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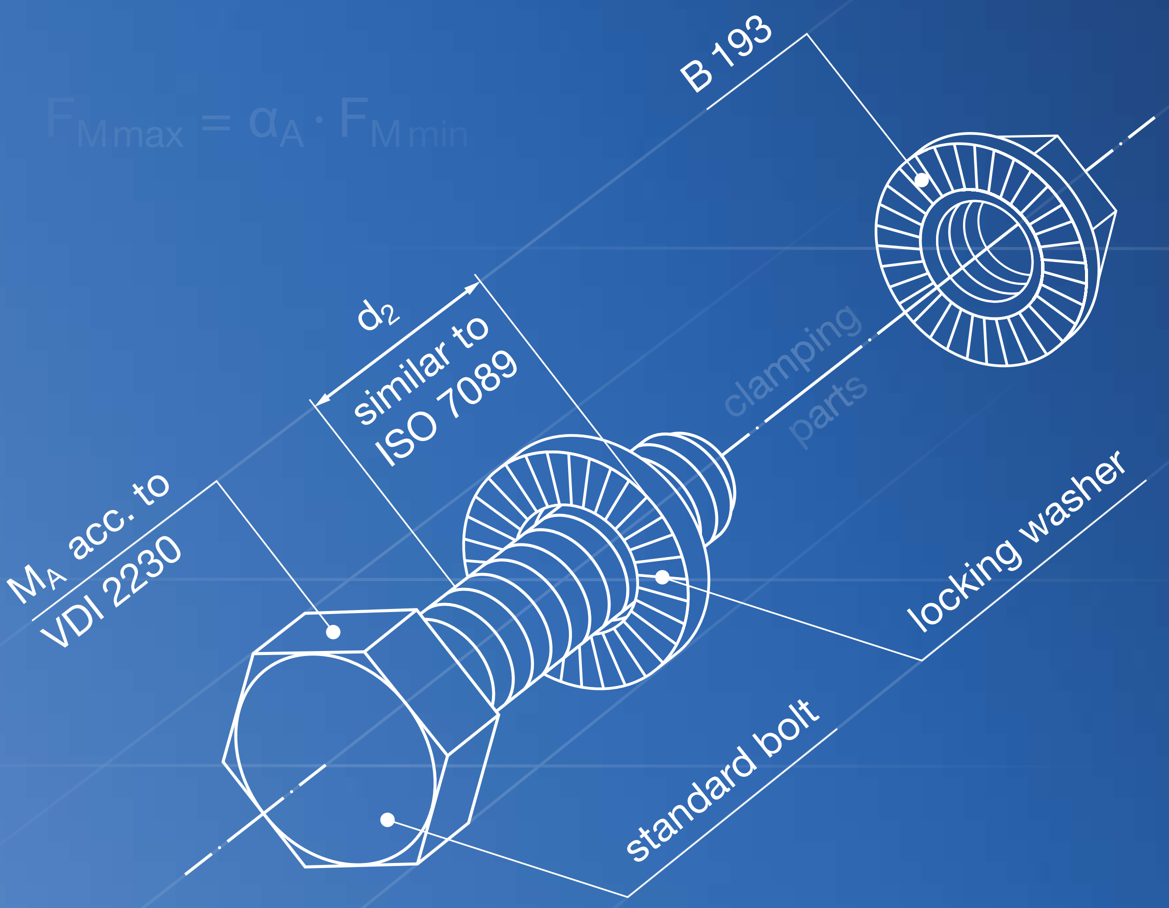
BÖLLHOFF

The Manual of fastening Technology

8th edition



THE MANUAL OF FASTENING TECHNOLOGY

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When working in the complex field of joining technology, questions arise almost every day that go beyond what's usually found in industry standards.

This technical manual provides an overview of the technology that revolves around screws to support users when these questions come up.

It shows connections between the products and their mechanical properties, provides support in the design, securing and assembly of fasteners, explains their significance and summarises information important for daily work.

The first edition of "Manual of fastening Technology" was published in 1987.
The content of the seventh edition from 2014 has been extensively revised and updated for the edition you are reading.

If you require further support, our Application Technology team is happy to help.

ECOTECH: Say "hello" to our connection optimisers

ECOTECH is an engineering consulting service that is unique in the market. With ECOTECH, Böllhoff offers technology-neutral, product-neutral solutions for various industries as a supplier of 360° joining technology and a competent manufacturer and service provider. This means that we always recommend the best possible joining technology for you, regardless of product, manufacturer or brand.

This creates outstanding potential for cost savings in procurement and for the customer when they use our joining technology. By perfecting joining technology, ECOTECH can optimise processes and thus reduce production costs. ECOTECH adapts existing or new threaded connections and brings costs down. Standardisation and reduction increase material and surface sustainability.

Table of Contents

A large number of options and individual applications demonstrate just how complex and comprehensive the task of identifying or qualifying the ideal fastener for the intended application can be.

This is particularly evident when you consider the diversity of variants involved when it comes to combining article attributes.

Strength classes and material variants	approx. 30
Common surfaces (zn, ZnNi, flZn, ZnFe, etc.)	approx. 100
Chemical coatings (adhesive, sticking, etc.)	approx. 20
Lubricant	approx. 10
Functional features according to DIN 962	approx. 50
Half dog points according to ISO 4753	approx. 25
Tool certificates, cleanliness requirements, sorting	approx. 10
Colour variants	approx. 20
Supplier specifications	min. 7
Types of packaging	approx. 15
Relevant standards for fasteners	min. 300
Dimensions per standard	approx. 20
Length gradations per standard	approx. 10
Thread types (metric or fine, UNF, etc.)	min. 20

A total of 15,120,000,000,000,000,000 (over fifteen trillion) combinations

Figure 1.1 Illustration of the complexity of fasteners through combinations of attributes

Figure 1.1 shows that these common characteristics alone produce more than fifteen trillion different fasteners. No warehouse could possibly accommodate such a range of products. This raises the question of how to classify such a diverse and extensive collection of products and variants in a clear way.

This is not the place to be providing a general, universally applicable answer to this question. Because it is clear that with such a large number of fasteners and possible combinations, not all attributes can be classified in one cluster. However, many elements are similar when it comes to geometry and/or the possible scope of application.

Screw connection type

Screw-nut connection:

This type of screw connection is probably the most common means of creating a screw connection. For this purpose, at least two elements (screw and nut) are screwed together, whereby the internal thread can also be located in one of the components to be assembled.

Tightening the screw-nut connection transmits a clamping force to the individual components. When selecting the screw, the following geometric distinctions can be made:

Inner drives

Advantages
- Good automation
- Lighter weight
- Variety of drive types

Disadvantages
- Risk of contamination
- Occasional low force transmission, e.g. cross recessed drives

External drives

Advantages
- Good tool availability
- No risk of contamination
- Good accessibility

Disadvantages
- Higher weight
- More space required for the assembly tool
- Tamper protection restricted

Aside from the types of drive and the geometric designs of the head shape, additional functions can be applied to screws and nuts. Examples for this are:

Screw-locking devices, which are intended to prevent the threaded connection from loosening even under high dynamic loads. Lead-in tips (see Figure 1.2), which can prevent damage to the nut thread even under adverse assembly situations.

So-called cross-threading is particularly common when a fitter applies the screw at an angle to the nut thread. This can lead to damage to classic screw threads. This can be remedied by appropriate Naviscrews, i.e. screws with a foundling tip that engages deeper into the thread (see Figure 1.3) and thus enables the screw to be centred.

Figure 1.2 Illustration of a Naviscrew

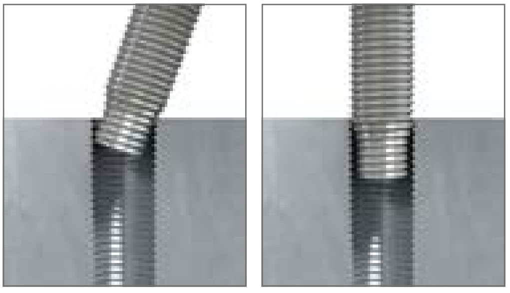


Figure 1.3 Screw-in situation when using a Naviscrew

Direct fastening

In the case of direct fastening, there is no need for an additional nut element or to create a thread in the assembly components, because the direct fastening generates its own holding thread in the screw-in part. Further details on this are provided in Chapter 8. However, at this point, it is essential to differentiate the fasteners in this cluster in terms of their application. In general, the materials into which the screws are to be screwed allow distinctions to be made.

Figure 1.4 Self-tapping screw

Sheet metal screws

Sheet metal screws are used in sheet metal, mostly thin-walled steel, non-rusting steel or light metal materials.

Three different product types can be distinguished here. Sheet metal screws for existing bores, i.e. screws where a screw hole has already been created in the workpiece by a drilling, punching or laser process.

Alternatively, if the hole cannot or should not be made on the workpiece, self-drilling screws can also be used, which have a drilling tool applied to the tip of the thread.

Another variant for sheet metal screws without a prepunched hole are so-called thin sheet screws. These have a pronounced tip geometry, which penetrates the thin sheet metal (usually < 1 mm) and forms a passage. The benefit here is that, in addition to making the process faster, more thread turns are engaged and higher loads can be transferred.

Figure 1.5 QUICK FLOW® thin sheet screw for thin sheet metal without prepunched hole

Figure 1.6 AMTEC® screws for thermoplastics

Use in plastics

Special flank geometries and core diameters are designed in order to ensure optimal performance in plastics. Different thread types can be distinguished, which are used depending on the type of plastic (thermoplastic or duroplastic).

Metallic materials

For metallic materials, a large number of screws are defined by standards (DIN 7500) and produce a metric or metric-compatible thread during initial assembly. These enable very economical to produce, but can be replaced with standard screws during maintenance.

Special types

There are also special types of screws that have been developed for fixed applications and are defined in DIN or ISO standards. These include DIN 580 eye bolts which are suitable for lifting loads, or factory standards in which additional security functions are combined with common fasteners, such as in our RIPP LOCK® range.

The variety of products shows that there is no such thing as the "right" screw or the "right" fastener. What really matters is a sensible selection and combination of suitable article attributes. Clever combinations of characteristics can open up new fields of application and help improve existing designs economically and technically.

The screw is a universal, widely used fastener.

Due to the different requirements for connections across industries and applications, certain types of screws, e.g. metric screws, self-tapping screws, sheet metal and thin sheet screws, wood screws, etc. established in the industry.

In addition to special solutions, a large number of internationally standardised fasteners are available worldwide in various shapes, dimensions, materials and strength classes.

Rules have been defined and recorded in standards for the design of certain screw connections, see Table 2.1.

Contents	Chapter
DIN EN 1591	Part 1 to 5: Flanges and their joints – Design rules for gasketed circular flange connections (see also DIN EN 1515)
AD 2000 data sheet B7	Design of pressure vessels – Boltings
VDI Guideline 2230	Systematic calculation of highly stressed bolted joints
DVS 2241	Part 1: Direct fastening into mouldings made of plastics
DIN 7500	Self-tapping screws for metals
DIN EN ISO 13445	Unfired pressure vessels – Part 3: Design
DIN 15018	Part 1 to 3: Cranes; principles relating to steel structures; design of cranes on vehicles
DIN 18800	Steel structures – Part 1: Planning and design
DIN 25201	Part 2 and 3: Design guide for railway vehicles and their components – bolted joints

Table 2.1 Rules and standards for the design of screw connections (Note: this list is not exhaustive)

In the field of mechanical engineering, for example, critical screw connections are designed and calculated according to VDI 2230 as high-strength, prestressed and non-slip connections. The tightening torque must be defined in such a way that the resulting preload force leads to pure friction locking in the joint between the components and these cannot be moved against each other. A bearing stress-based design, such as with fitted screws or rivet connections, is not permitted in mechanical engineering because the components here are supported on the screw shaft.

In the field of pressure equipment and pipeline construction, depending on the type of container, e.g. fired or unfired, and depending on the requirements, flange connections with seals in the main connection are not designed according to VDI 2230, but according to standards including DIN EN 1591, DIN EN ISO 13445 and AD 2000 data sheet B7. To assess stress processes, the degree of utilisation is determined for the flange, bolts and seal.

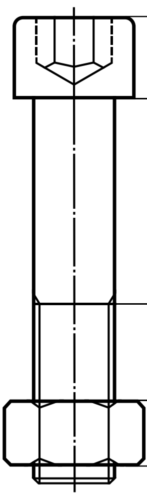
Self-tapping screws not only have to connect several components with one another, they also have to be able to form a counter-thread. The design to meet these requirements is found in DIN 7500 for metal self-tapping screws and in DVS 2241 for plastic self-tapping screws. No standardised, purely mathematical design is available at present due to a variety of factors. Therefore, screw connection tests are always performed to measure dimensions such as the drilling diameter and the joining torques and overtorques.

Ultimately, the design of screw connections depends largely on the application and the requirements for the connection. There are currently a number of standardised works for the design of screw connections. Only design in the field of mechanical engineering is considered below.

Design principle

The load capacity of a screw depends heavily on the screw geometry and the assembly and operating forces acting on the screw. If the load on the screw is too high, the screw will fail at the point of lowest load capacity.

If you look at a screw close-up, it can be divided into several load capacity areas. Figure 2.1 shows the load capacity areas and the possible screw failure types in these areas.



	Load capacity	Failure location	Failure due to:
Head	$F_{S\ head}$	1	Shearing off the screw head
		2	Fracture at the transition between head and shaft
Shaft	$F_{B\ shaft}$	3	Fracture in the unnotched part of the shaft
		4	Fracture in the thread outlet
free loadable thread	$F_{B\ thread}$	5	**Fracture in the free loaded thread**
		6	Fracture in the first load-bearing thread
engaged thread	$F_{S\ thread}$	7	Stripping off of the engaged bolt and/or nut thread

Figure 2.1 Design principle for screw connections in mechanical engineering (source: Screw connections – basics, calculation, characteristics, handling – Wiegand, Kloos, Thomala)

When designing screw connections in mechanical engineering, the design principle has long proven its worth. The design principle requires that the load capacity of the screw head, the screw shaft and the engaged thread, considered individually, be higher than the load capacity of the freely loaded thread.

Design principle: $F_{B\ thread} < F_{S\ head}$, $< F_{B\ shaft}$, $< F_{S\ thread}$

Put simply, if the threaded connection is overstressed, the screw should break in the free, loaded thread.

By coordinating the load capacity in this way, a defined failure limit of the screw connection is ensured in the event of overstressing. On the other hand, the imminent screw breakage at this point is usually indicated by a preceding plastic deformation in the form of a constriction and consequently by e.g. leaks or noise from loosened parts. It is possible to make a timely repair before the damage event occurs.

Most metric standard screws and nuts are designed according to this principle. For exceptions such as the DIN 6912 – cylinder screw with low head or the DIN EN ISO 4036 – low hexagon nut, refer to the reduced load capacity in the corresponding product standards.

