STEEL PROPERTIES OF SELF-TAPPING SCREWS

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1 INTRODUCTION

In general, the European Yield Model is used to design joints with laterally loaded screws, where the tensile capacity F_t and the yield moment M_y are necessary input parameters when it comes to steel properties. The speed of screw development is so immense that the current Eurocode 5 (2010) does not include bespoke rules for self-tapping screws, with the exception of few specific rules concerning axially loaded screws. Indeed, in order to design joints with screws, most input parameters (e.g. F_t, M_y) must be taken from technical documentation of the screws. In Europe, self-tapping screws can be certified in accordance with EN 14592 (2012) or through a European Technical Assessment (ETA) based on an EAD (2019). The steel properties to be determined in the framework of certification testing are F_t, M_y and the ultimate torsional moment M_{tor}.

The aim of this contribution is to analyse design equations regarding the parameters tensile capacity F_t and yield moment M_y that would eliminate the need to consult technical documentation of individual screw producers. An extensive database com-prising more than 10,000 test results carried out for certification purposes was analysed. Potential benefits are more robust design models covering a large range of screws, reduced testing and simplified design equations. More specifically, this contribution investigates in a first step the influence of different parameters such as the type of steel or screw on steel properties. Then, two approaches are examined that aim at facilitating testing. The yield moment M_y for instance is not easy to determine experimentally and results depend strongly on their interpretation and on the precise test setup (see section 4.2). The possibility to abandon these tests seems appealing. Proposals are made how M_y could be calculated in future, based on either tensile strength or ultimate torsional moment.

2 STATE OF THE ART

Self-tapping timber screws are one of the most important fastener typologies in modern timber engineering. Due to their good performance, ease of application and versatile ranges of use, the advent of modern timber screws is one of the primary factors for the advent of many modern engineered timber structures. Screws are often designed to accommodate specific purposes, such as screws optimised for specific timber products (Brandner, 2019) or screws with variable thread geometries to pre-stress timber (Steilner, 2014). Furthermore, screws are an effective means to reinforce against tensile failures perpendicular to the grain (Bejtka and Blaß, 2005), shear (Dietsch, 2012) or as reinforcement of beam supports (Bejtka and Blaß, 2006).

Consequently, the variety of modern self-tapping screws in terms of their geometrical and steel properties is enormous, ranging from fully threaded screws over screws with a partial thread or two threaded parts over the screw length to many different head, tip and thread shapes. Concerning steel properties, most screws are made of carbon steel and are hardened. These screws are usually galvanised to protect them against corrosion. Also stainless steel screws are widely applied, where, differently to nails (Sandhaas and Görlacher, 2017), the steel properties differ considerably to those of carbon steel screws because the latter are generally hardened. However, also martensitic stainless steel is used where higher steel properties come with the cost of lesser resistance against corrosion. Ringhofer (Ringhofer, 2017) gives a comprehensive and clear overview of these manifold screw types and explains thoroughly the effect of production processes and geometric and material choices on the screw performance.

As stated in the introduction, in current certification practice, the three steel properties M_y, F_t and M_{tor} are tested in accordance with EN 14592 or EAD 130118-01-0603, where both refer to the respective testing standards (EN 1383, 2016; EN 409, 2009; EN ISO 10666, 2010). The evaluated values on the characteristic level are then declared in technical documents. In the current version of Eurocode 5, design rules exist for “smooth shank screws, where the outer thread diameter is equal to the shank diameter” (8.7.1 (2)), and where reference is made to the rules for bolts (for screws with $d > 6$ mm; 8.7.1 (4)) and nails (for screws with $d \leq 6$ mm; 8.7.1 (5)). These screws however are screws with a standardised thread, which generally are different to self-tapping screws. Self-tapping screws are cold-formed, mostly hardened and their outer thread diameter is larger than the shank diameter. Generally, confusion exists if rules for bolts and nails apply also to self-tapping screws with a partial thread (fully threaded screws are not covered). Such rules encompass for instance Eq. (1), with which the characteristic yield moment $M_{y,Rk}$ in Nmm of nails and bolts can be calculated:

$$M_{y,Rk} = 0.3 \cdot f_{u,k} \cdot d^{2.6} \tag{1}$$

where $f_{u,k}$ = 600 MPa for nails (corresponds to minimum tensile strength of wire) / characteristic tensile strength of bolt in MPa; d = nominal diameter in mm.

