of wood studied as 550 kg/m³ to 900 kg/m³ as medium density hardwood from central Europe.

H Blass received confirmation that these screws would be intended for reinforcing hardwood and predrilling diameter would not be larger than the core screw diameter. H Blass stated that high insertion moment/torque can develop in the longer screws.

J W van de Kuilen received confirmation that the density dependency model was used for different wood species. He questioned whether the density model worked for only one species, for example, beech. U Hübner responded that calculation model was developed for European Ash first and adding another species increased COV a little and there was not too much difference between species.

J Munch Andersen received confirmation that the graphs were based on mean values.

# Withdrawal strength of self-tapping screws in hardwoods

Ulrich Hübner[a]

**Abstract** The axial withdrawal resistance of self-tapping screws of the diameters 6 mm (Z-9.1-435, 2009), 8 mm (Z-9.1-656, 2007), 10 and 12 mm (Z-9.1-519, 2011) was tested according to ON EN 1382 (1999) in glue laminated timer (GLT) made of European ash (*Fraxinus excelsior* L., $n = 2\,657$) with angles $\alpha$ between the fiber direction and the screw axis of $0°, 15°, \ldots, 90°$. Screws with 4 mm diameter (Z-9.1-435, 2009) and threaded bars ⌀ 20 mm (Z-9.1-777, 2010) according to DIN 7998 (1975) were pulled out parallel and perpendicular to the grain to determine the influence of the diameter over a large range. The influence of the screw tip and the screw embedment length were analyzed. Self-tapping screws of diameters 8, 10 and 12 mm were also pulled out of European beech (*Fagus sylvatica* L., $n = 371$) and Black locust (*Robinia pseudoacacia* L., $n = 300$) parallelly and perpendicularly to the grain.
If the moisture content rises 1 % the withdrawal resistance of screws decrease 2.7 % parallel to the grain and 2.4 % perpendicular to the grain direction. The lower withdrawal resistance of the tip should be considered with $l_{ef} = l_{nom} - 1.1\,d$, where $l_{nom}$ is the inserted nominal length of the screw. The characteristic withdrawal resistance of self-tapping screws in European hardwoods should be calculated for the regular thread with a bilinear design model with a constant resistance from 30° to 90° according to $R_{ax,k} = f_{ax,k}\,\pi\,d\,l_{ef}$ with $f_{ax,k} = 7 \cdot 10^{-4} \cdot \rho_k^{1.6} \cdot d^{-0.34}$ and a linear reduction of 30 % to $\alpha = 0°$. Additionally the thread of partial-threaded screws should be embedded at least $2\,d$ under the surface of the timber for $0° \leq \alpha \leq 30°$. If the summation of characteristic withdrawal resistances was calculated according the new design model for angels of $30°, 45°, \ldots, 90°$, the diameters 6, 8, 10 and 12 mm, the effective lengths of $4\,d$, $5\,d$, $6\,d$ and the characteristic density 672 kg/m$^3$ the result exceeds the solution according to ON EN 1995-1-1 (2009) by a factor of 1.79

## 1 Introduction

GLT made of birch (Griesser, 2012), chestnut (MPA Stuttgart, 2012), European beech (Z-9.1-679, 2011), European ash (Bogusch, 2011) and oak (Z-9.1-704, 2012) but also laminated veneer lumber (LVL) made of European beech (Pollmeier, 2012) was developed. Effective connections should use the impressive performance of these materials.

The design of withdrawal resistance of self-tapping screws according to ON EN 1995-1-1 (2009) is based on tests with spruce. Eckelman (1975), Jablonkay (1999) and Schneider (1999) gave an indication of the capacity of screws in hardwoods but they used old fashioned screws, only one diameter and species respectivelly. Thus it was necessary to analyses a wide range of screw diameters, angles between screw axis and fiber direction with one species (ring porous European ash) and to compare the results with two other species representing different wood anatomies and densities (diffuse porous European beech, ring porous Black locust) in order to create a reliable data base for a new design model.

[a]Association of the Austrian Wood Industries
huebner@holzbauindustrie.at
T +43 (0)1 712 26 01 23

Table 2.1: Ratio of the core diameter and the pitch to the outer diameter for self-tapping screws with a German technical approval (see DIBt, 2012)

| | core to outer diameter [–] | | | | pitch to outer diameter [–] | | | | characteristic tension strength $4\,R_{t,u,k}/\left(\pi d_2^2\right)$ [N/mm²] | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| diameter | 6 | 8 | 10 | 12 | 6 | 8 | 10 | 12 | 6 | 8 | 10 | 12 |
| # of approvals | 35 | 41 | 29 | 14 | 35 | 41 | 29 | 14 | 35 | 40 | 29 | 16 |
| Minimum | 0.60 | 0.63 | 0.60 | 0.57 | 0.37 | 0.42 | 0.39 | 0.36 | 588 | 554 | 567 | 623 |
| Mean | 0.64 | 0.65 | 0.63 | 0.60 | 0.58 | 0.62 | 0.57 | 0.49 | 878 | 862 | 816 | 763 |
| Maximum | 0.72 | 0.68 | 0.69 | 0.71 | 0.82 | 0.81 | 0.75 | 0.55 | 1 110 | 1 477 | 1 027 | 977 |

# 2 Method

The beech and ash logs were harvested in the Austrian region *Bucklige Welt* in the growth area *Östliche Randalpen*. The logs of Black locust came from Zalaegerzeg/Hungary. The ash and Black locust boards (27 mm) were glued with MUF Kauramin 683 and hardener Kauramin 688 to form the GLT. The ash specimens for $15° \leq \alpha \leq 75°$ were sawn from six GLT. The beech scantlings had a section of 60 mm × 120 mm. All specimens were predrilled with diameters equal to the root diameters round down to 0.5 mm. In general the specimens were stored in a climate chamber with (20±2) °C and (65 ± 5) % relative humidity. The influence of moisture contents from 5 to 24 % on the withdrawal strength was investigated parallelly and perpendicularly to the grain direction.

The geometry of the regular thread of the used screws of 4 mm, 6 mm, 8 mm, 10 and 12 mm are repesentative for most of the screws with a German technical approval. The Table 2.1 shows the mean but also minimum and maximum ratios of the core diameter and the pitch of the outer diameter.