Design

In a basic screw connection, at least two components are connected to each other by means of a form fit and force fit, see Figure 2.2. The tightening torque applied during assembly indirectly generates a mounting preload force in the screw. Due to the preload force generated, the screw is lengthened, the components are tightened and shortened against each other and friction locking occurs in all joints. It only usually becomes apparent that a screw connection has been well designed during the operation stage, when additional external operating forces act on the screw connection.

When designing a classic screw connection in mechanical engineering, great importance is attached to the preload force, see Figure 2.3. The preload force must be determined by a relatively complex calculation. The design of the screw connection and the mechanical properties of the fasteners required to withstand the preload force are specified in the calculation.

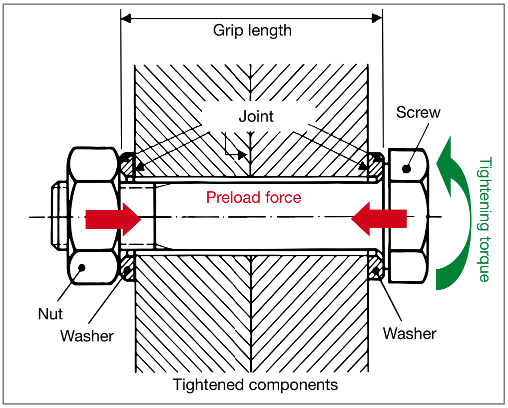


Figure 2.2 Assembly state of a prestressed screw connection

The assembly method selected to generate the preload force is also taken into account in the calculation. In certain cases, it must be checked whether the preload force generated remains during operation and whether a securing method needs to be provided.

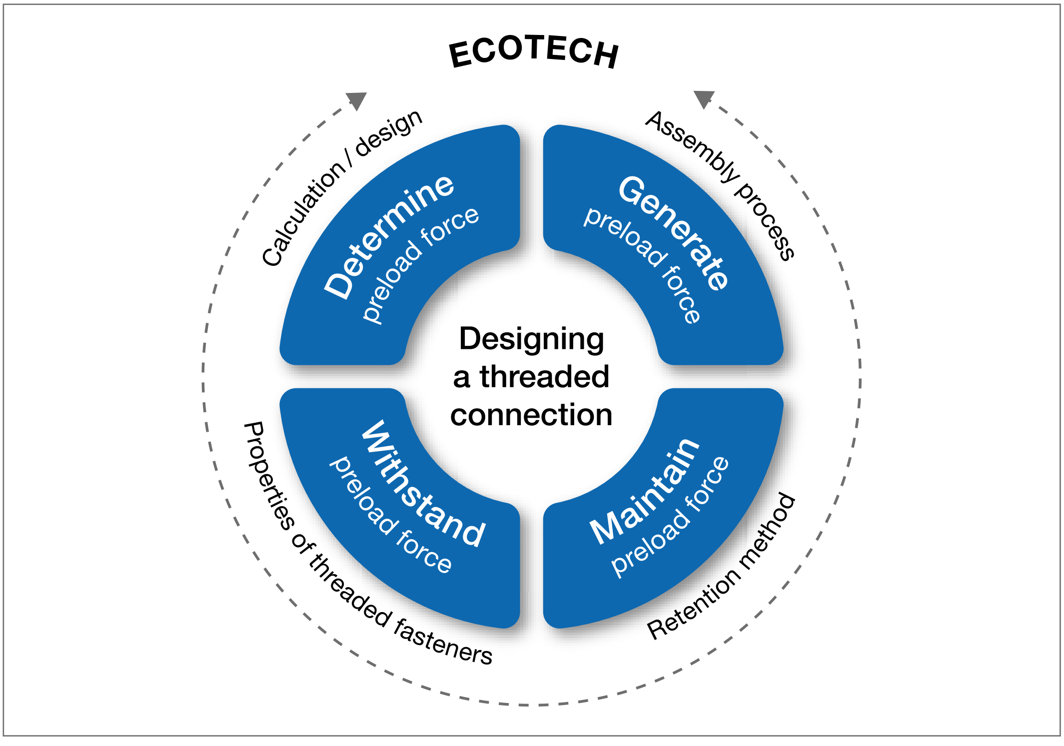


Figure 2.3 Importance of the preload force when designing a screw connection

The internationally recognised guideline VDI 2230 represents a systematic procedure for the functional and operationally reliable design of high-strength screw connections.

The guideline is divided into two parts. The first part specifies detailed calculation steps for calculating single-screw connections.

The second part deals with multi-screw connections. On the one hand, analytical calculation methods for determining the load distribution on the individual screw points of a multi-screw connection are shown, taking into account the deformation behaviour, the overall structure and the interaction of all screws.

On the other hand, possibilities of using the finite element method (FEM) as a numerical method for screw calculation are presented. FEM are used in particular to calculate multi-screw connections in geometrically complex structures that are difficult to calculate using analytical methods.

As a rule, the present multi-screw connection is analysed at the beginning of a screw calculation and the most heavily loaded screw connection is determined with its load values and extracted virtually.

The single-screw connection extracted in this way, with its known load and geometry parameters, is calculated according to the steps R0 to R13 specified in VDI 2230 Sheet 1, see Table 2.2.

Boundary conditions		
	Function, load, geometry, materials, strength classes, surfaces, tightening methods, tightening devices	
Requirements		
R0	Nominal diameter, limit dimension	d G
R1	Tightening factor	α_A
R2	Minimum clamping force	F_{Kerf}
Tension triangle		
R3	Distribution of the operating force Force ratio	F_{SA}, F_{PA} Φ
R4	Preload force changes	F_Z, $\Delta F'_{Vth}$
R5	Minimum mounting preload force	F_{Mmin}
R6	Maximum mounting preload force	F_{Mmax}
Stress cases and proof of strength		
R7	Assembly stress	$\sigma_{red, M}$, F_{Mperm}
R8	Operational stress	$\sigma_{red,B}$, S_F
R9	Vibration stress	σ_a, σ_{ab}, S_D
R10	Surface pressure	p_{max}, S_P
R11	Minimum screw-in depth	$m_{eff min}$
R12	Sliding, shearing	S_G, τ_{max}
R13	Tightening torque	M_A

Table 2.2 Calculation steps according to VDI 2230 Sheet 1 (source: VDI 2230-1)

This calculation can be roughly divided into three sections.

In the **first section**, steps R0 to R2, the screw diameter, amongst other measurements, is determined approximately, then the tightening method, and the tightening factor that determines the scatter between the maximum and minimum mounting preload force are determined, and then the clamping force, which is required for further calculation, is calculated or defined.

The focus of the **second section**, steps R3 to R6, is on calculating the mounting preload force.

$$F_{Mmax} = \alpha_A \left[F_{Kerf} + (1 - \Phi)\, F_A + F_Z + \Delta F_{Vth} \right]$$

All loads acting on the connection, such as the required clamping force, the maximum operating forces, the setting forces and the thermal loads, are taken into account in the calculation.

The required clamping force is determined by the requirements for the transmission of the transverse forces through friction locking in the joint, sealing against media or preventing gaping in the joint. The setting force depends on the number of joints and the flexibility of the screw and the clamped parts.

In this way, the level of mounting preload force is set sufficiently so that no relative movement occurs between the components during operation under any load.

The quantities determined can be shown in a stress diagram, see Figure 2.4. This shows, for example, how an operating force is distributed according to the elasticity of the screw and the clamped parts. In the case of tensile stress, the additional screw force increases only relatively slightly, but the clamping force remaining in the joint decreases relatively strongly.

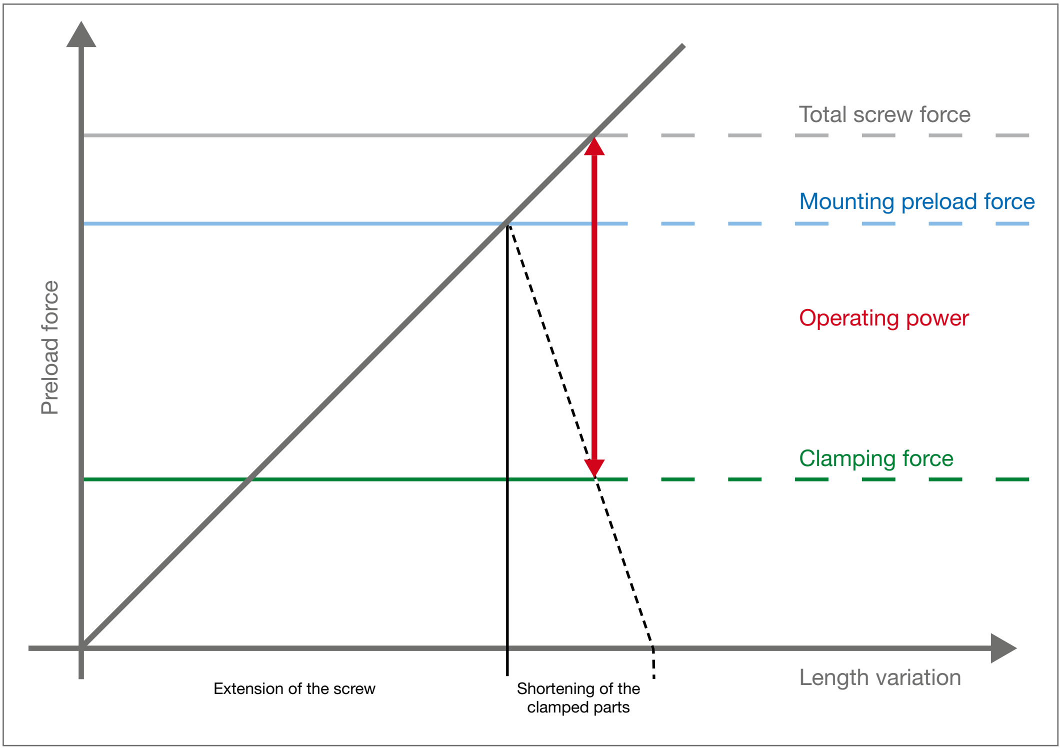


Figure 2.4 Stress diagram

In the **third section**, steps R7 to R12, load cases are calculated in the assembled state, mainly in the operating state, and the proof of strength is provided for each load case.

In order to rule out screw failure, the stresses in the screw arising under preload and operating load are verified against the minimum yield limit of the screw material.

In order to avoid creep processes, which would lead to a reduction in the preload, it is ensured that the surface pressure achieved due to the specified mounting preload force does not exceed the permissible boundary surface pressure of the clamped parts.

In order to ensure that, in the event of overloading of the connection, the screw fails in the free thread or in the screw shaft in accordance with the design principle, care is taken to ensure that the existing screw-in depth is not less than the minimum screw-in depth.

In order to rule out sliding, it is also ensured that the minimum residual clamping force occurring in the connection is not less than the clamping force required to transmit the transverse forces.

If the proof of strength is not provided, the calculation must be performed, e.g. by changing the screw geometry, the screw size or the screw strength in a new iteration loop.

In the event that the screw is oversized according to the approximate diameter determination, the utilisation of the physical characteristics of the screw is increased – e.g. by reducing the strength class. The rule is: the preload force should be so high that the screw is preloaded to at least 75% of its yield limit. According to VDI 2230, a level of 90% the minimum yield limit is the target. This makes optimum use of the screw, with a 10% certainty before plastic deformation begins.

Finally, in step R13, the tightening torque required to generate the required mounting preload force is calculated.

$$M_A = F_M \left(0.16 \cdot P + 0.58 \cdot d_2 \cdot \mu_G + \frac{D_{KM}}{2} \cdot \mu_K\right)$$

$$M_A = M_{GSt} + M_{GR} + M_K$$

The tightening torque consists of the thread pitch torque, the thread friction torque and the head friction torque. The calculation includes, among other things, the two coefficients of friction in the thread and under the head.

A screw connection designed and screwed according to VDI 2230 is usually designed to be safe. However, in case of dynamic loads, particularly vibrations, effects may occur that cause a screw connection to come loose, even though permissible limit values are not exceeded, see Figure 2.5.
The independent loosening is caused by vibrating transverse forces perpendicular to the screw axis that change direction over time. This eliminates the friction or the self-locking in the thread and on the contact surfaces of the screw head and the nut.

No standardised calculation to prevent independent loosening currently exists. The theory of independent loosening is described in DIN 25201-4.
The standard also describes a comparative test for evaluating securing elements. The evaluation of the screw connection, depending on the selected frequency and amplitude, is carried out by comparing the existing transverse displacement and the theoretical limit displacement.

Experience has shown that no additional securing measures against independent loosening are usually required for metallic components with a grip length/nominal diameter ratio of $l_K/d_{nominal} > 5$, a low number of joints, sufficient preload force and no dynamic loads. Otherwise, the use of an additional screw-locking devices should be considered, see Chapter 9.

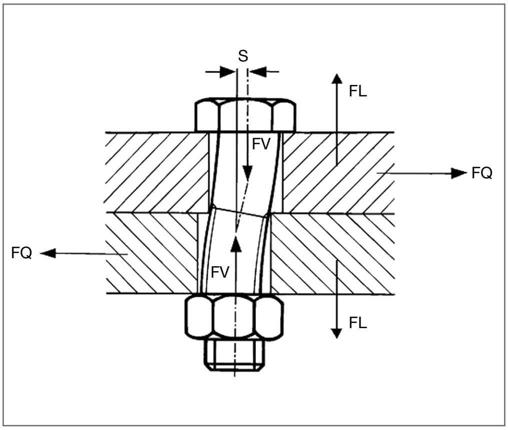


Figure 2.5 Independent loosening and shifting of limit S

Influence of friction

Since the preload force can only be set indirectly via the assembly tightening torque when assembling the screw, precise knowledge of the friction conditions is of crucial importance. A distinction must be made between the friction in the thread itself and on the contact surfaces.

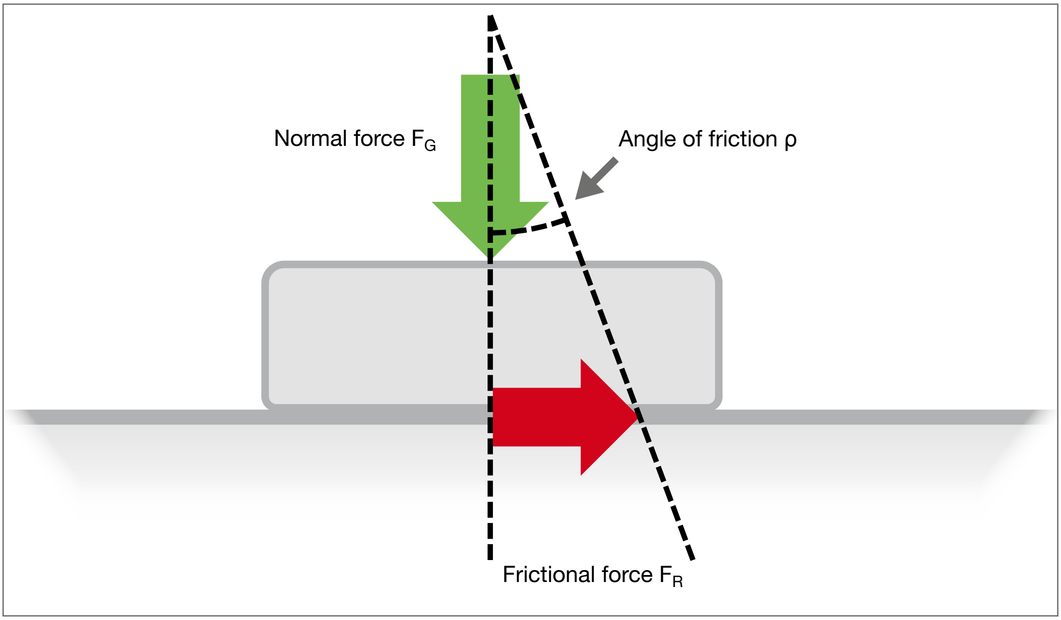


Figure 2.6 Relationship between normal and frictional force

The friction angle ρ describes the relationship between the normal force F_G and the resulting frictional force F_R.