3 DATABASE

The database consists of in total 10419 tests taken from 86 reports. Screws from 32 different producers were considered and the tests were carried out between 2010 and 2019, in accordance with the certification rules valid at the time of testing. Due to the large variability, a rough classification as shown in Figure 2 was used to create subgroups of screws. Partially threaded screws constituted 69% of the database; fully threaded screws 19%, screws with two threaded parts and with a high-low thread 6% each and only 1% were TCC screws. The geometrical properties given in Figure 1 are also recorded in the database. In total, screws with 26 different nominal diameters ranging from 2.5 mm to 14 mm were tested, where diameters of 5, 6 and 8 mm were the most frequent with about 15% each. The ratio between inner and outer thread diameter was between 0.55 and 0.76. Concerning the types of steel, for 33% of all data, the test reports did not explicitly state the types of steel of the screws, which means, with near-certain probability, that these screws were made from carbon steel and hardened. Therefore, these 33% were assigned to carbon steel screws, which then accounted for 72% of the database. 27% were stainless steel screws, 30 screws (0.3%) were hot-dip galvanised and 50 screws (0.5%) were made from unhardened carbon steel. No further information about steel grades was usually given, e.g. if austenitic or martensitic steels were used. The number of tests per parameter is given in Table 1. Concerning the individual parameters, the tensile capacity F_t and the torsional moment M_{tor} are measured maximum values. The given yield moment M_y is the value at a measured deformation angle of 45° or the reached maximum bending angle before rupture of the screws. It has to be pointed out here that issues around test execution and interpretation of results lead to uncertainties about the measured values (see section 4.2).

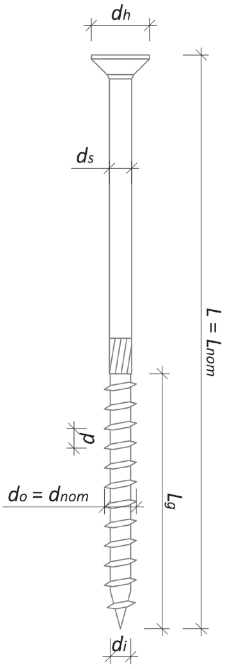

Figure 1.
Geometrical properties with

- d_h = *head diameter*
- d_s = *diameter of smooth shank*
- d_o = *outer thread diameter = nominal diameter* d_{nom}
- d_i = *inner thread diameter*
- *p = pitch*
- *L = length = nominal length* L_{nom}
- L_g = *length of threaded part*

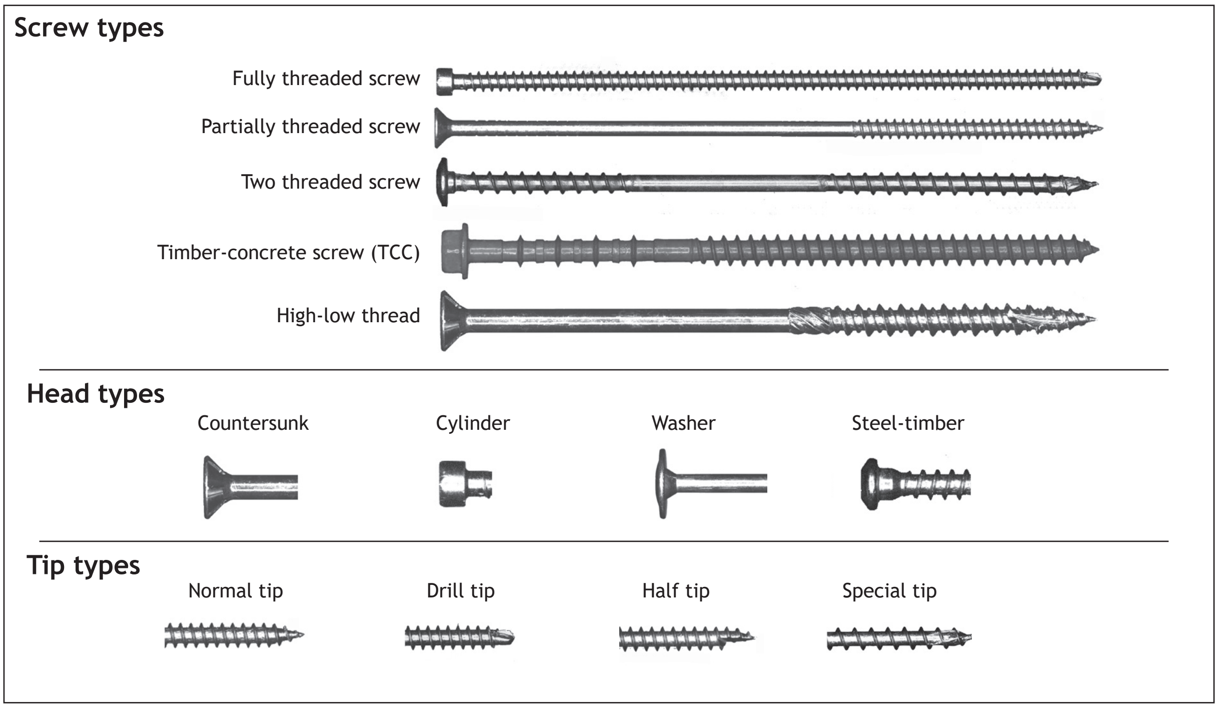

Figure 2. Classification of screws.