The regular spacing and edge distance was 5 $d$. The thickness of the specimens was limited by the tension resistance of the screws and rods. For the diameters 4 to 10 mm the thickness of the specimen was $l_{ef}6\,d$. Screws with ⌀ 12 mm were tested with $l_{ef}4\,d$ and the rods with $l_{ef}8\,d$ The minimum width of specimen for the rods (⌀ 20 mm) was 140 mm. Pilot tests showed the need for reinforcement normal to the rod axis with four or eight screws ⌀ 8/160 mm to prevent splitting (see Figure 3.5)). The density and the moisture content of the hardwood around the screw axis were determined on cuboids $4\,d \times 4\,d \times$ *specimen thickness* to minimize the influence of density variations within the specimens. The moisture content of the specimens was analyzed according to ON EN 13 183-1 (2004).

The withdrawal resistance was tested according to ON EN 1382 (1999) with the diameter of the free surface around the screw of 4 $d$ The influence of radial or tangential screw axis to the annual growth rings was neglected following Cockrell (1933).

The influence of the screw tip and the embedded length were also analyzed. The samples contained in general 60 specimens and for the comparison of mean values 40. The density of the samples were representative for the basic population corresponding to the third method proposed by Leijten, Köhler and Jorissen (2006, p. 9).

# 3 Analysis of the test results

## 3.1 Moisture content and density

The values for the moisture content are listed in Table 3.1. The mean moisture content of the regular specimens is equal to the mois-

Table 3.1: Moisture content of the regular samples

| Species | $n$ [–] | min. [%] | mean [%] | max. [%] | $CoV$ [%] |
|---|---|---|---|---|---|
| Ash | 2 657 | 8.20 | 10.75 | 14.80 | 3.33 |
| Beech | 371 | 10.30 | 11.02 | 11.80 | 1.93 |
| Black locust | 300 | 10.00 | 10.85 | 14.90 | 4.33 |
| All | 3 328 | 8.20 | 10.80 | 14.90 | 3.41 |

Table 3.2: Density $\rho_{12}$ $\left[\mathrm{kg/m^3}\right]$ of the samples

| Species | $n$ [–] | min. | mean | max. | $CoV$ [%] |
|---|---|---|---|---|---|
| Ash | 2 620 | 555 | 746 | 918 | 6.11 |
| Beech | 371 | 582 | 719 | 851 | 6.09 |
| Black locust | 300 | 609 | 750 | 884 | 6.84 |
| All | 3 291 | 555 | 744 | 918 | 6.29 |

ture content of ash in a climate of $(20 \pm 1)\,°\mathrm{C}$ and $(65 \pm 5)$ % relative humidity and desorption of moisture. Adsorption would lead to $u_{\mathrm{mean}} = 13.9\,\%$ as tested with 43 specimens.

Two samples ($n_{\parallel} = 37$, $n_{\perp} = 40$) made of ash were conditioned to a mean moisture content ($u_{\mathrm{mean},\parallel} = 31\,\%$, $u_{\mathrm{mean},\perp} = 27\,\%$) under the fiber saturation point of 33 % according to Popper and Niemz (2009) to analyses the influence of the moisture content on the withdrawal strength parallel and perpendicular to the grain direction. The two paired samples had a mean moisture content of 11 %. The equations (1) and (2) represent the regression lines for the withdrawal resistance versus the moisture content. If the moisture content rises 1 % the withdrawal resistance of screws parallel to the grain direction decreases 2.7 % and perpendicular to the grain 2.4 % relative to the withdrawal resistance at the reference moisture content of $u_{\mathrm{ref}} = 12\,\%$. This relationship was also used to adjust the withdrawal resistance of European beech and Black locust to $u_{\mathrm{ref}}$.

$$R_{\mathrm{ax,mean,0}} = -0.453\,u + 22.2 \tag{1}$$

$$R_{\mathrm{ax,mean,90}} = -0.438\,u + 23.8 \tag{2}$$

The density was adjusted to $u_{\mathrm{ref}}$ according to ON EN 384 (2010, p. 13) and Table 3.2 gives an overview.

## 3.2 Influence of the screw tip

It is obvious that the withdrawal strength of the screw tip is lower than that of the regular thread. Specimens of the same thickness were tested with the tip flush to the surface and outside the specimen. The sample references in Table 3.3 show *ES* for European ash, the screw diameter, the angle between screw axis and grain direction and the thickness of the specimen.

Table 3.3: Samples with screw tip outside or inside the specimens

| tip outside | tip inside | $x_i$ |
|---|---|---|
| ES08_00_48 | ES08_00_48S | 1.28 |
| ES08_90_32 | ES08_90_32S | *2.02* |
| ES08_90_48 | ES08_90_48S | 0.98 |
| ES08_90_64 | ES08_90_64S | *0.76* |
| ES10_00_60 | ES10_00_60S | 1.29 |
| ES10_90_60 | ES10_90_60S | 0.98 |
| ES12_00_60 | ES12_00_60S | 1.00 |
| ES12_90_60 | ES12_90_60S | 1.10 |
| Mean $\bar{x}$ | | 1.11 |

The mean value $\bar{x} = 1.11$ results if the outliers 2.02 and 0.76 in Table 3.3 are excluded and equation (3) was derived to calculate the effective embedment length $l_{\mathrm{ef}}$ based on the nominal embedment length $l_{\mathrm{nom}}$.

$$l_{\mathrm{ef}} = l_{\mathrm{nom}} - 1.11\,d \tag{3}$$

Equation (3) corresponds to the regulation $l_{\mathrm{ef}} = l_{\mathrm{nom}} - d$ in SIA 265 (2003, p. 66), ON EN 1995-1-1 (2006, p. 83), Pirnbacher and Schickhofer (2009, p. 35), Eckelman (1975, p. 35) the rule to subtract the tip length according to Newlin and Gahagan (1938, p. 6). CEN TC124 decided after a discussion over several years with the statement: "For screws it is clearly defined that the point length is included in the threaded length, both in EN 1995-1 and EN 14592. It is decided to have the same rules for calculation of the withdrawal capacity of screws and nails by using the profiled length" (Ravasse, 2011, p. 7). "... all scientists agrees that the truth is that the tip should be disregarded" (Munch-Andersen, 2013). The challenge is a coherent system of test and design standard with logical rules for all dowel-type connectors.

The withdrawal test according to ON EN 1382 (2012) should use specimens with a thickness relative to the diameter of the dowel type fastener because of the influence of the transverse strain near the surface, which can be seen as a systematic error. The penetration depth $l_d$ should only include the regular thread and not the whole profiled part including the tip and eventually the special threads of a reamer shaft.