With regard to a threaded connection, the normal force can be equated with the preload force as an initial approximation.

As long as the pitch angle φ of the thread is smaller than the friction angle ρ, the thread is self-locking. In order to optimise this effect, either the thread friction can be increased or the thread pitch reduced.

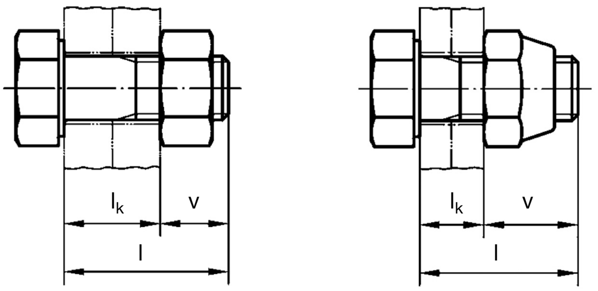
The influence of friction on the contact surfaces is much more difficult to determine. However, it can be stated that increased friction, e.g. under the screw head at the given tightening torque leads to a lower preload force on the one hand but counteracts an independent loosening of the screw on the other.

Layout

The selection of the required screw diameter and strength class is based on precise knowledge of all the loads that occur and is therefore dependent on the respective application.

However, some general recommendations can be given for determining screw length. The decisive factor here is that sufficient thread turns are engaged in order to transfer the forces that occur.

A distinction must be made between a bolt connection and a screw connection in a threaded blind hole:
When designing bolt connections, the nominal length of the screw results from the sum of the grip length l_K and the screw protrusion v (according to DIN 78 Screw Protrusions). Compliance with these protrusions must be observed specifically to ensure a secure connection.

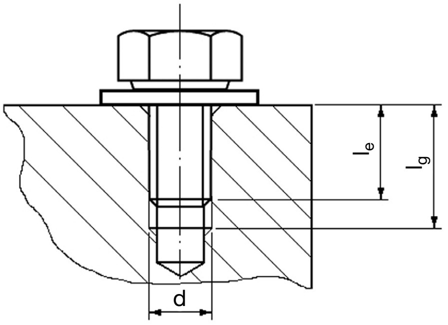


Hexagon head screws with hexagon nut

Hexagon head screw with self-locking nut

l_k: Grip length
v: Screw protrusion
l: Nominal length of the screw

Figure 2.7 Bolt connection – screw protrusions according to DIN 78



l_e: Screw-in length
d: Screw diameter
l_g: Usable thread length

Figure 2.8 Blind hole screw connection

The assignment of the screw to a nut according to strength class (a screw of strength class 8.8 should be paired with a nut of class 8 or higher) is very clear.

In contrast, with a blind hole screw connection, the required screw-in length l_e depends on the strength of the material of the respective component in which the internal thread was introduced, see Table 2.3.

Material of the components		Screw-in length l_e ❷ with strength class of the screw 3.6 / 4.6	4.8...6.8	8.8	10.9
Steel with	≤ 400	0.8 · d	1.2 · d	–	–
R_m N/mm²	400 … 600	0.8 · d	1.2 · d	1.2 · d	–
	> 600...800	0.8 · d	1.2 · d	1.2 · d	1.2 · d
	> 800	0.8 · d	1.2 · d	1.0 · d	1.0 · d
Cast iron		1.3 · d	1.5 · d	1.5 · d	–
Copper alloys		1.3 · d	1.3 · d	–	–
Light metals ❶	Al cast alloys	1.6 · d	2.2 · d	–	– ❸
	Pure aluminium	1.6 · d	–	–	– ❸
	Al alloy hardened	0.8 · d	1.2 · d	1.6 · d	– ❸
	not hardened	1.2 · d	1.6 · d	–	– ❸
Soft metals, plastics		2.5 · d	–	–	–

❶ In the case of dynamic loading, l_e must be increased by about 20%. Source: Roloff/Matek
❷ Fine pitch threads require an approximately 25% longer screw-in length.
❸ For higher strength screws, the shear strength of the internal thread material according to VDI 2230 must be taken into account.

Table 2.3 Minimum screw-in depths in blind hole threads (source: Roloff/Matek)

When determining the nominal length of screws, the possible tolerances of the parts to be screwed must be taken into account. Furthermore, the length tolerances of the screws and the tolerances of the nut height must be observed.

Whenever possible, the calculated length is to be rounded up to the next larger nominal length specified in the relevant product standards (dimensional standards).

In comparison to the above specifications for the minimum screw-in length depending on screw and component strength, the screw-in length can be reduced by using HELICOIL® thread inserts.
See DIN 8140.

Example:
Screw M 8 with strength class 10.9
in aluminium with a tensile strength of
R_m = 250 ... 270 N/mm²
and permissible shear stress
T_{perm} = 0,7 x R_m = 180 N/mm²
Without HELICOIL®:
Thread length min 2 x d (according to VDI 2230)
With HELICOIL®:
Thread length 1.5 x d (according to DIN 8140 T1 3.1)

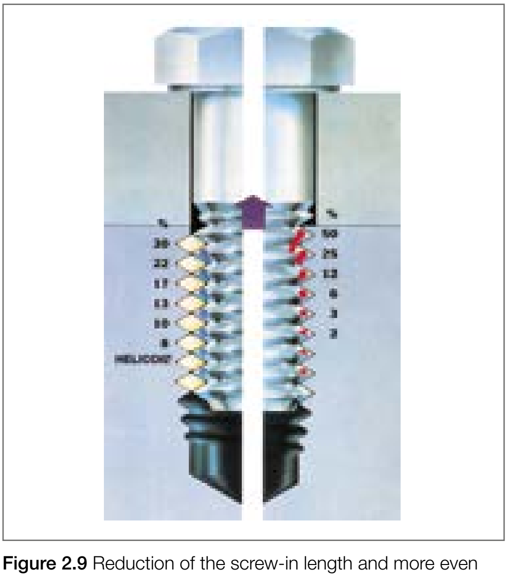


Figure 2.9 Reduction of the screw-in length and more even distribution of force in the thread thanks to HELICOIL® use

The load capacity of the connecting parts, and thus their mechanical properties, are the key factors for the user. These characteristics are not only determined by the material used, but also by the manufacturing process, during which the material characteristics can change.

The wire section of the starting material has different characteristics to the finished screw, which is cold-formed, quenched and tempered.

The manufacturer selects the material within the standard specifications with which they can achieve and deliver the required characteristics in the finished part. (Responsibility of the manufacturer or supplier)

The user selects the strength class that has the right mechanical properties for their application. (Responsibility of the designer)

Steel screws

There are 10 strength classes for screws.

Strength classes	3.6	4.6	4.8	5.6	5.8	6.8	8.8	9.8	10.9	12.9

The strength classes are denoted by two numbers separated by a dot. The first number corresponds to 1/100 of the minimum tensile strength in N/mm^2. The second number indicates 10 times the ratio between the lower yield limit (or 0.2 elasticity limit) and the tensile strength in N/mm^2.

Figure 3.1 Marking of the strength class on the screw head

Marking using strength class 5.6 as an example:
First number: 5 × 100 N/mm^2 = 500 N/mm^2 = minimum tensile strength
Second number: (6 × 500) : 10N/mm^2 = 60% of 500 N/mm^2 = 300N/mm^2 = yield limit

Strength class naming system

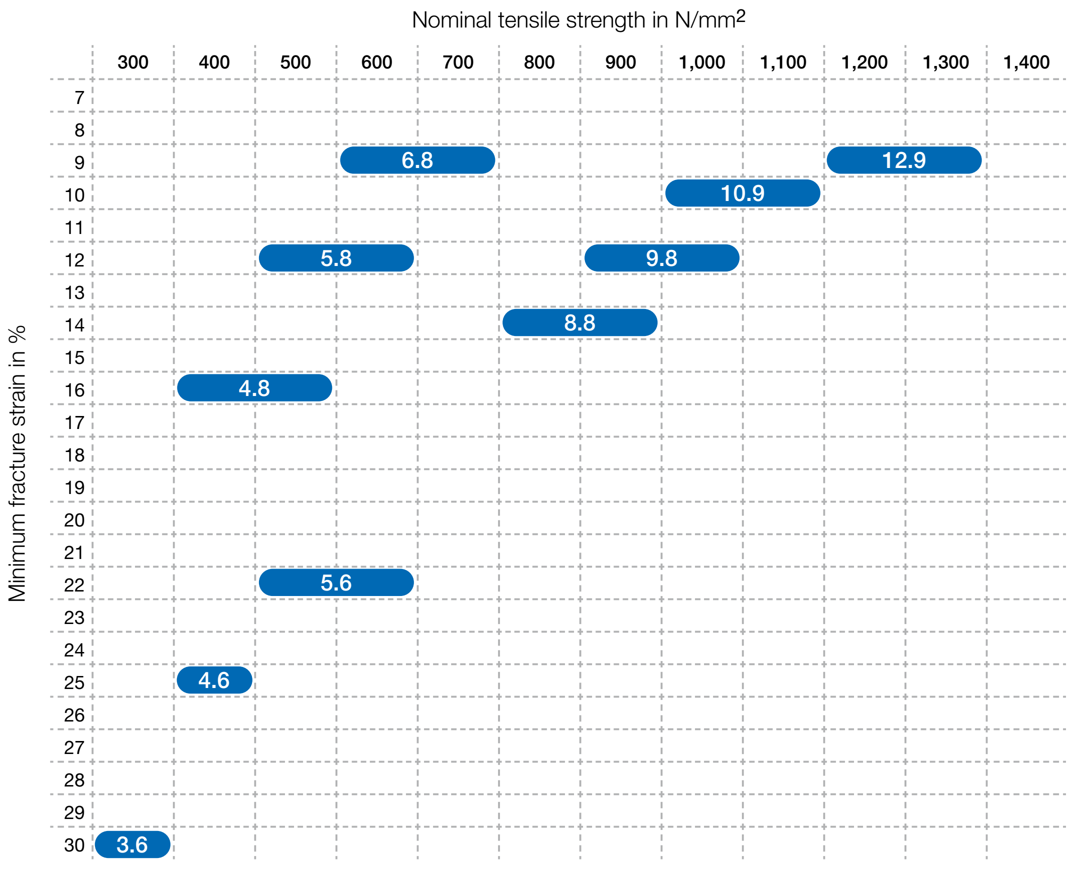


Table 3.1 Strength classes (source: DIN EN ISO 898-1)

The strength classes listed do not apply to all types of standardised screws.
A reasonable selection of strength classes is provided by the individual product standards.

03

Mechanical and physical characteristics

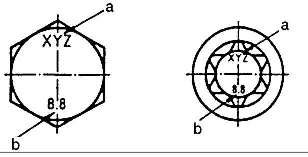
No.	Mechanical or physical property		Strength classes 4.6	4.8	5.6	5.8	6.8	8.8 d ≤ 16mm[a]	8.8 d > 16 mm[b]	9.8 d ≤ 16 mm	10.9	12.9/ 12.9
1	Tensile strength, R_m, N/mm^2	nom.[c]	400		500		600	800		900	1000	1200
		min.	400	420	500	520	600	800	830	900	1040	1220
2	Lower yield limit, R_{eL}[d], N/mm^2	nom.[c]	240	–	300	–	–	–	–	–	–	–
		min.	240	–	300	–	–	–	–	–	–	–
3	0.2% elasticity limit, $R_{p0.2}$, N/mm^2	nom.[c]	–	–	–	–	–	640	640	720	900	1080
		min.	–	–	–	–	–	640	660	720	940	1100
4	0.004 8 d elasticity limit for whole screws, R_{pf}, N/mm^2	nom.[c]	–	320	–	400	480	–	–	–	–	–
		min.	–	340[e]	–	420[e]	480[e]	–	–	–	–	–
5	Stress under test force, S_pf, N/mm^2	nom.	225	310	280	380	440	580	600	650	830	970
	Test strength ratio $S_{p,nom}/R_{eL\,min}$ or $S_{p,nom}/R_{p0.2\,min}$ or $S_{p,nom}/R_{pf\,min}$		0.94	0.91	0.93	0.90	0.92	0.91	0.91	0.90	0.88	0.88
6	Percentage fracture strain of a machined sample, A, %	min.	22	–	20	–	–	12	12	10	9	8
7	Percent reduction at break of a machined sample, Z, %	min.	–					52		48	48	44
8	Fracture elongation of a whole screw, A_f (see also Annex C)	min.	–	0.24	–	0.22	0.20	–	–	–	–	–
9	Head impact strength		No break									
10	Vickers hardness, HV F ≥ 98 N	min.	120	130	155	160	190	250	255	290	320	385
		max.	220 [g]				250	320	335	360	380	435
11	Brinell hardness, HBW F = 30 D^2	min.	114	124	147	152	181	238	242	276	304	366
		max.	209 [g]				238	304	318	342	361	414
12	Rockwell hardness, HRB	min.	67	71	79	82	89	–				
		max.	95.0 [g]				99.5	–				
	Rockwell hardness, HRC	min.	–					22	23	28	32	39
		max.	–					32	34	37	39	44
13	Surface hardness, HV 0.3	max.	–					h			h, i	h, j
14	Height of non-decarburised thread zone, E, mm	min.	–					½ H1			⅔ H1	¾ H1
	Depth of carburisation in thread, G, mm	max.	–					0.015				
15	Hardness drop after re-tempering (hardening), HV	max.	–					20				
16	Breaking torque, MB, Nm	min.	–					according to ISO 898-7				
17	Impact work, KV [k, l], J	min.	–		27	–		27	27	27	27	m
18	Surface condition according to		ISO 6157-1[n]									ISO 6157-3

Table 3.2 Mechanical and physical characteristics assigned to the strength classes (source: DIN EN ISO 898-1)

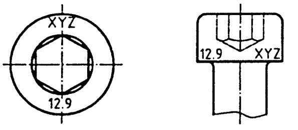
BÖLLHOFF

Marking for steel screws

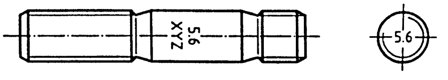
Hexagon head screws and hexagon head, all strength classes from thread diameter M 5 with manufacturer (a) and strength class (b).