Table 1. Composition of database, F_t in kN, M_y and M_{tor} in Nm.

	Tensile capacity F_t	Yield moment M_y	Torsional moment capacity M_{tor}
No. of tests	3851	2921	3647
Of which stainless steel	1085	756	1015
Of which hdg*	10	10	10
Of which unhardened #	50	50	50

* hdg = hot-dip galvanised; # = only screws made of carbon steel

4 ANALYSIS AND DISCUSSION

4.1 General

Usually, 10 tests per steel property were carried out using the same screw, i.e. from one batch. The steel properties can be analysed individually, which means that individual test results can be considered, e.g. to evaluate if the shank ribs have an influence on the tensile capacity of partially threaded screws (they have not). Furthermore, steel properties can be compared within test series, e.g. to investigate the relationship between M_y and M_{tor}. For the latter case, only mean values can be used, as there is no direct relationship between individual test values. For instance, M_{tor} cannot be measured on the very screw that was used to determine M_y. Therefore, experimental values contained in the database are grouped although screw parameters may be different, notably length and head type.

As stated before, most screws are made of carbon steel and are hardened. Only about a third of the database contains test results of stainless steel screws, where martensitic stainless steel screws can be hardened contrary to screws made of austenitic stainless steel. Work hardening effects will take place when rolling the thread and consequently, screws with smaller inner diameters (and hence relatively larger nominal diameters) may "benefit" more from work hardening. Subsequent hardening of screws, a process that includes a heat treatment, may reverse the effect of work hardening, but it will lead to higher properties. This heat treatment may again affect screws with smaller diameters more than thicker screws, leading to higher properties of screws with decreasing nominal diameters. In other words, the steel strength is not necessarily homogeneous over the cross-section. In EN ISO 10666 (2010), developed for screws in steel structures, this is considered because e.g. core and surface hardness need to be determined. Also the screw length may influence the steel properties, as the rolling of a long thread may lead to more notches, which in turn lead to reduced properties.

Hence, as a first step, influence factors on the steel properties are investigated. First, the influence of the **type of steel** is assessed. For this, test values must be converted in strength values in order to allow for comparison. The conversion in strength is done as shown in Eqs. (2) to (4), with d_i = measured inner thread diameter in mm. The consideration of d_i, however, does not lead to true strength values. As shown in Ringhofer (2017), the stressed area to consider when transforming capacity into strength is not circular in the case of screws. Moreover, possible notches, especially in the threaded part or in the transition area between thread and smooth shank of partially threaded screws, are not considered.

In Eq. (3), $Z_{tor,pl}$ is the full plastic polar section modulus of a round section in mm^3 and $\surd 3$ factor accounts for the ratio between tensile and shear strength.

The converted strength values are shown in Figure 3. The "yield strength" (top) and the "torsional strength" (bottom) are similar, whereas both are higher than the "tensile strength" (centre). Different stress states during testing may lead to this. For instance, during a test to determine M_y and M_{tor}, the outer fibres are first stressed whereas during a tensile test, the whole cross-section is stressed. As the hardening procedure is not influencing the whole cross-section evenly, the outer fibres with higher strength may lead to a higher "yield/torsional strength". During a tensile test instead, the whole cross-section with hardened outer fibres and less-hardened inner fibres is activated, leading to lower tensile strength values of hardened screws. When looking at stainless steel screws, two distinct groups can be identified. Obviously, screws made from martensitic stainless steel can reach strength values similar to those made from carbon steel.

Apart from the type of steel, also the ***screw type*** may influence the steel properties. The following observations made during testing are the reason behind this hypothesis:

- Tensile tests: Screws usually fail in the threaded part with the smallest stressed area (inner diameter). Unhardened stainless steel screws however may also fail in the smooth shank although the diameter of shank is greater than inner diameter. This leads to smaller tensile capacities of partially threaded screws in comparison to fully threaded screws (of the same group). An explanation is that work hardening effects do not occur in the smooth shank of stainless steel screws.