## 3.3 Influence of the diameter

Screws with diameters of 4, 6, 8, 10 and 12 mm and rods with a thread of ⌀ 20 mm according to DIN 7998 (1975) were pulled out parallelly and perpendicularly to the grain to determine the influence of the diameter on the withdrawal strength of European ash over a large range. Self-tapping screws of diameters 8, 10 and 12 mm with the same technical approvals were also pulled out of European beech and Black locust parallelly and perpendicularly to the grain.

Figure 3.1 shows the normalized ($\rho_{\text{mean}}$, $u_{\text{ref}}$) mean values of the withdrawal strength parallel and perpendicular to the grain for all diameters and wood species. Two different models were used for the regression analysis of the values for ash. The gray curves represent the equations (4) and (5) and the black curves the equations (6) and (7). Power functions are often used to express size effects, but the logarithmic functions leads to more realistic limit-

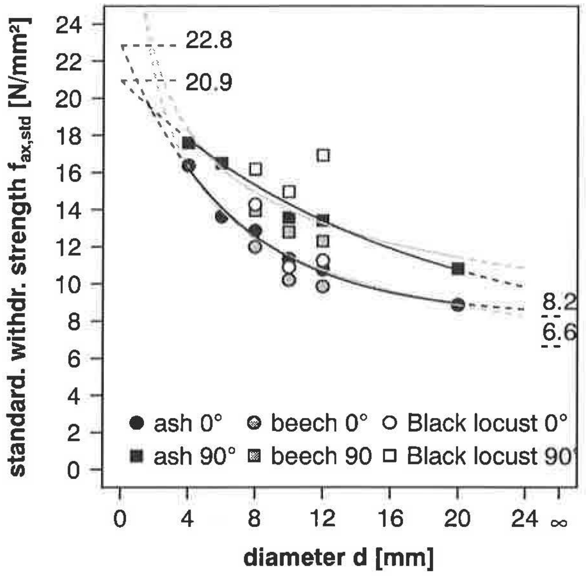



Figure 3.1: Standardized withdrawal strength versus diameter

ing values.

$$f_{\text{ax,0,mean}} = 27.5\, d^{-0.378} \tag{4}$$

$$f_{\text{ax,90,mean}} = 27.3\, d^{-0.291} \tag{5}$$

$$f_{\text{ax,0,mean}} = 8.25 + 14.6\, e^{-0.152\, d} \tag{6}$$

$$f_{\text{ax,90,mean}} = 6.63 + 14.3\, e^{-0.0624\, d} \tag{7}$$

Büeler (2011, p. 22) published $f_{\text{v,mean}} = 6.7\,\text{N/mm}^2$ ($CoV = 16.7\,\%$) for five tests with glulam beams made of European ash (W 140 mm, H 480 or 600 mm, L 1 380 to 2 420 mm). The rupture area due to withdrawal tests parallel to the grain have to be around the screw and not necessarily at the weakest area of the section. This could be the explanation for $\lim_{d\to\infty} f_{\text{ax,0,nrm}} = 8.2\,\text{N/mm}^2 > 6.7\,\text{N/mm}^2$. The gray and white filled circles for the other two species follow the curves for ash. The exception ROB12_90_60 proves the rule.

Finally the regression curve (8) based on a power function was calculated for the 5$^{\text{th}}$ percentiles of the withdrawal strength of all samples for $\alpha = 0°$ and $\alpha = 90°$.

$$f_{\mathrm{ax},05} = 23.3\, d^{-0.340} \tag{8}$$

This exponent of $1 - 0.340 = 0.660$ describes the influence of the screw diameter on the withdrawal resistance. Frese and Blaß (2009, p. 10) published the exponent $1 - 0.3423 = 0.656$ for self-tapping screws in spruce and Rajak and Eckelman (1993, p. 29) $1 - 0.355 = 0.645$ for MDF-panels. Thus the influence of the diameter of $d^{0.66}$ on the withdrawal resistance is reliable for MDF, soft- and hardwoods. The design model for the withdrawal resistance in ON EN 1995-1-1 (2009) emanates from $d^{0.5}$, published in the fundamental work of Bejtka (2005, p. 21) for screws with diameters from 6 to 12 mm. The wider range of diameters from 4 to 20 mm allows a more precise regression analysis.

## 3.4 Withdrawal resistance

Figure 3.2 on p. 6 shows the boxplots of the withdrawal strength at $u_{\mathrm{ref}}$ of all regular samples with European ash. The withdrawal strength decreases with increasing diameter as described in Section 3.3. The black bars of the medians for screws parallel are always lower than for screws perpendicular to the grain direction. The inter quartile range for $\alpha = 90°$ is in general wider than for $30° \leq \alpha \leq 75°$. Table 3.4 indicates the coefficients of variation for all samples including extreme values.

Table 3.4: Coefficients of variation for all samples of withdrawal strength $f_{\mathrm{ax},12}$ for European ash

| dia- | angle screw axis/fiber direction | | | | | | |
|---|---|---|---|---|---|---|---|
| meter | 0° | 15° | 30° | 45° | 60° | 75° | 90° |
| 4 | 13.8 | – | – | – | – | – | 14.7 |
| 6 | 13.0 | 13.9 | 10.7 | 9.2 | 9.4 | 10.1 | 11.8 |
| 8 | 19.4 | 16.3 | 9.8 | 11.0 | 9.8 | 8.1 | 14.3 |
| 10 | 18.5 | 15.6 | 11.1 | 10.9 | 9.2 | 7.7 | 12.2 |
| 12 | 17.1 | 17.1 | 12.6 | 13.3 | 8.7 | 8.4 | 14.6 |
| 20 | 15.2 | – | – | – | – | – | 8.8 |

## 3.5 From regression analysis to design model

The first regression analysis was based on the design model of ON EN 1995-1-1 (2009) for the withdrawal resistance and equation (9) shows the logarithmized version. This was necessary to obtain normal distributed residues with the same variation over the whole diameter range.

$$\ln R_{\mathrm{ax,mean}} = \ln A + B \ln l_{\mathrm{ef}} + C \ln \rho_{12} + \ldots \\ \ldots D \ln d - \ln\left(\sin^2\alpha + E\cos^2\alpha\right) \tag{9}$$

$$\ln R_{\mathrm{ax,mean}} = \ln A + B \ln l_{\mathrm{ef}} + C \ln \rho_{12} + \ldots \\ D \ln d - \begin{cases} \ln\left(1 - E\,(30° - \alpha)\right) & 0° \leq \alpha < 30° \\ 0 & 30° \leq \alpha \leq 90° \end{cases} \tag{10}$$

The standardization of the withdrawal strength of European beech, European ash and Black locust was calculated for the reference values is $\rho_{\mathrm{mean}} = 744\,\mathrm{kg/m^3}$, $d_{\mathrm{std}} = 10\,\mathrm{mm}$ and $l_{\mathrm{ef}} = 60\,\mathrm{mm}$ with the coefficients $B = 0.972$, $C = 1.604$ and $D = 0.666$ of equation (9).