Cylinder screws with hexagon socket and internal hex socket for 8.8 and higher from thread diameter M 5 with manufacturer and strength class.

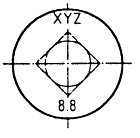


Engineer studs 5.6, 8.8 and higher from thread diameter M 5 with manufacturer and strength class or mark.

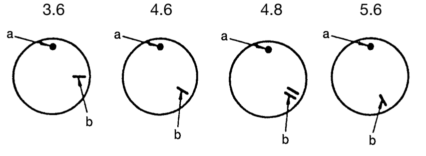


Strength class	5.6	8.8	9.8	10.9	12.9
Mark	—	○	+	□	△

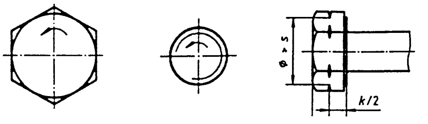
Cup square bolts with square neck 8.8 and higher from thread diameter M 5 with manufacturer and strength class.



Small screws and other head shapes
Marking by a dot or the manufacturer's mark at the 12 o'clock position (a).
The strength class is marked with a dash (b).



Left-hand thread screws are marked with an arrow on the head or thread end, or with notches on the hexagon.



Screws with reduced load capacity, e.g. which do not have the required fracture cross-section of the screw head, must be provided with a 0 in front of the strength class according to DIN EN ISO 898-1 (2013) (example 012.9). The products are partially standardised, e.g. low-head cylinder screws or EN ISO 7380 rounded head screws with hexagon socket.

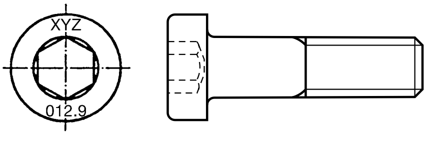


Figure 3.2 Markings on steel screws (source: DIN EN ISO 898-1)

03

Steel nuts

Only one code number is given for the strength classes for nuts. This number indicates approx. 1/100 of the test stress in N/mm^2. This corresponds to the minimum tensile strength of the associated screw.

A screw of strength class 8.8 is paired with a nut of strength class 8 (or higher). In this connection, the screw can be loaded up to the yield limit.

However, there are also nuts with a limited load capacity (see next page).

Test forces for nuts ISO 4032 with regular thread

Thread	Thread pitch	Nominal stress cross-section of the test mandrel	Strength class							
			4	5	6	8		10	12	
			Test force (As × S_p), N							
d	mm	mm^2	Type 1	Type 1	Type 1	Type 1	Type 2	Type 1	Type 1	Type 2
M 3	0.5	5.03	–	2,600	3,000	4,000	–	5,200	5,700	5,800
M 3.5	0.6	6.78	–	3,550	4,050	5,400	–	7,050	7,700	7,800
M 4	0.7	8.78	–	4,550	5,250	7,000	–	9,150	10,000	10,100
M 5	0.8	14.2	–	8,250	9,500	12,140	–	14,800	16,200	16,300
M 6	1	20.1	–	11,700	13,500	17,200	–	20,900	22,900	23,100
M 7	1	28.9	–	16,800	19,400	24,700	–	30,100	32,900	33,200
M 8	1.25	36.6	–	21,600	24,900	31,800	–	38,100	41,700	42,500
M 10	1.5	58	–	34,200	39,400	50,500	–	60,300	66,100	67,300
M 12	1.75	84.3	–	51,400	59,000	74,200	–	88,500	98,600	100,300
M 14	2	115	–	70,200	80,500	101,200	–	120,800	134,600	136,900
M 16	2	157	–	95,800	109,900	138,200	–	164,900	183,700	186,800
M 18	2.5	192	97,900	121,000	138,200	176,600	170,900	203,500	–	230,400
M 20	2.5	245	125,000	154,400	176,400	225,400	218,100	259,700	–	294,000
M 22	2.5	303	154,500	190,900	218,200	278,800	269,700	321,200	–	363,600
M 24	3	353	180,000	222,400	254,200	324,800	314,200	374,200	–	423,600
M 27	3	459	234,100	289,200	330,500	422,300	408,500	486,500	–	550,800
M 30	3.5	561	286,100	353,400	403,900	516,100	499,300	594,700	–	673,200
M 33	3.5	694	353,900	437,200	499,700	638,500	617,700	735,600	–	832,800
M 36	4	817	416,700	514,700	588,200	751,600	727,100	866,000	–	980,400
M 39	4	976	497,800	614,900	702,700	897,900	868,600	1,035,000	–	1,171,000

Table 3.3 Test forces for nuts according to ISO 4032 with regular thread (source: DIN EN 20898-2)

Marking for nuts with strength classes

Hexagon nuts of all strength classes from thread diameter M 5 on the contact surface or spanner flat.

Marking according to the clockwise system.
The 12 o'clock position is defined by a dot or the manufacturer's mark, the strength class by a dash.

Nuts with nominal heights ≥ 0.5 D but < 0.8 D are marked with a two-digit number. The load capacity of these nuts is limited.

Left-hand thread nuts are marked with an arrow on the contact surface or with notches on the hexagon.

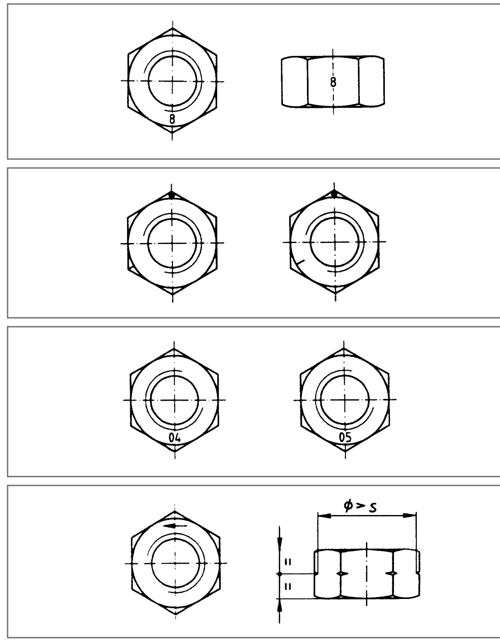


Figure 3.3 Markings on steel nuts (source: DIN EN 20898-2)

Nuts with limited load capacity

Nuts according to the withdrawn standard **DIN 934** (with nominal heights of approx. 0.8 D) cannot be safely loaded up to the yield limit of the associated screw. To differentiate, the marking of the strength class is supplemented by two vertical bars which sandwich the code, e.g. I8I instead of 8.

Nuts with nominal heights ≥ 0.5 D but < 0.8 D are marked with the strength classes 04 and 05.
DIN EN 20898-2 specifies test forces and stripping strengths for these flat nuts.

Nut strength class	Nut test voltage N/mm²	Minimum tension in the screw before stripping in N/mm² when paired with screws of the strength class			
		6.8	8.8	10.9	12.9
04	380	260	300	330	350
05	500	290	370	410	480

Table 3.4 Stripping strengths for nuts with nominal heights ≥ 0.5 D, but <0.8 D (source: DIN EN 20898-2)

No test forces are specified for **nuts with hardness classes**. The strength classes are named according to the minimum hardness. The numbers indicate 1/10 of the minimum hardness according to Vickers HV 5.

	Hardness class							
	11 H		14 H		17 H		22 H	
Mechanical property	min.	max.	min.	max.	min.	max.	min.	max.
Vickers hardness HV 5	110	185	140	215	170	245	220	300
Brinell hardness HBW 30	105	176	133	204	162	233	209	285

Table 3.4 Hardness classes for nuts without specified test forces (source: DIN 267-24)

Set screws

Set screws and similar threaded parts made of carbon steel and alloyed steel that are not subject to tensile stress are standardised according to DIN EN ISO 898 Part 5.
The hardness classes are based on the Vickers hardness.

Set screw with slot and flat point

Set screw with hexagon socket and flat point

Figure 3.4 Set screws

	Hardness class			
Mechanical property	14 H	22 H	33 H	45 H
Vickers hardness HV min	140	220	330	450

Table 3.6 Naming of the hardness classes in relation to the Vickers hardness (source: DIN EN ISO 898-5)

There does not have to be a marking for the hardness class on the fasteners for these parts.

Screws and nuts made of non-rusting steel

In addition to fasteners made of steel with strength classes such as 8.8 or 10.9, fasteners made of non-rusting steel are often used. Stainless steel is often used when e.g. special requirements are placed on corrosion resistance or cleanliness.

Iron oxide forms on the surface of fasteners made of low-alloy steels. The steel rusts. Fasteners made of low-alloy steels usually have to be coated to protect against corrosion. Chromium oxide forms on the surface of fasteners made of alloyed steels with a chromium content of 10.5% or more. The thin chromium oxide layer protects the fastener from corrosion. The steel is rust resistant.

Naming systems for rustproof screws, nuts and set screws

from DIN EN ISO 3506-1 and DIN EN ISO 3506-2

The rust-resistant screws and nuts are divided into steel groups, steel grades and strength classes according to DIN EN ISO 3506 Part 1 and Part 2.

In DIN EN ISO 3506 Part 3, set screws and similar fasteners that are not subject to tensile stress are divided into steel groups, steel grades and hardness classes.

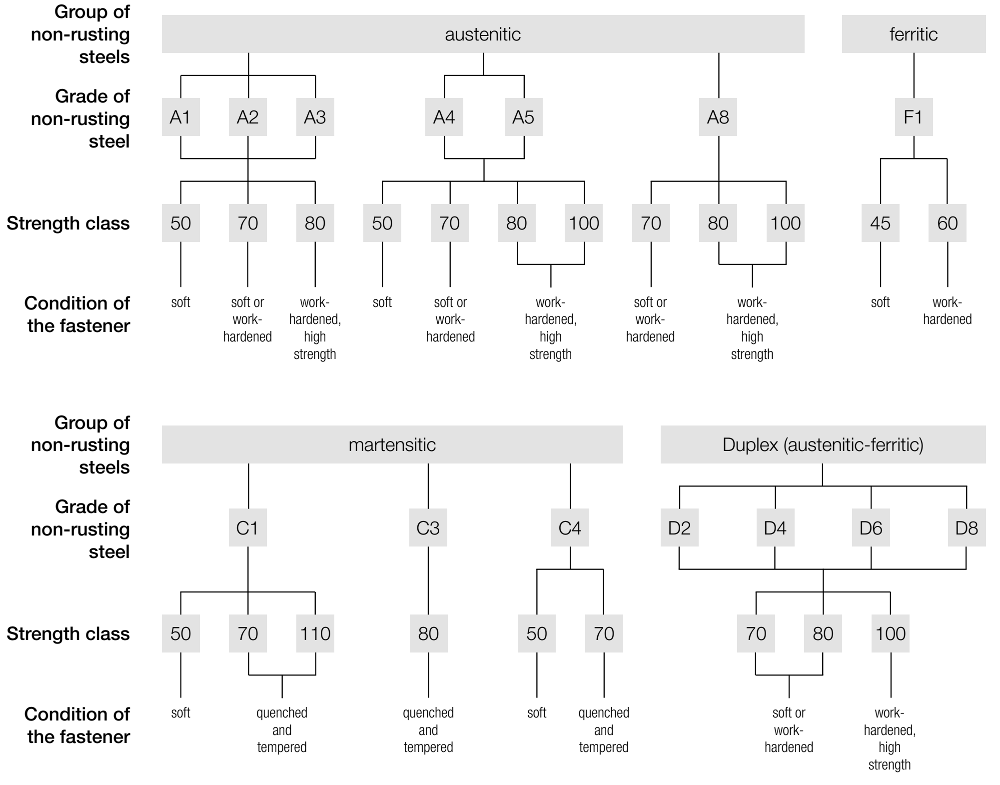


Figure 3.5 Naming system for rustproof screws (source: DIN EN ISO 3506-1:2020-08)

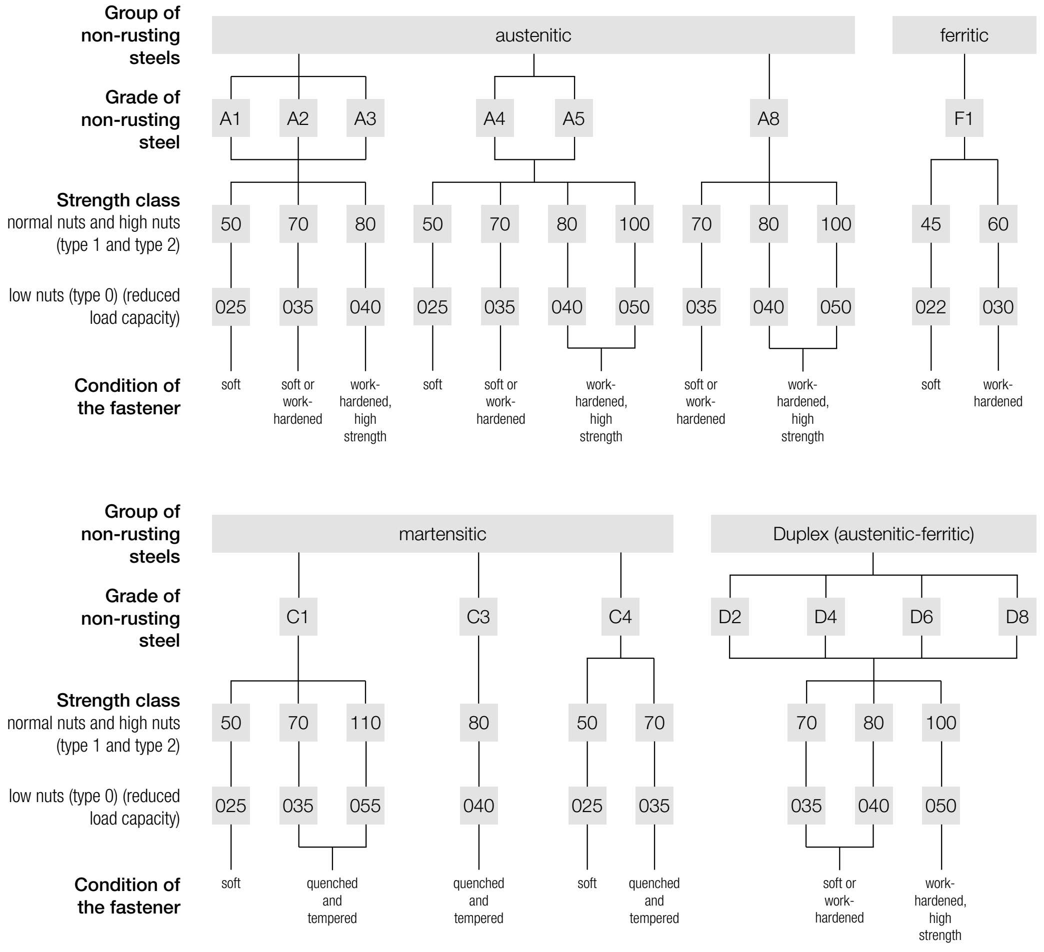


Figure 3.6 Naming system for rustproof nuts (source: DIN EN ISO 3506-2:2020-08)

Austenitic chromium-nickel steels with an alloy content of 15 – 20% chromium and 5 – 15% nickel have excellent corrosion resistance, good ductility, can be hardened by cold forming and are relatively slightly magnetisable. Grades A2 and A4 are most commonly used.