- Yield moment tests: The weakest section of partially threaded screws usually is in the area of the last thread directly adjacent to the smooth shank (the "transition" area). This may be due to local stress concentrations. Within the same group, partially threaded screws may hence have lower yield moments in comparison to fully threaded screws.

- Often, fully threaded screws have higher steel properties than partially threaded screws, as the latter are less hardened.

"Yield strength σ_{My}" in MPa: $\sigma_{My} = \frac{6 \cdot M_y}{d_i^3}$ (2)

"Tensile strength f_t" in MPa: $f_t = \frac{4 \cdot F_t}{\pi \cdot d_i^2}$ (3)

"Torsional strength f_{tor}" in MPa: $\sigma_{tor} = \sqrt{3} \cdot \frac{M_{tor}}{Z_{tor,pl}} = \sqrt{3} \cdot \frac{M_{tor}}{\pi \cdot d_i^3 / 12}$ (4)

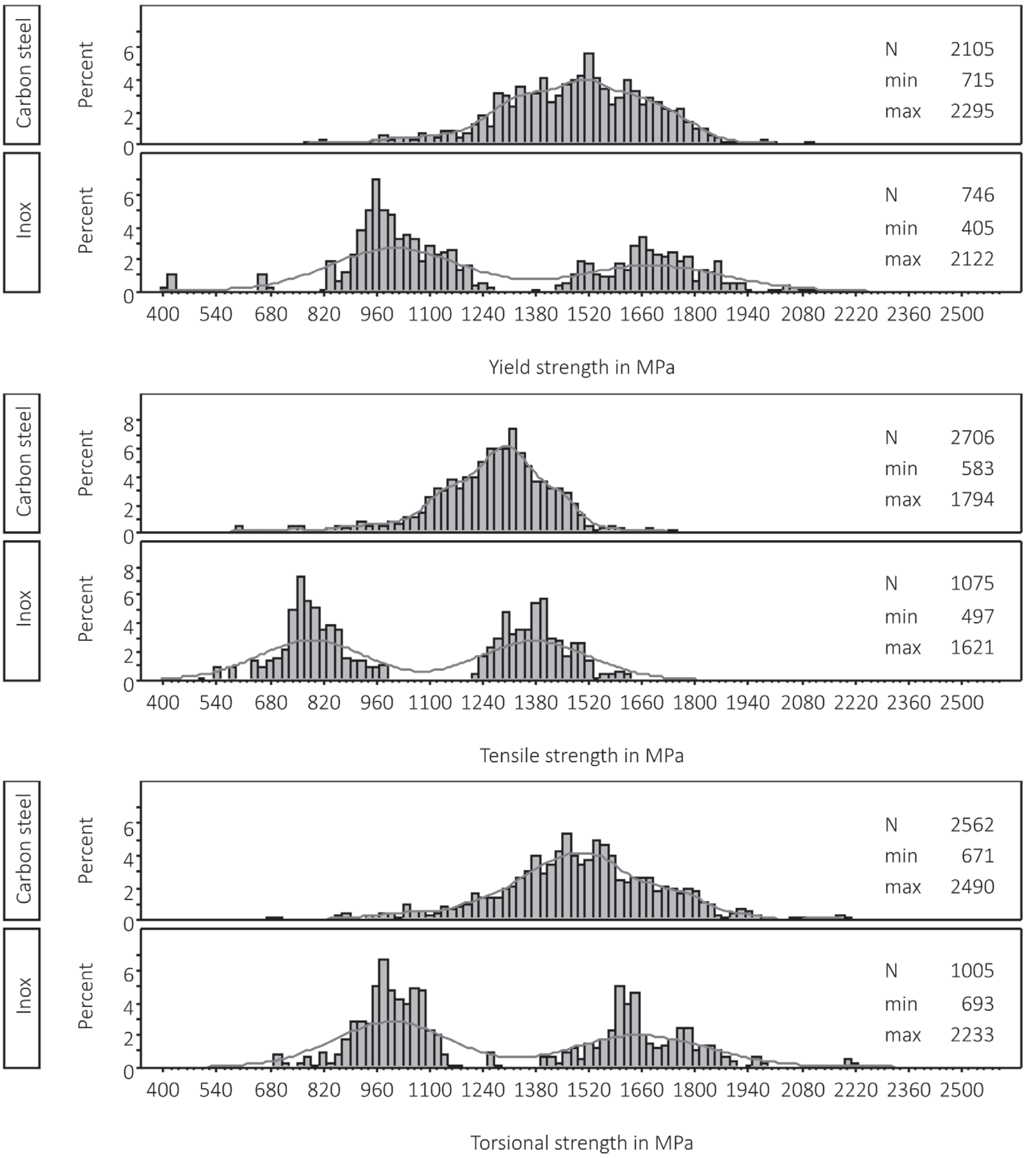

Figure 3. Histograms of strength values per type of steel. Results for hdg and unhardened screws are not shown and only results for screws with recorded inner diameter d_i are shown.