Table 3.5: Parameters for equation (10)

| parameter | estimate | standard error |
|---|---|---|
| $A$ | −12.9 | 0.230 |
| $B$ | 1.08 | 0.0208 |
| $C$ | 1.58 | 0.0346 |
| $D$ | 0.568 | 0.0218 |
| $E$ | 0.00576 | 0.000136 |

The boxplot for the normalized withdrawal strength of all tested ash samples are shown in Figure 3.3 for different angles between screw axis and grain direction. The white squares indicate the $5^{\mathrm{th}}$ percentiles and the dotted curve connects the $5^{\mathrm{th}}$ percentiles for $\alpha = 0°$ and $\alpha = 90°$ with a Hankinson-function. The white squares for $15° \leq \alpha \leq 75°$ are always above the dotted line on the (very) safe side.

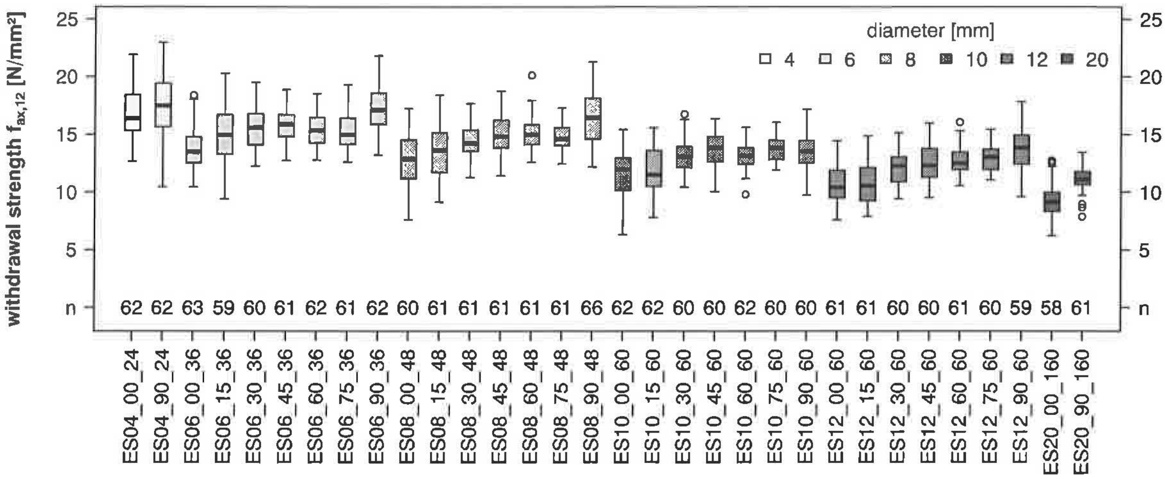



Figure 3.2: Boxplots of the withdrawal strength for ash

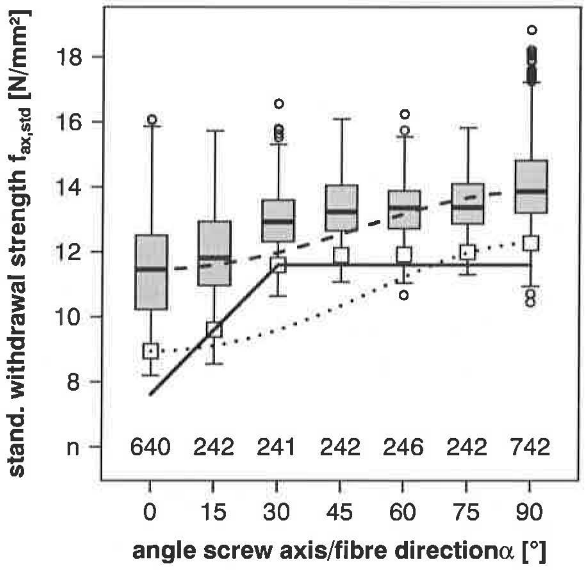



Figure 3.3: Boxplots of standardised withdrawal strength

The break of slope for the bilinear curve is always the 5$^{th}$ percentile for $\alpha = 30°$. The slope of the left part results from the tangent to the 5$^{th}$ percentile for $\alpha = 15°$. The sum of the differences between the 5$^{th}$ percentiles and the bilinear curve is smaller than between the bilinear curve and the dotted line. The following regression analysis was thus based on the bilinear equation (10).

$$\tilde{\epsilon} - 5.2\,\mathrm{med}\left(|\hat{\epsilon}_i - \tilde{\epsilon}|\right) \leq \hat{\epsilon}_i \leq \tilde{\epsilon} + 5.2\,\mathrm{med}\left(|\hat{\epsilon}_i - \tilde{\epsilon}|\right) \quad (11)$$

Equation (11) was choosen due to its robustness according to Hampel (1985, p. 98) to eliminate 24 outliers of 2 621 datasets based on the residues $\hat{\epsilon}_i$ and the mean residue $\tilde{\epsilon}$.

$$R_{\mathrm{ax,mean}} = 2.39 \cdot 10^{-3}\, l_{\mathrm{ef}}\, \rho_{\mathrm{mean}}^{1.6}\, d^{0.66} \ldots$$
$$\ldots \begin{cases} 1 - 0.006\,(30° - \alpha) & 0° \leq \alpha < 30° \\ 1 & 30° \leq \alpha \leq 90° \end{cases} \quad (12)$$

$$R_{\mathrm{ax,05}} = 2.2 \cdot 10^{-3}\, l_{\mathrm{ef}}\, \rho_{05}^{1.6}\, d^{0.66} \ldots$$
$$\ldots \begin{cases} 1 - 0.006\,(30° - \alpha) & 0° \leq \alpha < 30° \\ 1 & 30° \leq \alpha \leq 90° \end{cases} \quad (13)$$

The estimates and their standard errors of the parameters in equation (10) are listed in Table 3.5. For practical reasons the parameter $B$ was set to 1.0 and the other parameters were calculated again. Then $C$ was rounded to 1.6. The regression analysis was repeated until all parameters were rounded and fixed. $R_{\mathrm{ax,mean},i}$ according to equation (12) and the test results are plotted in Figure 3.4 and form an ideal type scatter band. The orange circles for Black locust and the red circles for beech fit to the circles for ash. The different wood anatomies can be sufficiently represented by the densities.