Ferritic steels F1 can be hardened by cold forming and are magnetic.

Martensitic steels can be hardened by heat treatment, have low ductility and are magnetic. Martensitic grades C1, C2 and C3 typically have lower corrosion resistance than austenitic grades.

Duplex steels with a microstructure with austenitic and ferritic phases have a higher Cr content and a lower Ni content than austenitic steels. Duplex steels have excellent corrosion resistance, can be hardened by cold forming, have high strength and are magnetic.

Austenitic steels

Austenitic chromium-nickel steels cannot be hardened by heat treatment. Parts in strength class 50 are hot-worked or machined. The higher strength classes 70, 80 and 100 are achieved through the pressing pressures during cold forming. Although these steel grades are not magnetic, the parts produced by cold forming can become slightly magnetic.

The superordinate material-specific statements are summarised in ISO 3506-6:2020-04.

A1
- For machining with approx. 2% copper content.
- Relatively low corrosion resistance.
- Not suitable for salty and chlorinated water.

A2
- Frequently used type of steel with approx. 18% chromium and approx. 8% nickel.
- Good corrosion resistance.
- Not suitable for salty and chlorinated water.

A3
- Characteristics similar to A2.
- Stabilised with Ti (titanium), Nb (niobium) or Ta (tantalum), so no chromium carbide formation even at high temperatures.

A4
- Frequently used material.
- Higher corrosion and acid resistance than A2 due to 2 – 3% molybdenum content, therefore conditionally suitable for salty and chlorinated water.
- Not suitable for use in swimming pools where chlorine is used as a cleaning agent or in marine environments.

A5
- Characteristics similar to A4.
- Stabilised like A3.

A8
- Higher corrosion and acid resistance than A4 due to 6 % molybdenum content, therefore suitable for salty and chlorinated water.
- Suitable for use in swimming pools where chlorine is used as a cleaning agent and in marine environments.

Screws made from these types of steel are divided into strength classes 50, 70 and 80. These numbers indicate 1/10 of the minimum tensile strength in N/mm^2.

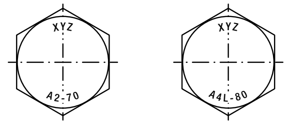
Grade of non-rusting steel		Strength class	Tensile strength R_m min. MPa	0.2% elasticity limit R_{pf} min. MPa	Fracture lengthening A min. mm
Austenitic	A1, A2, A3, A4, A5	50	500	210	0.6 d
		70	700	450	0.4 d
		80	800	600	0.3 d
	A4, A5	50	500	210	0.6 d
		70	700	450	0.4 d
		80	800	600	0.3 d
		100	1000	800	0.2 d
	A8	70	700	450	0.4 d
		80	800	600	0.3 d
		100	1000	800	0.2 d

Table 3.7 Mechanical properties of screws made of austenitic steels (source: DIN EN ISO 3506-1)

Markings on screws and nuts made of rust-resistant and acid-resistant steel

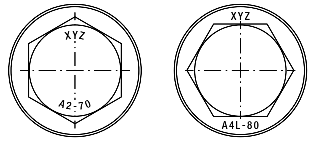
Hexagon head screws with thread ≥ M5 with full load capacity

on the head face or on the spanner flat with manufacturer, steel grade and strength class



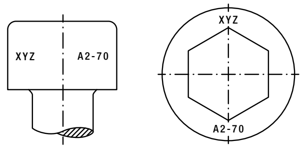
Hexagon head screws with flange and thread ≥ M5 with full load capacity

on the head face or on the flange with manufacturer, steel grade and strength class



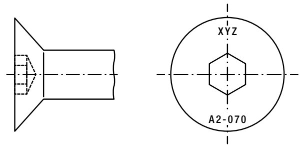
Screws with hexagon socket or internal hex socket with thread ≥ M5 with full load capacity

on the head face or on the side of the head with manufacturer, steel grade and strength class



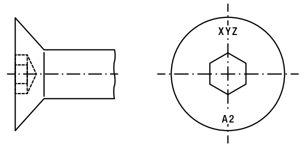
Screws with thread ≥ M5 and with reduced load capacity and thread length b ≥ 3d (tensile test possible)

with manufacturer, steel grade and strength class, whereby the strength class must be preceded by the number "0".



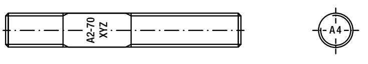
Screws with thread ≥ M5 and with reduced load capacity and thread length b < 3d (tensile test not possible)

with manufacturer and steel grade; strength class must not be specified



Threaded engineer studs ≥ M5

on the unthreaded shaft with manufacturer, steel grade and strength class or on the nut end with the steel grade



Screws with left-hand thread ≥ M5

on the head face or on the thread end with an arrow pointing to the left

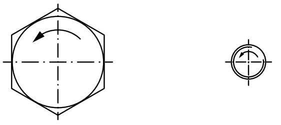
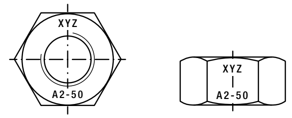


Figure 3.7 Examples of markings on screws made of non-rusting steel (source: DIN EN ISO 3506-1:2020-08)

03

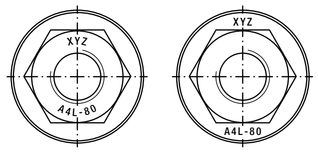
Hexagon nuts with thread ≥ M5 with full load capacity

on the top of the nut or on the spanner flat with manufacturer, steel grade and strength class



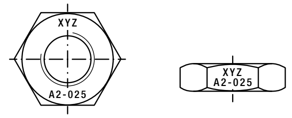
Hexagon nuts with flange and thread ≥ M5 with full load capacity

on the top of the nut or on the flange with manufacturer, steel grade and strength class



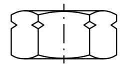
Hexagon nuts with thread ≥ M5 and with reduced load capacity

with manufacturer, steel grade and strength class, whereby the strength class must be preceded by the number "0".



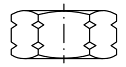
Hexagon nuts with thread ≥ M5 and grade A2 and strength class 50 or 025

with a notch (alternative marking)



Hexagon nuts with thread ≥ M5 and grade A4 and strength class 50 or 025

with two notches (alternative marking)



Nuts with left-hand thread ≥ M5

on the top of the nut and on the same surface as the strength class mark with an arrow pointing to the left

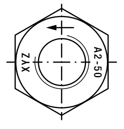


Figure 3.8 Examples of markings on nuts made of non-rusting steel (source: DIN EN ISO 3506-2:2020-08)

In the case of austenitic non-rusting steels with a low carbon content of 0.030% or less, fasteners may also be marked with the letter "L" directly after the steel grade. Example: A4L-80.

Screws and nuts made of heat-resistant and low-temperature steels

DIN 267 Part 13 recommends suitable materials for screws and nuts for use at very high and very low temperatures.

There are no strength classes for these applications. The designer determines the material that is suitable for the operating conditions and corresponds to the technical regulations.

Steels and nickel alloys according to DIN EN 10269 for low or high operating temperatures

Temperature range documented in DIN EN 10269			Material				Hardness HV of the screw and/or nut	
min.	Long term ❶	Short term ❷	Abbreviation	Number	Short name	Condition ❸	min.	max.
-120 °C	–	–	KB	1.5680	X12Ni5	+NT	157	203
-120 °C	–	–	KB	1.5680	X12Ni5	+QT	173	235
–	400 °C	500 °C	Y ❹	1.1181	C35E	+N	150	200
–	400 °C	500 °C	YK	1.1181	C35E	+QT	165	210
–	400 °C	–	YB	1.5511	35B2 ❼	+QT	165	210
-60 °C	500 °C	550 °C	KG	1.7218	25CrMo4	+QT	195	240
-100 °C	500 °C	–	GC	1.7225	42CrMo4	+QT	275	337
–	500 °C	550 °C	GA	1.7709	21CrMoV5-7	+QT	225	272
–	600 °C	500 °C	GB	1.7711	40CrMoV4-6	+QT	272	320
–	500 °C	600 °C	V ❺	1.4923	X22CrMoV12-1	+QT 1 ❺	256	303
–	500 °C	600 °C	VH ❻	1.4923	X22CrMoV12-1	+QT 2 ❻	287	367
–	600 °C	600 °C	VW	1.4913	X19CrMoVNbN11-1	+QT	287	367
–	650 °C	670 °C	S	1.4986	X7CrNiMoBNb16-16	+WW +P	210	272
-196 °C	650 °C	650 °C	SD	1.4980	X6NiCrTiMoVB25-15-2	+AT +P	287	367
-196 °C	650 °C	800 °C	SB	2.4952	NiCr20TiAl	+AT +P	320	417

❶ Upper temperature range limit with specified elasticity limits and tensile strengths
❷ Upper limit of the temperature ranges with specified time elasticity limits and creep strengths
❸ +N: normalised
+NT: normalised and tempered
+QT: quenched and tempered (hardened and tempered)
+WW: hot-deformed
+AT: annealed solubilised
+P: hardened for precipitation
❹ For nuts only
❺ Code V for material X22CrMoV12-1 according to DIN EN 10269 with 0.2% elasticity limit $R_{p\,0.2} \geq 600$ N/mm^2 (+QT 1)
❻ Code VH for material X22CrMoV12-1 according to DIN EN 10269 with 0.2% elasticity limit $R_{p\,0.2} \geq 700$ N/mm^2 (+QT 2)
❼ See also VdTÜV Material Sheet 490

Table 3.8 Steels and nickel alloys for low or high operating temperatures (source: EN 10269)

The table below applies to the use of austenitic materials at temperatures as low as – 196 °C. The characteristics must meet the specified requirements in DIN EN 3506-1 and DIN EN ISO 3506-2 for the respective steel grades and strength classes.

Application of non-rusting steel screws at low temperatures (austenitic steel only)

Steel grade		Lower operating temperature limits for continuous operation
A2, A3		– 196 °C
A4, A5	Screws ❶	– 60 °C
A4, A5	Engineer studs	– 196 °C

❶ The stability of the austenite is reduced in conjunction with the alloying element Mo, and the transition temperature shifts to higher values if greater degrees of deformation are used in the manufacture of the screw.

Table 3.8 Lower operating temperature limits for continuous operation for screws made of austenitic materials (source: DIN EN ISO 3506-1:2020-08)

	Temperature			
	+ 100 °C	+ 200 °C	+ 300 °C	+ 400 °C
Grade of non-rusting steel	R_{pf} at elevated temperature, in per cent of the value at room temperature (only strength classes 70 and 80 ❶, ❷)			
A2, A3, A4, A5, A8	85	80	75	70
C1	95	90	80	65
C3	90	85	80	60
D2, D4, D6, D8	85	75	❸	❸

❶ No data is currently available for strength class 100.
❷ The fastener manufacturer should be consulted for grades of austenitic non-rusting steel and strength class 50. However, an estimate based on EN 10269 (15) for materials in the annealed solubilised condition (+ AT) may be possible.
❸ In the case of stainless duplex steels, exposure to temperatures in excess of + 250 °C is not recommended due to the possibility that a 475 °C embrittlement is triggered (a-phase + a^{1}-phase). For temperatures of 250 °C up to and including 315 °C, it is advisable to consult an experienced metallurgist for fasteners (see also ISO 3506-5 and ISO 3506-6).

Table 3.9 Influence of temperature on the 0.2% elasticity limit R_{pf} for fasteners (source: DIN EN ISO 3506-1:2020-08)

Screws and nuts made from non-ferrous metals

In non-ferrous metals (NF), the iron content is not higher than 50 %. A distinction is made between light metals and heavy metals.

Heavy metals	Copper and copper alloys such as brass, Kuprodur, etc. Nickel and nickel alloys such as Monel
Light metals	Aluminium and aluminium alloys, titanium and titanium alloys

Material			Thread diameter d	Tensile strength rm N/mm² min.	0.2% elasticity limit $R_{p\,0.2}$ N/mm² min.	Fracture strain A % min.
Mark	Abbreviation	W no.				
CU1	Cu-ETP or Cu-FRHC	2.0060	d ≤ M 39	240	160	14
CU2	CuZn37 (old Ms 63)	2.0321	d ≤ M 6	440	340	11
CU2	CuZn37 (old Ms 63)	2.0321	M 6 < d ≤ M 39	370	250	19
CU3	CuZn39Pb3 (old Ms 58)	2.0401	d ≤ M 6	440	340	11
CU3	CuZn39Pb3 (old Ms 58)	2.0401	M 6 < d ≤ M 39	370	250	19
CU4	CuSn6	2.1020	d ≤ M 12	470	340	22
CU4	CuSn6	2.1020	M 12 < d ≤ M 39	400	200	33
CU5	CuNi1Si	2.0853	d ≤ M 39	590	540	12
CU6	CuZn40Mn1Pb	2.0580	M 6 < d ≤ M 39	440	180	18
CU7	CuAl10Ni5Fe4	2.0966	M 12 < d ≤ M 39	640	270	15
AL1	AlMg3	3.3535	d ≤ M 10	270	230	3
AL1	AlMg3	3.3535	M 10 < d ≤ M 20	250	180	4
AL2	AlMg5	3.3555	d ≤ M 14	310	205	6
AL2	AlMg5	3.3555	M 14 < d ≤ M 36	280	200	6
AL3	AlSiMgMn	3.2315	d ≤ M 6	320	250	7
AL3	AlSiMgMn	3.2315	M 6 < d ≤ M 39	310	260	10
AL4	AlCu4MgSi	3.1325	d ≤ M 10	420	290	6
AL4	AlCu4MgSi	3.1325	M 10 < d ≤ M 39	380	260	10
AL5	AlZnMgCu0,5	3.4345	d ≤ M 39	460	380	7
AL6	AlZn5,5MgCu	3.4365	d ≤ M 39	510	440	7

Table 3.10 Mechanical properties for screws made of non-ferrous metals (source: DIN EN 28839)

Mechanical properties

In the tensile test, a screw or a test bar is loaded on a testing machine until it breaks. The specimen first becomes elastically longer under the load. When the load is released, the part returns to the original length. With a greater load, the sample stretches permanently, the part is plastically deformed. If the load is further increased, the screw or the test bar will break.

Figure 3.9 Tensile test in accredited laboratory in Bielefeld

The following values are determined in the tensile test:

R_e The **yield limit** is the transition from elastic to plastic deformation.
R_{eL} is the lower yield limit.
R_{eH} is the upper yield limit.