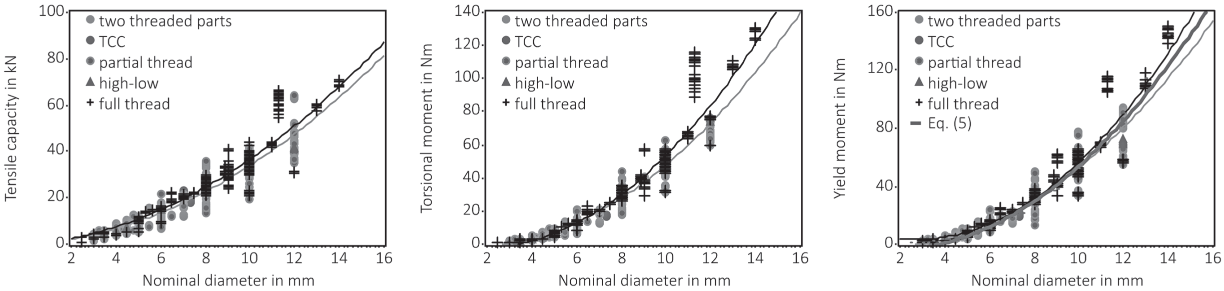

Figure 4. Properties versus d_{nom}, identified by screw type (hdg and unhardened screws not shown). From left to right : F_t (70.4% partial thread, 17.4% full thread), M_{tor} (66.6% partial thread, 20.5% full thread), M_y (69.3% partial thread, 17.5% full thread). The black and red lines are the quadratic regression lines (forced through zero) for partially threaded (red) and fully threaded (black) screws.

Figure 4 shows all three steel properties versus the nominal diameter. Nearly 90% of all screw types were partially threaded and fully threaded screws. The black and red lines in Figure 4 are the quadratic regression lines for partially threaded screws (the red line) and for fully threaded screws (the black line). Considering that the regression for nominal diameters larger than 12 mm is not reliable (few test results and no results for partially threaded screws, i.e. the regression line for partially threaded screws is not correct for large diameters), the two lines do not differ significantly. Therefore, on the level of individual test results, no difference between screw types can be found. In Figure 3 and in Figure 4, the significant scatter of steel properties within the whole population of screws is obvious, which will impact on the quality of design rules.

To conclude this general section, it can be said that the type of steel influences the steel properties, where yield and torsional strength have very similar values. Moreover, it should be taken into account that two distinct groups of stainless steel screws exist in case any simplified equations based on tensile strength values are used. This is proposed in the current draft for the new Eurocode (CEN/TC 250/SC 5/WG 5 N148, 2020), but only a single value of 500 MPa is given as characteristic tensile strength for stainless steel screws. Finally, no clear influence of the screw type can be seen and scatter of steel properties within the whole population of screws is significant. This is in stark contrast to the scatter within the single test series determining M_y, F_t and M_{tor}, where coefficients of variation larger than 0.05 were observed only in 3.5% of the series.

4.2 Challenges to determine M_y

Before pursuing two approaches aimed at calculating M_y instead of executing tests, challenges around the experimental determination of yield moments and their implication for derived characteristic values are discussed. Lack of clarity in testing standards is indeed hampering proper analysis of test data. Both EN 14592 and EAD 130118-01-0603 refer to EN 409 as testing standard, where four-point bending tests are described, with the free length L_2 between the two load insertion points ranging between d and 3 · d. As L_2 has a significant influence on the obtained M_y-values, this range is too large. Furthermore, in EN 409, the test location along the screw axis is not specified. Especially for partially threaded screws, the exact definition of this location is necessary in order to determine M_y in the weakest section. It is not clearly stated that the screw must be allowed to move horizontally, so that there is scope to find the weakest section. Moreover, EN 409 prescribes different bending angles for different fastener types and timber products, leading to different bending angles for different wood densities. Meanwhile, the EAD states that the yield moment "is the value at the plastic bending angle $\alpha = 45/d^{0.7}$ degrees", whereas neither EN 409 nor EN 14592 mention the word "plastic". This however is crucial, as most test setups measure the global bending angle, whereas only the plastic (not elastic) bending angle should be considered. Steilner and Blass (2014) addressed this issue and proposed a solution to determine the plastic bending angle. Different laboratories therefore most certainly determine different M_y-values for the same screws, with significant implications for characteristic values. In view of these issues and as said in section 3, M_y-data contained in the database is raw data and no adjustments neither in accordance to Steilner and Blass nor Blass et al. (2000) were made. However, machine slip is still included in all results contained in this database, as the used test setup measures the bending angle directly through the rotation of the machine. This is less of an issue because the registered value for M_y is very close to the plateau value, where only a very slight increase in yield moment with increasing bending angle is observed. It is this dependency on the bending angle which makes a clear and unequivocal definition of M_y impossible.