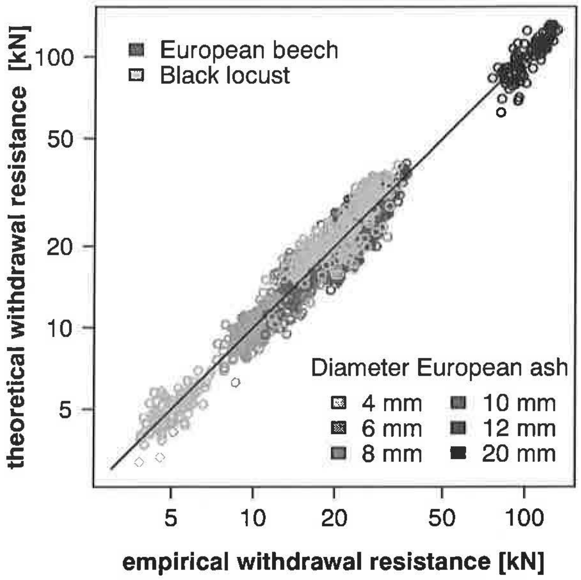



Figure 3.4: Tested versus theoretical withdrawal resstance according to equation (12)

The adjusted coefficient of determination was $r^2_{adj} = 0.966$. The normal distributed residues had an estimated standard deviation of $\hat{\sigma} = 0.1073$. Thus the expected value for the withdrawal resistance has a coefficient of variation of 10.77 %. The relation of the $5^{th}$ percentile to the mean of the expected withdrawal resistance is constant for all parameter combinations according to the design model and equal to 0.823. The $5^{th}$ percentile of the density of the dataset is 672 kg/m$^3$ and the mean value 743 kg/m$^3$. If the characteristic density is introduced in equation (12) a reduction to 90.5 % follows. The parameter $\exp(A)$ has to be multiplied with $1-(0.905-0.823) = 0.917$ to get the necessary 82.2 % of the expected withdrawal resistance equal to the estimated $5^{th}$ percentile of equation (13).

The $5^{th}$ percentile of the density of each species was calculated and introduced in equation (13) to calculate with each dataset of $l_{ef,i}$ and $\alpha_i$ the estimated $5^{th}$ percentile of the withdrawal resistance. These theoretical values were compared to all the measured values and for 32 of 44 samples all test values including the extreme values exceed the estimates. In nine samples 98 % passed, in two sampels 97 % and in one sample the limit of 95 % was reached. Only 16 out of 2 621 vaues or 0.6 % were on the unsafe side.

Pirnbacher and Schickhofer (2012, p. 132) stated concerning the long term behavior of screws parallel to the grain: "when the applied load does not exceed a threshold at about 73 % of the ultimate strength their behavior is covered by the application of $k_{mod}$ as currently present in the EC5". SIA 265 (2012, p. 71) requires a minimum effective thread length of 100 mm or $8\,d$ respectively for screws parallel to the grain direction. A similar rule was formulated in SIA 265 (2003). Uibel and Blaß (2013, p. 132) reported about long term tests in spruce with screws axially loaded with 70 % of the design resistance. 19 of the 48 screws (40 %) failed during the test of almost five years. Equation (13) is valid for short term loads with a load duration of $(300 \pm 120)$ s. Pirnbacher (2011, p. 81) reported a positive effect of the embedment of the thread of partially-threaded screws on the long term behavior. Summarizing these publications it is necessary to reduce the withdrawal resistance for screws parallel to grain with the factor 0.01 instead of 0.006 in equation (13) and additionally use an embedment length of $l_{emb} = 2\,d$.

$$R_{ax,k} = 2.2 \cdot 10^{-3}\, l_{ef}\, \rho_k^{1.6}\, d^{0.66} \ldots$$
$$\ldots \begin{cases} 1-0.01\,(30^\circ - \alpha) & 0^\circ \leq \alpha < 30^\circ \cap l_{emb} = 2\,d \\ 1 & 30^\circ \leq \alpha \leq 90^\circ \end{cases} \quad (14)$$

If all the characteristic withdrawal resistances are calculated according to equation (14) for angles of $30^\circ, 45^\circ, \ldots, 90^\circ$, the diameters 6, 8, 10 and 12 mm, the effective lengths of $4\,d$, $5\,d$, $6\,d$ and the characteristic density 672 kg/m$^3$ the results exceed the solution according to ON EN 1995-1-1 (2009) by the factor 1.79. A second advantage is that the new model covers a wider range of diameters from 4 to 20 mm and angles between screw axis and grain direction from 0° to 90°.

Engineers like mechanically logical design models where the parameters with their corresponding units give reasonable results. In equation (15) $f_{\mathrm{ax,k}}$ is the withdrawal *strength* in $\mathrm{N/mm^2}$ not the withdrawal *parameter* according to ON EN 1995-1-1 (2009).

$$R_{\mathrm{ax,k}} = f_{\mathrm{ax,k}}\, \pi\, d\, l_{\mathrm{ef}} \tag{15}$$

The description of $f_{\mathrm{ax,k}}$ should cover complete different rupture mechanisms. The withdrawal strength parallel to the grain is the shear strength around the outer diameter of the screw with an influence of the screw tip and the transverse strain near the surface of the timber. The withdrawal resistance perpendicular to grain is much more complicated to describe. The rupture is a mix of shear cracks parallel to grain due to the bending of the fibers, rolling shear, compression and tension perpendicular to grain (see Figure 3.5). Additional size effects have to be considered. The equation (14) summarizes the different parameters and effects. The alternative is to combine equations (15) and (16).