$R_{p\,0.2}$ For high-strength screws from strength class 8.8, the **elasticity limit** is measured instead of the yield limit.
Here, too, the transition from elastic to permanent (plastic) deformation with a 0.2 % change in length must be taken into account.
This value is decisive for the calculation of the screw load.

R_m When the sample reaches its **tensile strength**, it has absorbed the highest load it can withstand.
After that, resistance decreases and the sample breaks.
With screws, the break must not occur under the head, but in the thread or in the shaft.

A The **fracture strain** is the permanent extension in %, based on the initial length.
The fracture strain is determined on machined test bars.

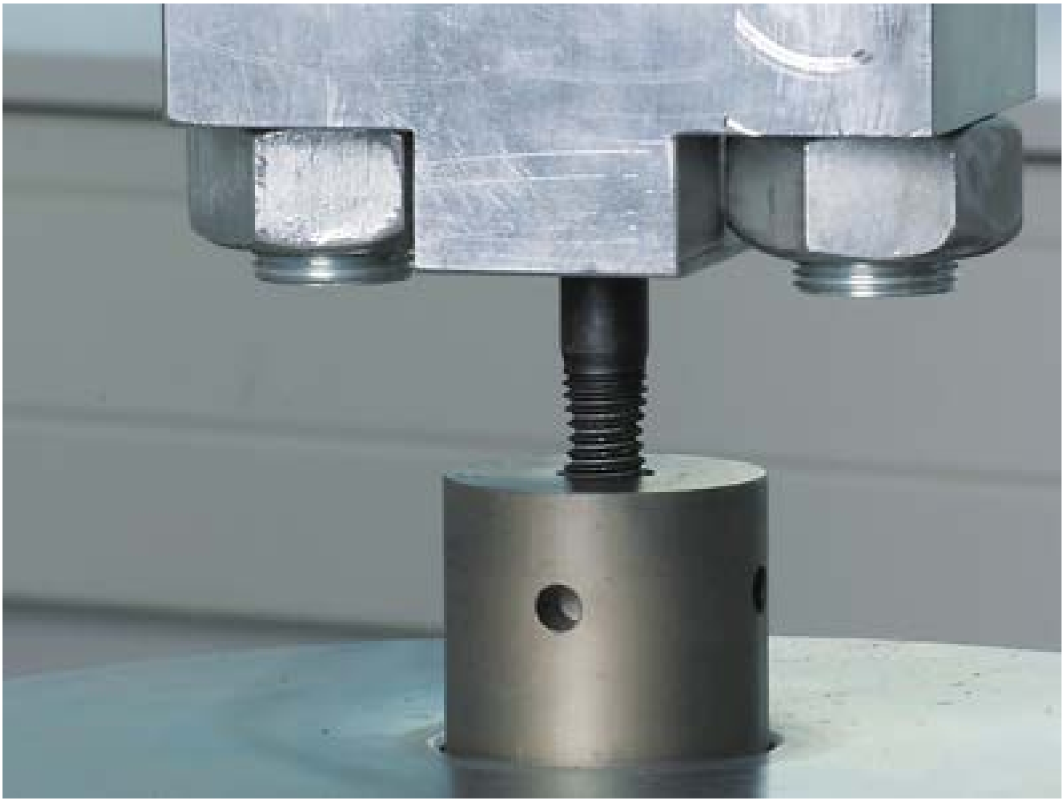


Figure 3.10 Tensile test with a screw

Hardness tests

The hardness test measures the resistance that the material offers to an indented test specimen.

HB **Brinell** hardness test for soft to medium-hard materials.
A hardened ball is pressed into the material.
The indentation diameter is measured.

HV **Vickers** hardness test for soft to hard materials.
The impression is made with a diamond pyramid.
The diagonals of the indentation are measured.

HR **Rockwell** hardness tests. The difference between a preload and the test force is measured. The measurement can be read directly on the device.
HRC and HRA are tests with a diamond cone for hard materials.
HRB and HRF are tests with a hardened steel ball for soft materials.

Figure 3.11 Hardness test in laboratory in Bielefeld

Compilation of the test certificates

Naming of the test certificates according to EN 10204			
Type	Naming	Content of the description	Confirmation of the certificate by
2.1	Certificate of compliance	Confirmation of compliance with the order	the manufacturer
2.2	Inspection certificate	Confirmation of compliance with the order stating results of non-specific testing	the manufacturer
3.1	Acceptance test certificate 3.1	Confirmation of compliance with the order stating the results of specific tests	the manufacturer's acceptance officer, who is independent of the Production department
3.2	Acceptance test certificate 3.2	Confirmation of compliance with the order stating the results of specific tests	the manufacturer's acceptance officer, who is independent of the Production department, and the acceptance officer commissioned by the customer or the acceptance officer specified in the official regulations

Table 3.11 Compilation of the test certificates

The certified values are not "guaranteed characteristics". Test certificates are no substitute for an incoming goods inspection.

The costs for the test parts, tests and test certificates are not included in the product price.

The Working Group on Pressure Vessels (AD) has created data sheets for pressure vessels, which also apply to screws and nuts.

AD data sheet W 2	for austenitic steels (rust and acid resistant)
AD data sheet W 7	for screws and nuts made of ferritic steels
AD data sheet W10	for ferrous materials for low temperatures
TRD 106	for nuts and bolts made of steel

TRD = Technical Rules for Steam Boiler Construction

Only the prescribed materials may be used for the pressure vessel area.

The products may only come from approved manufacturers whose production is monitored by independent certification bodies.

These manufacturers are regularly audited and approved. The names, addresses and manufacturer's marks are listed on the data sheets.

Which screws can be welded?

Suitability for welding is influenced by the alloying elements in the steel.

The following are suitable for welding
- weld nuts
- welding studs
- welding studs, etc.

The functional standards for other screws and nuts do not contain any information about weldability.

The strength classes also do not specify an exact material but leave the manufacturer free to select the appropriate steel for their production method within a defined framework. This is why it is not evident from the strength class whether the material is suitable for welding.

High-strength screws from strength class 8.8 and over are quenched and tempered. The mechanical properties are achieved through this heat treatment. These characteristics change if the parts are exposed to high temperatures during welding. This means that after welding, a fastener may no longer correspond to the original strength class.

There are also many different welding processes that have different effects on material behaviour.

Only a welding specialist can decide whether a material is suitable for a specific welding process.

Standards

A standard is a document that clearly describes requirements for products, services or processes. This creates clarity about the characteristics, designs and applications of products, services or processes, and promotes the free exchange of goods. In principle, anyone can formulate a standard, but the universal acceptance of a standard is what matters.

The German Institute for Standardisation eV (DIN) is an independent and privately organised platform for standardisation in Germany. DIN has existed for over a hundred years and has a very good international reputation. Around 3,000 companies with over 12,000 subsidiaries are members of DIN. They represent a major share of the membership, with more than 34,000 experts working in the individual DIN standards committees. In 1975, DIN entered into a public-private partnership through a contract with the Federal Republic of Germany, which recognised DIN as the only national standardisation organisation. The German body of standards currently comprises around 34,000 standards. These are published by Beuth Verlag.

Is the application of DIN standards mandatory?

The application of DIN standards is basically voluntary. Standards are only binding if they are stipulated in contracts or when legislation makes them binding. Even though they do not represent carte blanche in the event of possible liability, those who comply with DIN standards, as recognised rules of technology, can more easily prove correct behaviour. An example of this is the German Product Safety Act (ProdSG). A manufacturer can apply the relevant DIN standards to meet the legally required minimum requirements and then assume that they are in compliance with the basic safety and health requirements (presumption of conformity).

DIN standards have a defined life cycle: A status has the status "Draft" while it is being created or revised; it is only considered "Released" after it has been reviewed. If the content of a standard no longer corresponds to the current state of the art, it will be "withdrawn" – either "with reference" to another standard, or "without replacement" if the technology as a whole is considered obsolete. The status "invalid" that is commonly mentioned in this context does not actually exist: Even standards that have been withdrawn may still be applied if their use is not explicitly prohibited by law.

To facilitate the international exchange of goods and remove trade barriers, national standards are increasingly being replaced by internationally harmonised standards. As a result, internationally uniform terms and descriptions are available, quality is standardised at a high level, and the products can be exchanged worldwide. The ISO (International Organisation for Standardisation), based in Geneva, is responsible for international standardisation. Their results are published under the name ISO.

Many ISO standards are adopted as European standards and thus receive the status of a DIN standard (DIN EN ISO). Some ISO standards are also adopted directly as DIN standards (DIN ISO). Due to the 1991 Vienna Agreement on cooperation with ISO, members of the (European Committee for Standardisation) (CEN), ISO standards that meet European legislative and market requirements are adopted by CEN. Any conflicting national standards are withdrawn. Standards may have different names:

DIN	National German standard
ISO	International standard
DIN ISO	German edition of an unchanged ISO standard
EN	European standard
DIN EN	German edition of a European standard
EN ISO	European edition of an unmodified ISO standard
DIN EN ISO	German edition of an EN ISO standard

Products that are standardised in this way are simply referred to as DIN or ISO.

For example, hexagon head screws with a shaft according to DIN EN ISO 4014 are simply referred to as "ISO 4014" in drawings, parts lists, commercial documents and on the packaging.

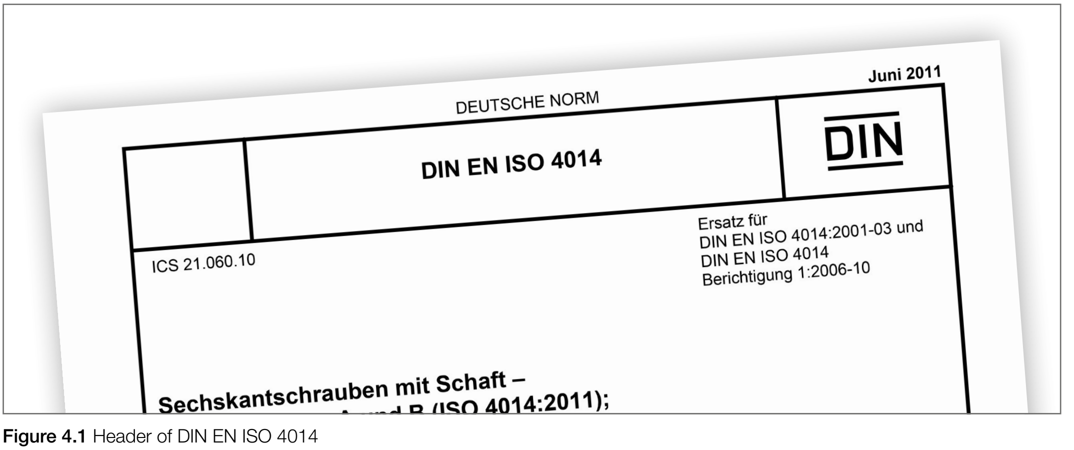


Figure 4.1 Header of DIN EN ISO 4014

Most mechanical fasteners (screws, nuts, washers, pins, etc.) are named after the standards that specify their shapes, dimensions, tolerances, and mechanical properties. In general, standards that describe individual articles in their various embodiments are designated as "**product standards**". These standards also specify how the individual variants are to be designated.

ISO 4014 – M12 × 80 – 8.8

describes, for example, a hexagon head screw with a metric thread M12, nominal length l = 80 mm and strength class 8.8.

In addition, product standards refer to other standards that regulate materials, mechanical properties, surface coatings and more. These are so-called "**functional standards**". In addition, "**basic standards**" are used; these describe the fundamental and generally applicable requirements for fasteners. Basic standards define e.g. thread designs, thread run-outs, tips, tolerances, force application, acceptance tests or special geometric features.

Based on the aforementioned ISO 4014, it should now be shown which dimensions are described in a product standard.

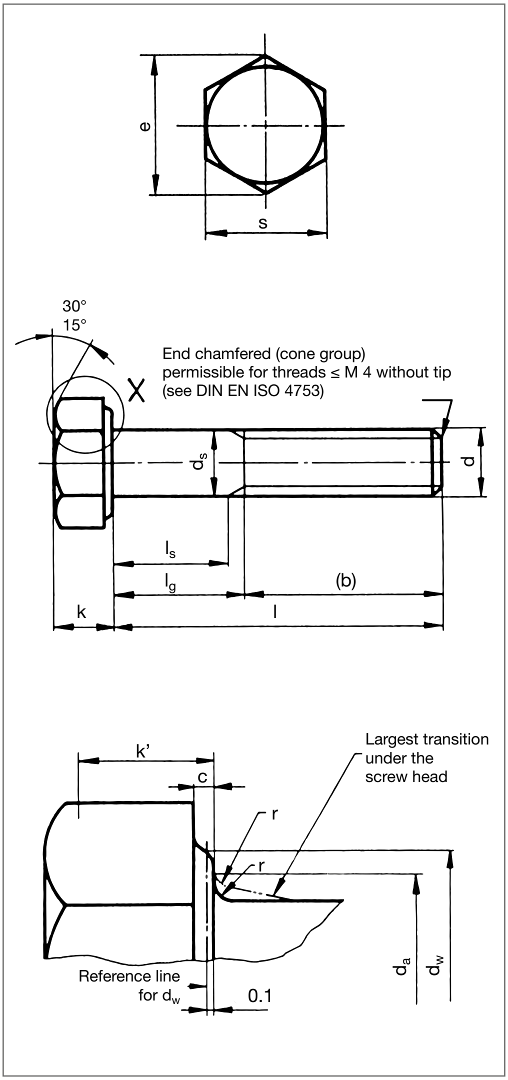


Figure 4.2 Hexagon head screw with shaft DIN EN ISO 4014 (source: DIN EN ISO 4014)

Description of dimensions

b	Thread length
c	Height of bolt collar
d	External diameter (nominal diameter) of the thread
d_a	Inner diameter of the contact surface
d_s	Shank diameter
d_w	Diameter of the contact surface
e	Square measure
k	Head height
k'	Drive height
l	Nominal length
l_g	Distance of the last thread turn from the contact surface
l_s	Shaft length
r	Transition radius under the screw head
s	Width across flats

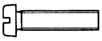
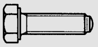
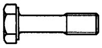
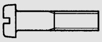
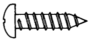
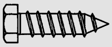
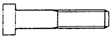
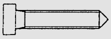
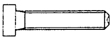
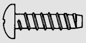
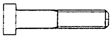
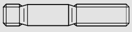
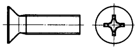
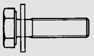
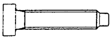
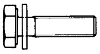
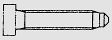
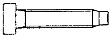
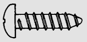
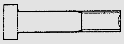
These abbreviations and the designation of the dimensions are specified in DIN EN ISO 225. By specifying the nominal diameter and nominal length, all other dimensions for the respective product result from the product standard.

04

Special types

Additional designations in the article information designate special designs.
ISO 4014/8.8M12×50 **S** means "**with split pin hole**".