4.3 Calculation of the yield moment using tensile strength

Eq. (5) in Figure 4 on the right shows the mechanics-based full plastic bending moment M_{mech} for a circular section calculated as follows:

$$M_{mech} = \frac{1}{6} \cdot 1200\,\text{MPa} \cdot \left(0.64 \cdot d_{nom}\right)^3 \tag{5}$$

where 1200 MPa = mean tensile strength of all screws (mean of 3846 individual values, COV = 21%), calculated using the inner diameter d_i, see Eq. (2); 0.64 = mean ratio of d_i/d_{nom}, i.e. d_i is on average 64% of d_{nom} (mean of 27282 individual values, COV = 5.6%).

Giving a first look at Figure 4 on the right, the comparison of Eq. (5) with experimental values for M_y seems to pave the way for a calculation of M_y using tensile strength values, similar to Eq. (1). Therefore, two nonlinear regression analyses based on mean values were carried out, using the format of Eq. (1) with the prefactor and the exponent as regression variables α and β. The process was iterative, eliminating all outliers with studentised residuals larger than |3|. Different independent variables were used, varying the considered diameter between inner diameter d_i and nominal diameter d_{nom}. The results are given in Table 2, where the lower indices indicate the considered diameter when calculating the tensile strength in analogy to Eq. (3). The regression results do not differ much among themselves and are close to the mechanics-based equation that has a prefactor of 1/6 and an exponent of 3. More pragmatic, but less mechanically correct is model B, as nominal diameters of screws are known to engineers in practice. Model C is further simplified by forcing the exponent to be equal to three.

Figure 5 on the left shows the results of the more pragmatic model B as the ratio of experimental over expected values in order to better identify differences, seeing that the high $R^2 = 0.999$ would not allow to see these differences if the values are plotted versus each other. Data for higher nominal diameters are scarce and the ratio scatters more for smaller diameters, where more data is available. The mean value of the ratio is 0.99 (COV = 6.7%) and the observed 5th percentile is 0.89. A last step to obtain design rules is to derive characteristic values. One option is to correct model B by a factor of 0.89 and replace the mean tensile strength with its characteristic value. By doing so, it is implicitly assumed that the scatter of M_y and f_t is the same, which is reasonable seeing that both are steel properties.

Table 2. Results of nonlinear regressions based on mean values. The outliers concern mostly screws with $d_{nom} \geq 8$ mm.

Model		No of test series	Regression variables		R^2	Outliers
			α	β		
A	$M_{y,mean} = \alpha \cdot f_{t,di,mean} \cdot d_i^{\beta}$	256	0.188	3.019	0.999	27
B	$M_{y,mean} = \alpha \cdot f_{t,dnom,mean} \cdot d_{nom}^{\beta}$	239	0.149	2.911	0.999	44
C	$M_{y,mean} = \alpha \cdot f_{t,dnom,mean} \cdot d_{nom}^{3}$	238	0.123	-	0.998	45