$$f_{\mathrm{ax,k}} = 7 \cdot 10^{-4} \cdot \rho_{\mathrm{k}}^{1.6} \cdot d^{-0.34} \ldots$$
$$\ldots \begin{cases} 1 - 0.01\,(30° - \alpha) & 0° \leq \alpha < 30° \cap l_{\mathrm{emb}} = 2\,d \\ 1 & 30° \leq \alpha \leq 90° \end{cases} \tag{16}$$

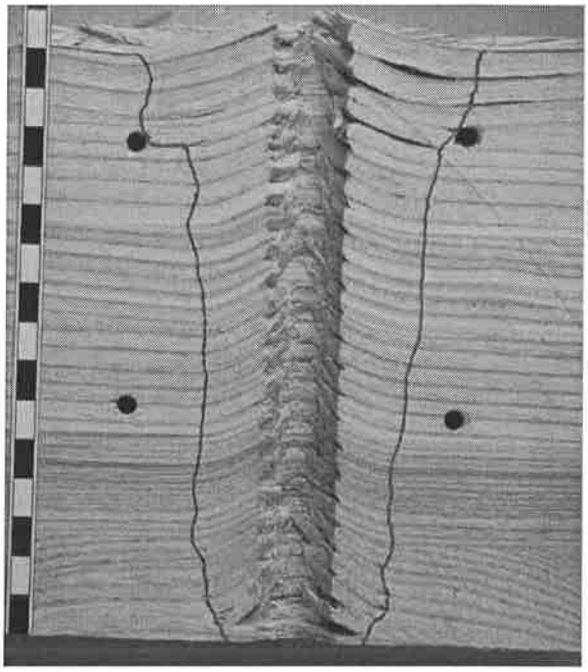
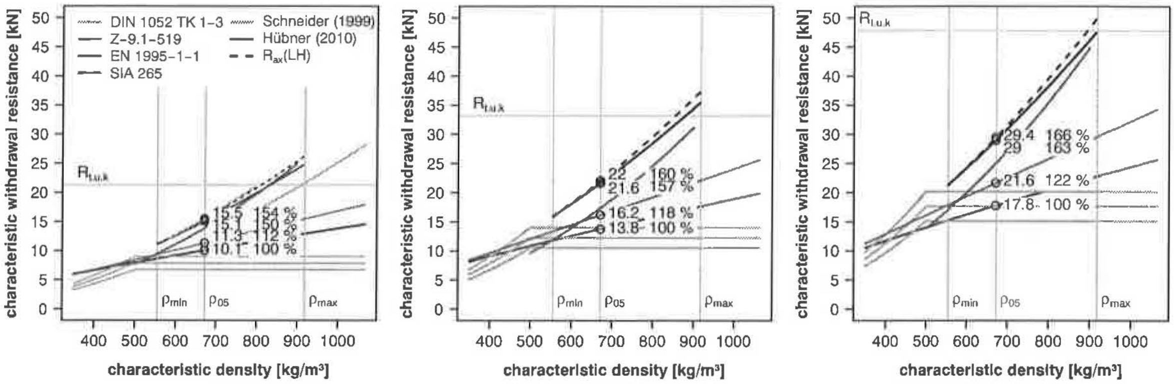


Figure 3.5: Cut in half specimen after withdrawal test (ES20_90_160_54, ⌀ 20 mm, $\alpha = 90°$)

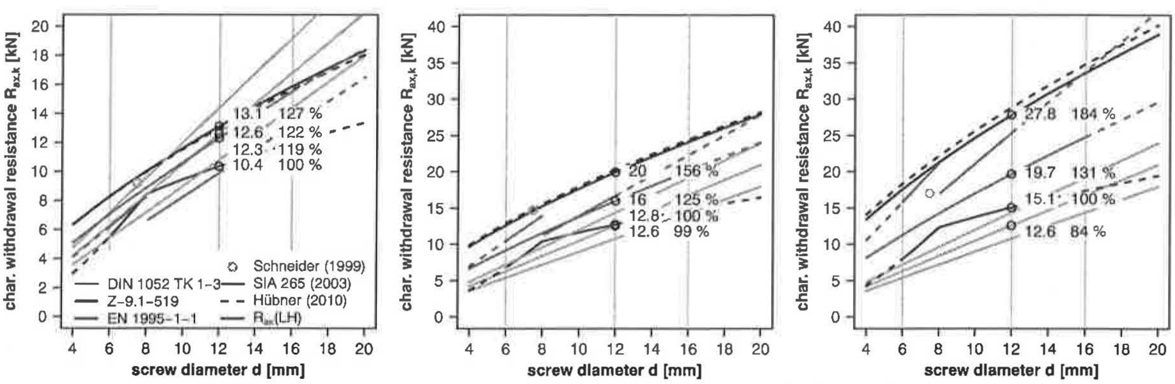
## 4 Comparison with other design models

Schneider (1999) published a design model for the withdrawal resistance of self-tapping screws (anchor for window frames ⌀ 7.5 mm) in European beech. The orange curve and circle in Figure 4.1 a and 4.2 a respectively represent this model. Equation (14) was plotted as the black curve and the design model for European ash according to Hübner, Rasser and Schickhofer (2010) as the black dashed curve. The blue curve was plotted according to ON EN 1995-1-1 (2009). The slope of the blue curve in Figure 4.1 is flat due to the $\rho_{\mathrm{k}}^{0.5}$ for softwoods. The design model of SIA 265 (2003) is no longer valid but the red curve was plotted to show the former performance compared to ON EN 1995-1-1 (2009). DIN 1052 (2008) was replaced by the Eurocode. The light green horizontal lines limitation according to DIN 1052 (2008) are the result of the restriction to $\rho_{\mathrm{k}} = 500\,\mathrm{kg/m^3}$ for softwoods for the three load bearing classes for screws. The steep slope due to $\rho_{\mathrm{k}}^2$ in the former design model is remarkable. The German technical approval Z-9.1-519 (2012) was the first which allowed the application of modern screws in hardwoods. The dark green curves are the closest to the black curve for equation (14). Figure 4.1 shows that the design models for soft- and hardwoods should consider the different influences of the density. The influence of the diameter is the same for soft- and hard-




(a) diameter 8 mm (b) diameter 10 mm (c) diameter 12 mm

Figure 4.1: Withdrawal resistance for screw diameters ($l_{\mathrm{ef}} = 7\,d$, $\alpha = 90°$)




(a) characteristic density 500 kg/m$^3$ (b) charact. density 650 kg/m$^3$ (c) characteristic density 800 kg/m$^3$

Figure 4.2: Withdrawal resistance for different characteristic densities ($l_{\mathrm{ef}} = 60$ mm, $\alpha = 90°$)

woods. The curves in Figure 4.2 are more parallel with the exception of the blue curve for ON EN 1995-1-1 (2009). The slope for diameters $d \geq 8$ mm is too flat but for $d < 8$ mm it is too steep.