Abbreviations for shapes and models

Abbr.	Explanation	Example	Image
A	Thread almost up to the head (DIN 962)	A M 6 × 40	
Ak	Radiussed half dog point (DIN 962)	M 10 × 50 Ak	
B	Shank diameter ≈ effective diameter (DIN 962)	B M 8 × 80	
C	Shank diameter ≈ thread diameter (DIN 962)	C M 12 × 90	
C	Sheet metal screws with pointed tip (DIN EN ISO 1478)	ST 3.5 × 9.5 C	
CA	Thread tip (DIN EN ISO 4753)	M 10 × 50 CA	
CH	Flat point (DIN EN ISO 4753)	M 10 × 50 CH	
CN	Pointed tip (DIN EN ISO 4753)	M 10 × 50 CN	
CP	Cup point (DIN EN ISO 4753)	M 10 × 50 CP	
F	Sheet metal screws with tang (DIN EN ISO 1478)	ST 3.5 × 9.5 F	
FL	Truncated cone (DIN EN ISO 4753)	M 10 × 50 FL	
Fo	Engineer studs without tight fit thread (DIN 962)	M 10 Fo × 50	
H	Philips – cross recessed / cruciform drive	M 5 × 20 H	
L	Washers for screw-and-washer assemblies (large) (DIN EN ISO 10644)	M 10 × 50 S2-L	
LD	Long tang (DIN EN ISO 4753)	M 10 × 50 LD	
LH	Left-hand thread (DIN 962)	M 12 LH × 75	
N	Washers for screw-and-washer assemblies (medium) (DIN EN ISO 10644)	M 10 × 50 S2-N	
PC	Insertion tang with coned half dog point (DIN EN ISO 4753)	M 10 × 50 PC	
PF	Insertion tang, flat (DIN EN ISO 4753)	M 10 × 50 PF	
R	Sheet metal screws with rounded pointed tip (DIN EN ISO 1478)	ST 3.5 × 9.5 R	
Ri	Thread undercut (DIN 1)	M 10 × 50 Ri	
RL	Without tip (DIN EN ISO 4753)	M 10 × 50 RL	

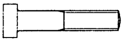
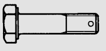
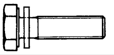
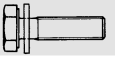
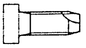
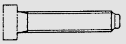
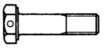
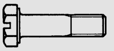
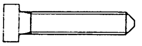
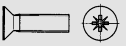
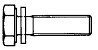
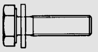
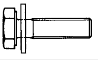
Abbr.	Explanation	Example	Image
RN	Oval point (DIN EN ISO 4753)	M 10 × 50 RN	
S	Split pin hole (DIN 962 / DIN 34803)	M 10 × 50 S	
S	Washers for screw-and-washer assemblies (small) (DIN EN ISO 10644)	M 10 × 50 S4-S	
S1-S6 S10-S13	Different head types for screw-and-washer assemblies with flat washers S, N or L (DIN EN ISO 10644)	M 10 × 50 S2-N	
SC	Scraper groove (DIN EN ISO 4753)	M 10 × 50 SC	
SD	Short tang (DIN EN ISO 4753)	M 10 × 50 SD	
Sk	Securing hole in the head / wire hole (DIN 962 / DIN 34803)	M 10 × 50 Sk	
Sz	Slot	M 10 × 50 Sz	
TC	Flattened tip (DIN EN ISO 4753)	M 10 × 50 TC	
Z	Pozidriv – cross recessed / cruciform drive	M 5 × 20 Z	
Z 0	Screw-and-washer assembly with small washer (DIN EN ISO 10644)	M 10 × 50 Z 0	
Z 1	Screw-and-washer assembly with normal washer (DIN EN ISO 10644)	M 10 × 50 Z 1	
Z 2	Screw-and-washer assembly with large washer (DIN EN ISO 10644)	M 10 × 50 Z 2	

Table 4.1 Abbreviations for shapes and finishes

Comparison of old and new abbreviations for screw ends

The publication of DIN EN ISO 4753, which has largely replaced DIN 78, has seen the abbreviations for numerous screw ends (previously threaded ends) change. To make it easier to find the abbreviations that are now valid, the old and new abbreviations are compared below:

Old abbreviation	Explanation	New abbreviation
K	Flat point	CH
Ka	Half dog point / short tang	SD
Ko	Without tip	RL
Ks	Truncated cone	FL
L	Oval point	RN
Rs	Cup point	CP
Sb	Scraper groove	SC
Sp	Flattened tip	TC
Za	Spigot / long tang	LD

Table 4.2 Abbreviations for screw ends

Conversion DIN – ISO

In the course of the transition from national to internationally harmonised standards, the following changes have occurred in the individual product groups:

Standard changes for **hexagon products**

DIN	ISO	Naming
931	4014	Hexagon head screws with shaft (product class A and B)
601	4016	Hexagon head screws with shaft (product grade C)
933	4017	Hexagon head screws with thread to the head (product class A and B)
558	4018	Hexagon head screws with thread to the head (product class C)
960	8765	Hexagon head screws with shaft and metric fine pitch thread
961	8676	Hexagon head screws with thread up to the head, with metric fine pitch thread
934	4032	Hexagon nuts type 1 (product class A and B)
439	4035	Hexagon nuts (low form)
934	8673	Hexagon nuts type 1 (product class A and B), fine pitch thread
7991	10642	Countersunk nib bolts with hexagon socket

Table 4.3 Changes in standards for hexagonal products due to the DIN-ISO conversion

Changes of **width across flats**

Thread diameter	Small hexagon DIN 561, 564		Standard hexagon		Large hexagon HV products		Square neck DIN 478, 479, 480	
	DIN	ISO	DIN	ISO	DIN	ISO	DIN	ISO
M 10	–	–	17	16	–	–	–	–
M 12	17	16	19	18	22	21	–	–
M 14	–	–	22	21	–	–	–	–
M 16	19	18	–	–	–	–	17	16
M 20	–	–	–	–	32	34	22	21
M 22	–	–	32	34	–	–	–	–

Table 4.4 Width across flats change due to the DIN-ISO conversion

Changes in height for **hexagon nuts**

Thread d	Nut height m					
	DIN 934			ISO 4032 Type 1		
	min.	max.	m / d ❶	min.	max.	m / d ❶
M 5	3.7	4	0.8	4.4	4.7	0.94
M 6	4.7	5	0.83	4.9	5.2	0.87
M 7	5.2	5.5	0.79	6.14	6.5	0.93
M 8	6.14	6.5	0.81	6.44	6.8	0.85
M 10	7.64	8	0.8	8.04	8.4	0.84
M 12	9.64	10	0.83	10.37	10.8	0.9
M 14	10.3	11	0.79	12.1	12.8	0.91
M 16	12.3	13	0.81	14.1	14.8	0.92
M 18	14.3	15	0.83	15.1	15.8	0.88
M 20	14.9	16	0.8	16.9	18	0.9
M 22	16.9	18	0.82	18.1	19.4	0.88
M 24	17.7	19	0.79	20.2	21.5	0.9
M 27	20.7	22	0.81	22.5	23.8	0.88
M 30	22.7	24	0.8	24.3	25.6	0.85
M 33	24.7	26	0.79	27.4	28.7	0.87
M 36	27.4	29	0.81	29.4	31	0.86
M 39	29.4	31	0.79	31.8	33.4	0.86

❶ Note: m/d represents the ratio of nut height to thread diameter

Table 4.5 Height changes for hexagon nuts due to the DIN-ISO conversion

Standard changes for **threaded screws** and **sheet metal screws**

Threaded screws		Sheet metal screws / self-drilling screws	
DIN	ISO	DIN	ISO
84	1207	7971	1481
85	1580	7972	1482
963	2009	7973	1483
964	2010	7976	1479
965	7046	7981	7049
966	7047	7982	7050
7985	7045	7983	7051
–	–	7504	10666, 15480, 15481, 15482, 15483

Table 4.6 Changes in standards for threaded screws and sheet metal screws due to the DIN – ISO conversion

Instead of the pan head screw DIN 7985 – flat head screw ISO 7045 with modified head shape.

The change in standard for threaded screws and sheet metal screws results in the following changes:

- The countersink angle for countersunk and raised countersunk sheet metal screws has been changed from 80° to 90°.
- The ST 3.9 diameter for sheet metal screws does not apply.
- The head dimensions have been changed, some slightly within the tolerances.
- Self-drilling screws (DIN 7504) were divided into five individual standards.

Standard changes for **bolts, pins, set screws and washers for bolts**

Item group	DIN	ISO	The most important changes
Taper pins, parallel pins	1	2339	Length l new according to ISO **with** tips (previously according to DIN **without** tips)
	7	2338	Length l new according to ISO **with** tips (previously according to DIN **without** tips), Shapes A, B, C (shape A / tolerance m 6 new with tip / chamfer)
	6325	8734	New: Shape A with chamfer/tip, through-hardened (largely identical to DIN 6325), Form B with chamfer, case-hardened
	7977 7978 7979/D	8737 8736 8733/ 8735 A	No major changes, DIN and ISO almost identical
Grooved pins, grooved drive studs	1470 1471 1472 1473 1474 1475	8739 8744 8745 8740 8741 8742	Length l new according to ISO **with** tips (previously according to DIN **without** tips) and the shear forces were increased
	–	8743	New: Centre grooved pin, half length, grooved
	1476 1477	8746 8747	Shape A = no major changes, Shape B with introductory end
Spring-type straight pins, spiral spring pins	1481 7346	8752 13337	Shape A = regular version (previously 0 – 12 mm) with 2 chamfers (previously 0 – 6 mm) in addition Shape B = non-snagging
	7343 7344	8750 8748	No major changes
	–	8749 8751	New: Pins, grooved pins: Shear test New: Spiral spring pins: lightweight version
Slotted set screws	417 438 551 553	7435 7436 4766 7434	No major changes, DIN and ISO almost identical
Bolt	1443 1444	2340 2341	Some nominal lengths are different, changed length tolerances
	1433 1434 1435 1436	–	These standards have been withdrawn (1.94), however, ISO 2340 / 2341 are comparable
Washers for bolts	1440	8738	Some external diameters and thicknesses changed (generally not at risk of replacement)

Table 4.7 Changes in standards for bolts, pins, set screws and washers for bolts due to the DIN-ISO conversion

04

Comparison DIN EN ISO 10642 – DIN 7991

In contrast to DIN 7991, the dimensions M 18, M 22 and M 24 are not listed in DIN EN ISO 10642. In addition to strength class 8.8, DIN EN ISO 10642 also includes higher strength classes (10.9 and 12.9). These classes are not included in DIN 7991.

While DIN EN ISO 10642 only lists steel as a material, DIN 7991 also lists non-rusting steel and non-ferrous metals. In DIN EN ISO 10642, the version with shaft ends only begins with longer lengths than in DIN 7991.

The value "w", which measures the ground under the force application, was introduced in DIN EN ISO 10642. Instead, in DIN 7991, the maximum penetration depth "t_{Max}" is dimensioned. Because of the reduced load capacity of countersunk heads, a table with lower minimum breaking forces was added to DIN EN ISO 10642. When marking the strength class, the reduced load capacity of the screw is indicated by a preceding zero.

Further deviations relating to thread length, head diameter and head height can be found in the following table:

Thread diameter	Thread length (auxiliary dimension) b		Head diameter d_k				Head height k_{Max}	
			DIN EN ISO 10642		DIN 7991			
d	DIN EN ISO 10642	DIN 7991	max.	min.	max.	min.	DIN EN ISO 10642	DIN 7991
M 3	18	12	6.72	5.54	6.0	5.70	1.86	1.7
M 4	20	14	8.96	7.53	8.0	7.64	2.48	2.3
M 5	22	16	11.20	9.43	10.0	9.64	3.10	2.8
M 6	24	18 / 24 ❶	13.44	11.34	12.0	11.57	3.72	3.3
M 8	28	22 / 28 ❶	17.92	15.24	16.0	15.57	4.96	4.4
M 10	32	26 / 32 / 45 ❶	22.40	19.22	20.0	19.48	6.20	5.5
M 12	36	30 / 36 / 49 ❶	26.88	23.12	24.0	23.48	7.44	6.5
(M 14)	40	34 / 40 / 53 ❶	30.80	26.52	27.0	26.48	8.40	7.0
M 16	44	38 / 44 / 57 ❶	33.60	29.01	30.0	29.48	8.80	7.5
M 18	–	42 / 48 / 61 ❶	–	–	33.0	32.38	–	8.0
M 20	52	46 / 52 / 65 ❶	40.32	36.05	36.0	35.38	10.16	8.5
M 22	–	50 / 56 / 69 ❶	–	–	36.0	35.38	–	13.1
M 24	–	54 / 60 / 73 ❶	–	–	39.0	38.38	–	14.0

❶ depending on the nominal length

Table 4.8 Comparison DIN EN ISO 10642 and DIN 7991

Guidelines

In addition to standards, there are other guidelines that are important for fasteners. Similar to standards, these sets of rules are regarded as "state of the art". Their application is only mandatory if compliance is required by law. An example is the EU Machinery Directive 2006/42/EG, which has been implemented into national law in Germany as the Machinery Ordinance (9th ProdSV). Here, among other things, certain requirements for fasteners in machine safety devices are prescribed by law.

Another example is the VDI Guideline 2230, which describes the systematic calculation of high-strength screw connections and is internationally regarded as a standard. Details on VDI Guideline 2230 can be found in the "Selection and calculation" chapter. If established professional associations such as the VDI (Association of German Engineers) issue design recommendations in the form of guidelines, these are also considered recognised rules of technology that must be taken into account.

Product certificates are used to clearly and comprehensibly document defined material characteristics of products. DIN 50049 Inspection Documents for the Delivery of Metallic Products in which the certificates for material tests were regulated was valid until 1995, when it was superseded by DIN EN 10204 It first came into force in 1951 and was last amended in 1992.

It used to be common for retailers to rewrite certificates of compliance (2.1), inspection certificates (2.2), factory test certificates (2.3), as well as acceptance test certificates (3.1B) because it was not in their interest to name the sub-supplier.

With the introduction of the designation "manufacturing and processing plant" in the July 1982 edition, the trade was forced, for the first time, to enclose copies of the certificates with deliveries at the customer's request.

DIN 50049:1992-02 was the German version of EN 10204:1991 – this was replaced in 1995 by DIN EN 10204:1995.

The latter standard contains the changes required, for example, due to the adjustment to the European Pressure Equipment Directive 97/23/EC and is harmonised with the EU directive.

Inspection certificates (2.3) were deleted, acceptance test certificate 3.1B became 3.1 and acceptance test certificates 3.1A, 3.1C and acceptance test reports 3.2A and 3.2C (of the previous edition) were replaced by 3.2 (see Table 4.9).