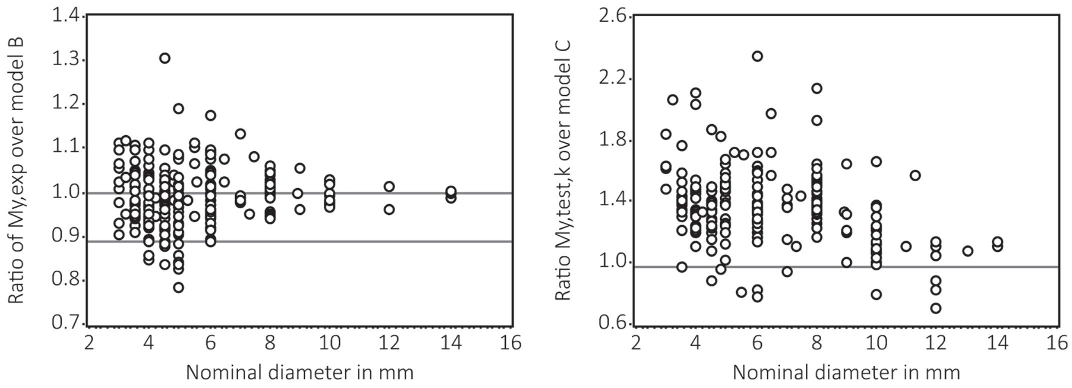

Figure 5. Left: Ratio of mean experimental value of M_y over expected value of model B. The horizontal line at 0.89 indicates the observed 5th percentile. Right: Ratio of characteristic values over $M_{y,k} = 0.123 \cdot 365$ MPa $\cdot\, d_{nom}$3. Only test results for hardened screws made of carbon steel are shown. The horizontal line at 0.98 indicates the observed 5th percentile

However, if the aim of any possible design rule is to make consultation of declarations of performance of individual screw producers superfluous, then a general characteristic value for the tensile strength valid for all screws of a certain type of steel is needed. For instance, 365 MPa, which is the observed 5th percentile of the tensile strength $f_{t,dnom,k}$ of hardened screws made of carbon steel, calculated considering the nominal diameter, can be chosen as characteristic value for the tensile strength. Now, model C is chosen to check regression results, and $f_{t,dnom,k}$ = 365 MPa is inserted instead of $f_{t,dnom,mean}$. The result is shown in Figure 5 on the right, where it is compared with characteristic values determined in accordance with EN 14358 (2016) and where only hardened screws made of carbon steel were considered. The mean value of the shown ratio is 1.35 (COV = 19%) and the observed 5th percentile is 0.98. Therefore, the chosen value for $f_{t,dnom,k}$ = 365 MPa allows for a calculation of $M_{y,k}$. It must be remembered here that the considered M_y-values were not adjusted in terms of bending angles, see section 4.2. However, such an adjustment leads to even lower M_y-values and hence to an even more punishing situation for many screws.

To conclude, design equations of manifold shapes are possible, but all of them can reproduce only a conservative value for $M_{y,k}$, if the whole population of self-tapping screws is considered. The two main decisions to be taken by code writers are which and how many strength values should be considered (e.g. based on which diameter and for how many subgroups). Finally, the database must be extended with data for larger diameters, as any design equation derived does not hold for diameters larger than ca. 10 – 12 mm, which gets particularly important if exponential approaches are chosen.

4.4 Comparison between M_y and M_{tor}

As concluded in section 4.1, yield and torsional strength give very similar values which leads to the obvious idea of comparing M_y and M_{tor} directly. This would be straightforward approach without any need of geometrical data. Tests to determine M_{tor} are much easier to execute than tests to determine M_y, and inaccuracies as discussed in section 4.2 are less likely to occur. Above all, M_{tor} is determined independently of any deformation; it is the maximum moment measured before the screw breaks. The torsional moment is not needed for design; the test is carried out to make sure that screws can be driven in without breaking.

In total, mean values of 270 series contained in the database can be compared, as only for these series both M_y (2646 individual values) and M_{tor} (2670 individual values) were determined. If M_{tor} is directly compared to M_y, the torsional moment tends to be slightly lower. Indeed, a direct comparison between yield and torsional moment cannot be done from a mechanical point of view, as a bending test leads to normal stresses in the screw, and a torsional test to shear stresses (see also Eq. (4)). Furthermore, not only the "stress type" is different, but also the section moduli differ. As a consequence, M_{tor} was corrected in accordance with Eq. (6). Figure 6 on the left shows the comparison between mean values of M_y and $M_{tor,corr}$, revealing a promising relationship (M_y-values not adjusted). Differences between both values scatter around ±20%, where 117 series had higher and 153 series lower M_y-values than $M_{tor,corr}$.

$$M_{tor,corr} = \sqrt{3} \cdot M_{tor} \cdot \frac{Z_{pl}}{Z_{tor,pl}} = \sqrt{3} \cdot M_{tor} \cdot \frac{d^3/6}{\pi \cdot d^3/12} = \sqrt{3} \cdot M_{tor} \cdot \frac{2}{\pi} \approx 1.1 \cdot M_{tor} \quad (6)$$