## 5 Further research

The new design model allows reaching the tensile resistance of the screws with shorter effective lengths. The question is how to increase the transferable load. One answer could be screws with a greater ratio of core to outer diameter. Another answer are optimized minimum spacings's and edge/end distances. In technical approvals for screws the spacing perpendicular to the grain direction can be reduced to $a_2 = 2.5\,d$ if $a_1 \cdot a_2 = 25\,d^2$.

Plieschounig (2010) recommends $a_1 \geq 7\,d$ and $a_2 \geq 3{,}5\,d$ with $a_1 \cdot a_2 = 24.5\,d^2$ for screws perpendicular to the grain. Parallel to the grain direction a quadratic grid with $a = 5\,d$ and for $\alpha = 45°$ seam $a_1 \geq 6\,d$ and $a_2 \geq 4\,d$ with $a_1 \cdot a_2 = 24\,d^2$ logically. For the time being these are theoretical considerations and more research like published by Mahlknecht (2011) has to be carried out.

# 6 Acknowledgment

This research work Was part of the COMET-K-project *1.2.3_ hardwood_ connections* of the competence centre holz.bau forschungs gmbh and was carried out in collaboration with the Institute for Timber Engineering and Wood Technology at the Graz University of Technology and industrial partners *HAAS Fertigbau GmbH & Co.KG* and *SPAX International GmbH & Co. KG*. The withdrawal tests were executed with the aid of Bernd Heissenberger, Markus Kummer, Manuel Lögl and Mathias Rasser. The research work was financed through the Austrian State Ministry of Economic Affairs and Employment, the Ministry of Transport, Innovation and Technology as well as by the *Steirischen Wirtschaftsförderungsgesellschaft mbH* and the federal state Steiermark.

# References

[Bejtka 2005] BEJTKA, Ireneusz: *Karlsruher Berichte zum Ingenieurholzbau.* vol. 2: *Verstärkungen von Bauteilen aus Holz mit Vollgewindeschrauben.* Karlsruhe : Universitätsverlag Karlsruhe, Januar 2005. – URL `http://digbib.ubka.uni-karlsruhe.de/volltexte/1000003354`. – date of access: 12. Juli 2010. – ISBN 3-937300-54-6

[Büeler 2011] BÜELER, Michael: *Schubverhalten von Brettschichtholzträgern aus Buche und Esche.* Zürich, Institut für Baustatik und Konstruktion – Stahl-, Holz- und Verbundbau, ETH Zürich, Masterarbeit, 4. Juli 2011

[Bogusch 2011] BOGUSCH, Walter: Eschenholz im Tragwerkbau. In: *Newsletter Forum Holzbau* 51 (2011), März

[Cockrell 1933] COCKRELL, Robert A.: A study of the screw-holding properties of wood / New York State College of Forestry. Syracuse, New York, 1933. – Technical Publication No. 44

[DIBt 2012] DIBT: Verzeichnis der allgemeinen bauaufsichtlichen Zulassungen – Zulassungsbereich: Holzbau und Holzwerkstoffe. Berlin : Deutsche Institut für Bautechnik (DIBt), 22. Februar 2012. – research report

[DIN 1052 2008] DIN 1052: *Entwurf, Berechnung und Bemessung von Holzbauwerken – Allgemeine Bemessungsregeln und Bemessungsregeln für den Hochbau.* Dezember 2008

[DIN 7998 1975] DIN 7998: *Gewinde und Schraubenenden für Holzschrauben.* Februar 1975

[Eckelman 1975] ECKELMAN, Carl A.: Screwholding performance in hardwoods and particleboard. In: *Forest Products Journal* 25 (1975), No. 6, p. 30–35

[Frese and Blaß 2009] FRESE, Matthias ; BLASS, Hans Joachim: Models for the calculation of the withdrawal capacity of self-tapping screws. In: *Proceedings of CIB-W18.* Dübendorf, Schweiz, August 2009. – Paper 42-7-3

[Griesser 2012] GRIESSER, Doris: Fichte und Birke als tragende Elemente. In: *Der Standard* (2012), 7. März, p. 17

[Hampel 1985] HAMPEL, Frank R.: The breakdown points of the mean combined with some rejection rules. In: *Technometrics* 27 (1985), No. 2, p. 95–107

[Hübner et al. 2010] HÜBNER, Ulrich ; RASSER, Mathias ; SCHICKHOFER, Gerhard: Withdrawal resistance of screws in common ash (*Fraxinus Excelsior* L.). In: *Proceedings of 11$^{th}$ World Conference on Timber Engineering (WCTE)* vol. 1. Riva del Garde, Italy, 21. Juni 2010. – Paper 481

[Jablonkay 1999] JABLONKAY, Peter: *Schrauben auf Ausziehen*, ETH Zürich, Forstwissenschaften, Abteilung VI, diploma thesis, 1999

[Leijten et al. 2006] LEIJTEN, Ad J. M. ; KÖHLER, Jochen ; JORISSEN, André J. M.: Timber density restrictions for timber connection tests according to EN 28 970/ISO 8970. In: *Proceedings of CIB W18.* Florence, Italy, August 2006. – Paper 39-21-1

[Mahlknecht 2011] MAHLKNECHT, Ursula: *Untersuchung von rechtwinklig zur Faser eingebrachten, axial beanspruchten Schraubengruppen im Vollholz und Brettsperrholz*, Institut für Holzbau und Holztechnologie der TU Graz, diploma thesis, 2011

[MPA Stuttgart 2012] MPA STUTTGART: *EC-Certificate of Conformity 0672 for GLT made of sweet chestnut.* Sierolam S. A., Los Cuentos s/n Argüelles, 33188 Siero, Spain. 31. August 2012. – certificate number 0672-CPD-114.21.53

[Munch-Andersen 2013] MUNCH-ANDERSEN, Jørgen: *Re: AW: Effective length l_ ef for screws.* E-Mail. 14. Juni 2013

[Newlin and Gahagan 1938] NEWLIN, J. A. ; GAHAGAN, J. M.: Lag-screw joints: Their behavior and design / United States Departement of Agriculture. Washington, D. C., Januar 1938. – Technical bulletin No. 597

[ON EN 13183-1 2004] ON EN 13183-1: *Feuchtegehalt eines Stückes Schnittholz – Teil 1: Bestimmung durch Darrverfahren.* 1. Februar 2004

[ON EN 1382 1999] ON EN 1382: *Holzbauwerke – Prüfverfahren – Ausziehtragfähigkeit von Holzverbindungsmitteln.* 1. November 1999

[ON EN 1382 2012] ON EN 1382: *Timber Structures – Test methods – Withdrawal capacity of timber fasteners.* Mai 2012

[ON EN 1995-1-1 2006] ON EN 1995-1-1: *Eurocode 5: Bemessung und Konstruktion von Holzbauten – Teil 1-1: Allgemeines – Allgemeine Regeln und Regeln für den Hochbau.* November 2006

[ON EN 1995-1-1 2009] ON EN 1995-1-1: *Eurocode 5: Bemessung und Konstruktion von Holzbauten – Teil 1-1: Allgemeines – Allgemeine Regeln und Regeln für den Hochbau.* 1. Juli 2009

[ON EN 384 2010] ON EN 384: *Structural timber – Determination of characteristic values of mechanical properties and density.* 15. Mai 2010

[Pirnbacher 2011] PIRNBACHER, Gernot: Screws_Long_Time: Zeitabhängige Entwicklung der Traglast und Kriechverhalten von selbstbohrenden Holzschrauben / holz.bau forschungs gmbh. Graz, Oktober 2011. – Vorläufiger interner Forschungsbericht

[Pirnbacher and Schickhofer 2009] PIRNBACHER, Gernot ; SCHICKHOFER, Gerhard: Base parameters of self-tapping screws. In: *Proceedings of CIB-W18.* Dübendorf, Schweiz, August 2009. – Paper 42-7-1

[Pirnbacher and Schickhofer 2012] PIRNBACHER, Gernot ; SCHICKHOFER, Gerhard: Zeitabhängige Entwicklung der Traglast und des Kriechverhaltens von axial beanspruchten, selbstbohrenden Holzschrauben / holz.bau forschung gmbh. 2012. – research report

[Plieschounig 2010] PLIESCHOUNIG, Stefan: *Ausziehverhalten axial beanspruchter Schraubengruppen.* Graz, Institut für Holzbau und Holztechnologie der TU Graz, diploma thesis, November 2010

[Pollmeier 2012] POLLMEIER MASSIVHOLZ GMBH & CO. KG: Furnierschichtholz aus Buche: Datenblatt/Statische Kennwerte. Creuzburg, 21. Dezember 2012. – research report

[Popper and Niemz 2009] POPPER, Rudolf ; NIEMZ, Peter: Wasserdampfsorptionsverhalten ausgewählter heimischer und überseeischer Holzarten. In: *Bauphysik* 31 (2009), No. 2, p. 117–121

[Rajak and Eckelman 1993] RAJAK, Zaini Ithnin Bin Haji Abdul ; ECKELMAN, Carl A.: Edge and face withdrawal strength of large screws in particleboard and medium density fiberboard. In: *Forest Products Journal* 43 (1993), No. 4, p. 25–30

[Ravasse 2011] RAVASSE, François: *Minutes meeting Paris REV 2011 on April 19 and 20.* 27. Juli 2011. – N 1079

[Schneider 1999] SCHNEIDER, Patric: Auszugsfestigkeit von EJOT-Rahmenschrauben / Eidgenössische Technische Hochschule. Zürich, 29. Oktober 1999. – research report

[SIA 265 2003] SIA 265: *Holzbau.* 1. März 2003

[SIA 265 2012] SIA 265: *Holzbau.* 1. Januar 2012

[Uibel and Blaß 2013] UIBEL, Thomas ; BLASS, Hans J.: Joints with dowel type fasteners in CLT structures. In: HARRIS, R. (eds.): *Focus Solid Timber Solutions - European Conference on Cross Laminated Timber (CLT).* Graz : TU Graz, 21./22. Mai 2013, p. 119–134. – ISBN 1-85790-181-9

[Z-9.1-435 2009] SCHMID SCHRAUBEN HAINFELD GMBH: Holzbauschrauben Star Drive, Rapid, Rapid Perfekt und Schmid SP als Holzverbindungsmittel. Berlin : Deutsches Institut für Bautechnik, 16. Dezember 2009. – Allgemeine bauaufsichtliche Zulassung Z-9.1-435

[Z-9.1-519 2011] SPAX INTERNATIONAL GMBH & CO. KG: Spax-S Schrauben mit Vollgewinde als Holz-Verbindungsmittel. Berlin : Deutsches Institut für Bautechnik, 11. März 2011. – Allgemeine bauaufsichtliche Zulassung Z-9.1-519

[Z-9.1-519 2012] SPAX INTERNATIONAL GMBH & CO. KG: Spax-S Schrauben mit Vollgewinde als Holz-Verbindungsmittel. Berlin : Deutsches Institut für Bautechnik, 31. Januar 2012. – Allgemeine bauaufsichtliche Zulassung Z-9.1-519

[Z-9.1-656 2007] SCHMID SCHRAUBEN HAINFELD GMBH: Holzbauschrauben Star Drive Vollgewinde und Star Drive 2 Gewinde als Holzverbindungsmittel. Berlin : Deutsches Institut für Bautechnik, 25. Juni 2007. – Allgemeine bauaufsichtliche Zulassung Z-9.1-656

[Z-9.1-679 2011] STUDIENGEMEINSCHAFT HOLZLEIMBAU E. V.: BS-Holz aus Buche und BS-Holz Buche-Hybridträger. Berlin : Deutsches Institut für Bautechnik, 7. Juni 2011. – Allgemeine bauaufsichtliche Zulassung Z-9.1-679

Z-9.1-704 2012] ELABORADOS Y FABRICADOS GÁMIZ S. A.: VIGAM Brettschichtholz aus Eiche. Berlin : Deutsches Institut für Bautechnik, 04. Mai 2012. – Allgemeine bauaufsichtliche Zulassung Z-9.1-704

Z-9.1-777 2010] SFS INTEC GMBH: Gewindestangen mit Holzgewinde als Holzverbindungsmittel. Berlin : Deutsches Institut für Bautechnik, 30. November 2010. – Allgemeine bauaufsichtliche Zulassung Z-9.1-777