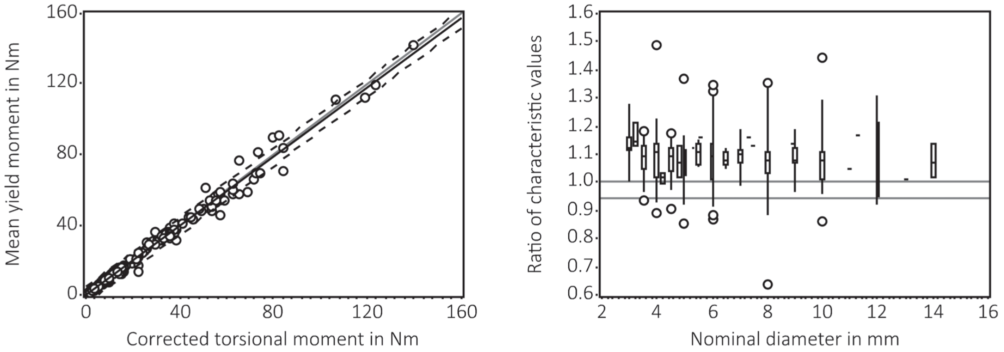

*Figure 6. Left: Yield moment versus corrected torsional moment. Mean values of 270 test series. Red line is bisect line, black line is linear regression line, dotted lines are 95% confidence intervals. Right: Boxplot of ratios of characteristic yield moments divided by characteristic torsional moments, which were calculated in accordance with EN 14358 (2016) using **uncorrected** M_{tor}-values. 5th and 95th percentiles are specified.*

where $\sqrt{3}$ = correction factor: $\tau = f_y/\sqrt{3}$; Z_{pl} = full plastic section modulus of a circular section in mm^3; $Z_{tor,pl}$ = full plastic polar section modulus of a circular section in mm^3.

Concerning a possible calculation of the characteristic yield moment based on the characteristic torsional moment, the two characteristic values could be compared directly, where 5% of the $M_{y,k}$-values can be lower than the $M_{tor,k}$- values. Therefore, the factor of 1.1 given in Eq. (6) is not applied, and uncorrected M_{tor}-values were used to calculate 5th percentiles in accordance with EN 14358 and based on a lognormal distribution. Analogously, 5th percentiles for M_y were calculated for each of the available 270 series. Figure 6 on the right shows a boxplot of the ratio of characteristic values, $M_{y,k}$ divided by $M_{tor,k}$, versus the nominal diameter. The observed 5th percentile is 0.94. This means that an additional conversion factor of 0.94 is needed. Eq. (7) shows a possible equation to calculate $M_{y,k}$ based on $M_{tor,k}$:

$$M_{y,k} = 0.94 \cdot M_{tor,k} \tag{7}$$

Simply eliminating tests to determine the yield moment is not constructive however. The ability of screws to bend without rupture cannot be validated with torsional tests. Current commonly accepted design practice asks for sufficient ductility of joints and hence sufficient elongation of screws. Independently of any possible changes in methodology, the findings of this section allow for plausibility checks, as a comparison of M_y- and M_{tor}-values can help to identify erroneous values.

5 CONCLUSIONS AND OUTLOOK

A large database comprising in total 10419 individual tests evaluating the tensile capacity, the yield and the torsional moment of a large variety of self-tapping screws was analysed. In general, about 10 tests per steel property were carried out per screw type. The observed coefficient of variation within the single test series is max. 5% as can be expected when dealing with steel properties. Between test series however, for instance considering screws with a nominal diameter of 8 mm, observed coefficients of variation were approx. 12% for carbon steel screws and approx. 28% for stainless steel screws. Consequently, the derivation of general equations valid for the whole screw population comes with the cost of conservative values for certain screws, which will be problematic in seismic design. Particularly screws made of stainless steel should be divided in austenitic and martensitic in order to differentiate between these two different types of stainless steel. Nevertheless, using the database, general design equations to determine the characteristic yield moment valid for a large range of screws can be derived. These general equations can be based on tensile or torsional test results, where the drawback of tensile tests is that capacities are determined whereas strength values are needed. For this, it must be decided if tensile capacities are transferred into tensile strength values using inner or nominal diameters. As a pragmatic approach, it is recommended to use nominal diameters, as these are known to practitioners. Considering inner diameters and a circular section is mechanically more precise, albeit not fully (Ringhofer, 2017), and there is no scope to simulate a mechanical preciseness although the test results show a persistent large scatter.

The database lacks data for screws with nominal diameters larger than 10 mm. This gap should be filled, particularly considering that exponential approaches are best suited to predict the yield moment. Concerning the experimental determination of the yield moment, EN 409 should be reviewed, extended with precise guidelines e.g. concerning the free testing length, and it should only be used to show that screws have enough deformation capability before breaking. If this is not wished for, then also precise information concerning the definition and measurement of the bending angle should be included.

Finally, a decision must be taken at which bending angle the yield moment shall be determined and how to deal with the higher yield moment in the smooth shank area of partially threaded screws.

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