Type	Number		Test responsibility	Signature	Confirmation of the certificate by
	Old	Current	Old		Current
Certificate of compliance	2.1	2.1	manufacturing or processing plant		the manufacturer
Inspection certificate	2.2	2.2			
Factory test certificate	2.3	Not applicable			Not applicable
Acceptance test certificate	3.1B	3.1	specialist independent of the Production department	factory specialist	the manufacturer's acceptance officer, who is independent of the Production department
	3.1A	3.2	specialist independent of the Production department	expert named in the official provision of the law	the manufacturer's acceptance officer, who is independent of the Production department, and the acceptance officer commissioned by the customer or the acceptance officer specified in the official regulations
	3.1C			specialist commissioned by the customer	
Acceptance test report	3.2A	Not applicable	as for 3.1A	additional signature of the factory specialist	Not applicable
	3.2C		as for 3.1B		

Note: "Old" refers to DIN 50049:1992, "Current" to DIN EN 10204:2005

Table 4.9 Test certificates compared to previous standards and according to DIN EN 10204-2005-1

The international version is ISO 10474:2013-07 "Steel and steel products – Inspection documents", it is practically the English translation of DIN EN 10204:2005-01. Table 4.10 (see below) gives the English designations and descriptions of the test certificates.

Name of the document	Standard designation	Contents of document	Document visited by
Declaration of compliance with the order	2.1	Manufacturer's declaration of compliance with the order without test results	the manufacturer
Test report	2.2	Manufacturer's declaration of compliance with the order, with test results based on non-specific inspection	
Inspection certificate	3.1	Manufacturer's declaration of compliance with the order, with test results based on specific inspection	the manufacturer's authorized inspection representative independent of the manufacturing department
	3.2		the manufacturer's authorised inspection representative and either purchaser's authorised representative or by an inspector designated by a third party

Table 4.10 Test certificates according to ISO 10474:2013-07

The certificate of compliance and the inspection certificate are created on the basis of non-specific tests by the manufacturer. The basis for the acceptance test certificates 3.1 and 3.2 are specific tests based on the requirements specified between the customer and the manufacturer.

In this context, "non-specific" means that the test requirements result from the standard, "specific" are customer-specific, additional requirements. The dealer is instructed, and it is defined how, to deal with test certificates.

Citation: "*An intermediary shall only pass on either an original or a copy of the inspection documents provided by the manufacturer without any alteration. This documentation shall be accompanied by suitable means of identification of the product, in order to ensure the traceability between the product and the documentation.*"

The German Product Liability Act certainly also plays a role here, because the direct liability chain no longer applies to warranty claims, although the direct product liability chain does transfer warranty claims from the customer to the supplier (end customer to retail, retail to wholesale, wholesale to manufacturer).

Citation: "*An organisation that receives products from a manufacturer and passes them on without further processing or, if processed, without changing the characteristics specified in the order and in the product specification on which the order is based.*"

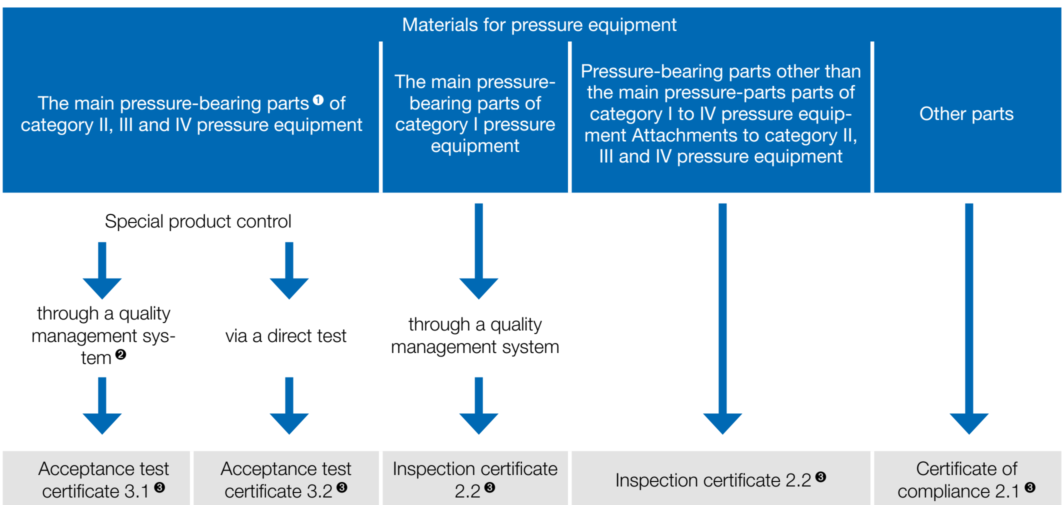
Copies of the original certificate are acceptable provided that:

- procedures to ensure traceability are applied,
- the original certificate is available on request.

If copies are made, it is permissible to replace the indication of the original delivery quantity with the current partial quantity. The certified values are not "guaranteed characteristics". Test certificates are no substitute for an incoming goods inspection.

The costs for the test parts, tests and test certificates are not included in the product price. The types of test certificates that are required can be found in the applicable guidelines/rules/regulations and laws.

Example:
The test certificates for materials for pressure equipment are assigned depending on the respective application in Table 4.11 below.



❶ Main pressure-bearing components are components where a failure can lead to a sudden release of pressure energy, see e.g. Guideline 7/8
❷ according to Annex I, Paragraph 4.3 of the Directive 2014/68/EU (ex. 97/23/EC)
❸ according to DIN EN 10204:2005-01

Table 4.11 Test certificates for materials for pressure equipment
(based on DIN EN 764-5, Figure 1 – types of test certificates required)

The connections to Directive 2014/68/EU Pressure Equipment Directive (PED) result, for example, from the harmonised DIN EN 764-5:2015-03, Pressure Equipment – Part 5: Test certificates for metallic materials and compliance with material specification. The relationship between the requirements and the test certificate is shown in Table 4.11.

Acceptance test certificates are only useful if the components are marked in such a way that they can be traced back to the material used. This is specified in individual harmonised standards and must be observed.

DIN EN ISO 16228

This standard defines four types of test certificate for standardised, finished mechanical fasteners. These certificates adopt the results from test certificates for the primary materials (according to DIN EN 10204) and document the test results from tests on the finished fasteners. There is no requirement to forward the test certificates for the primary materials.

As in DIN EN 10204, four test certificates are defined.

According to DIN EN ISO 16228, each test certificate also represents a declaration of conformity for the overall condition of the mechanical fasteners supplied, regardless of whether test results are specified or not. This declaration includes all characteristic features specified in the relevant standards, even if they are not listed in the document.

The publication of the standard, which was specially developed for mechanical fasteners, represents a special milestone because it defines rules for test certificates in a very special and extremely largely standardised product range, which represent a better solution by far for the customer and/or the manufacturer or supplier than the documents according to EN 10204.

DIN EN ISO 16228 has not yet been incorporated into the regulatory structure. We do not expect this to happen in the foreseeable future, because the committees involved are always "lagging behind" with updates and changes to their technical rules.

Therefore, test certificates according to DIN EN 10204 will continue to be issued and made available to you for both primary materials and finished screws and nuts.

Cold forming

Screws and nuts are usually produced by cold forming. This process is a ductile forming at room temperature. Unalloyed steels, case-hardened and Q and T steels, stainless and acid-resistant steels, copper, brass and aluminium alloys can be formed. Cold forming is the most efficient manufacturing process. However, it is only economical for large production batch sizes. Cold forming is a non-cutting type of shaping and is possible for screws and bolts with a shank diameter of up to 30 mm and lengths of up to 300 mm.

The first prerequisite for a flawless end product is careful selection of the primary material. In the case of fasteners, a heat treatment process is usually necessary after cold forming in order to influence the mechanical properties of the material in a targeted manner.

Depending on the requirements of the area of application, the user selects the strength class required for the threaded connection. Normally, the user does not choose the starting material, because although the mechanical properties have their origin in the material used, they change during the manufacturing process and are therefore dependent on the process. The manufacturer therefore usually selects the material within the standard specifications with which they can achieve and deliver the required characteristics in the finished part. The preliminary material is delivered to the screw manufacturer as wire with a diameter of approx. 1 – 30 mm, wound up on coils.

These coils of wire have a weight of approx. 1,000 kg. Before forming, the coils are pickled, drawn to the required external diameter and straightened. The wire is often processed in a phosphated state, which makes processing easier and minimises tool wear.

Figure 5.1 Raw material for cold forming

A blank is sheared off the coils on the machines (presses) and processed further.
The shaping processes in cold forming are divided into compression, reduction and extrusion. These methods can also be combined with one another accordingly.
This produces a wide array of design options. The integration of machining is planned for individual products: e.g. for deburring hexagon head screws or for attaching special crests or bores.

However, modern technologies also allow the non-cutting production of multifunctional features.

Figure 5.2 Rolled paint scraper groove / auxiliary feature for threading the screw through thread flank design

A distinction can be made between two product groups in the cold forming of screws:

- Relatively simple screw geometries are produced on so-called double pressure presses. Here, a two-step compression process is applied: Pre-compression and final compression.
- Fasteners with more complex shapes are produced by multi-stage compression and reduction with segment punches on so-called multi-stage presses. These tools have a die side and a punch side.

After each press stroke, the press blank is transported from one station to the next within the die side by means of gripper tongs. This results in the sequence of steps for the cold-formed parts. Depending on the screw design, different tool sets and pressing sequences are used.

In the case of a hexagon head screw, the production steps are arranged in the following order:
- wire section
- pre-compression and reduction of the shaft
- compression of a round head
- deburring the head to the hexagon
- shaping the tip
- and in a final operation on a separate machine, the thread is rolled.

Figure 5.3 Forming stages of a hexagon head screw

Advantages of cold forming:

- The material hardens in the formed zones
- The tensile strength and yield limit increase
- A smooth surface is created
- The grain flow is not interrupted
- Material defects become visible through the forming.
- Economical manufacturing

Hexagon nuts are also commonly cold formed. As with hexagon head screws, wire with a round cross-section is used as the starting material.

Figure 5.4 Forming stages of a hexagon nut

Hot working

Hot forming is used to a lesser extent than cold forming. When batch numbers are too small for the cold forming process or the stamping ratio is too large, then hot forging is a manufacturing option.

Hot forming or head forging takes place after the pre-material has been heated (in whole or in part) to forging temperature. Rod material is used here.

The material is highly malleable when warm, so that even more complex shapes can be manufactured. In contrast to cold forming, the material is not hardened. With this method, even small quantities can be manufactured more easily than with cold forming. The machines and tools are less expensive and complicated for hot working than for cold working. The surface of the parts is relatively rough, a typical feature of hot working.

The following are hot-worked:
- Large diameters (from M 30)
- Overlengths (from 300 mm)
- Complex shapes
- Small quantities (small series or prototypes)

Due to the rough outer structure and the large manufacturing tolerances, post-machining is often carried out on the hot-formed part.

Figure 5.5 Hot-formed part

Drop forging

In some cases, standard parts are manufactured as drop forgings. The dies are superimposed tools that form a cavity. The blank is heated to forging temperature and pressed into the desired shape in this cavity.

Cutting production

Machined parts are commonly referred to as turned parts. Likewise, some fasteners are manufactured by cutting. Example: knurled screws. The process can also be used as a manufacturing or post-processing method for parts with special contours, small radii or desired sharp edges. In addition, there are special materials that can only be formed by cutting.

These parts are manufactured on automatic lathes, which process the starting material from rods or wire rings. The semi-finished product always has the largest diameter of the finished part. The shaping is done by cutting with the lathe tools. Unlike cold or hot working, this destroys the grain flow of the starting material. This must be taken into account for stressed parts such as fasteners.

As a rule, no special tools are required, as standard lathe tools, milling cutters, drills, etc. are used.

In machining, cylindrical shapes are not only created by lathing, but also by milling surfaces, drilling, grinding or other fine work, e.g. to achieve defined degrees of roughness.

Figure 5.6 Machining

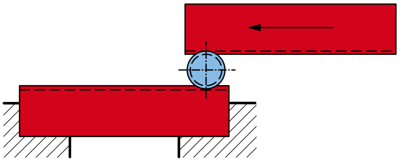
Machining process on an automatic lathe

Machining is done with:
- small quantities
- shapes and radii with tight tolerances
- reworking (e.g. grinding fitting bolts)
- special materials

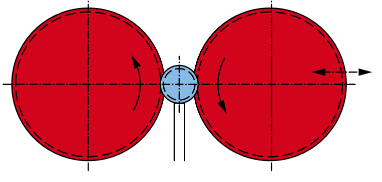
Figure 5.7 Turned part

Thread production

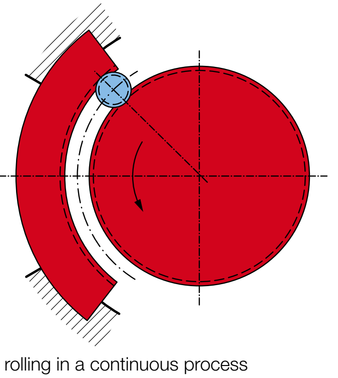
The bolt thread for screws is usually rolled. This cold forming can be done by flat jaws, rollers or roller segments. These tools have a negative thread profile. During thread rolling, the material on the starting diameter (rolling diameter) is radially displaced into the negative profile of the tools. During rolling, the thread tips form outwards. This makes it possible to attach shims to screw-and-washer assemblies so that they are captive. All standard thread profiles are manufactured, including trapezoidal, sheet metal screw and wood threads.



Thread rolling with flat dies



Thread rolling with the plunge-cut method



Thread rolling in a continuous process

Figure 5.8 The thread production process

Thread rolling usually is done before quenching and tempering. For special requirements, it can be done after heat treatment. This is usually referring to as final rolling.

The differences between rolled and cut threads become clear in the schematic representation of the structure. With thread rolling, the starting diameter is roughly equal to the effective diameter, while with thread cutting it is equal to the external diameter of the thread to be produced.

In the case of nuts, the internal threads are usually cut. This is done on machines with a reduced-shank tap. With a cut thread, the surface is rougher than with a rolled thread and the grain flow is interrupted.

Due to the rolling process, cold-formed threads have the following advantages over cut threads:
- The output quantity is high, so production is efficient.
- Chip-free manufacture
- Smooth surface quality
- Improvement in tensile and fatigue strength

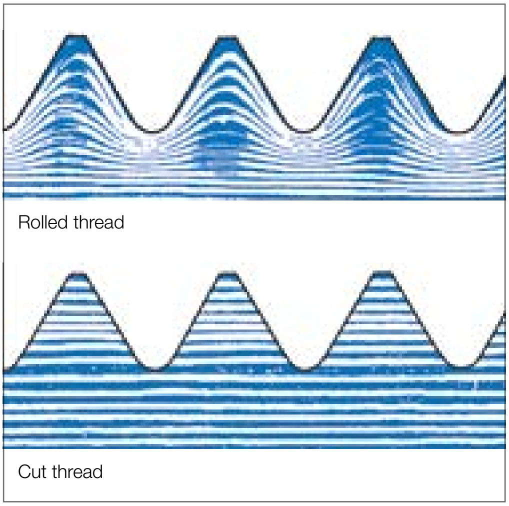


Figure 5.9 Rolled and cut thread

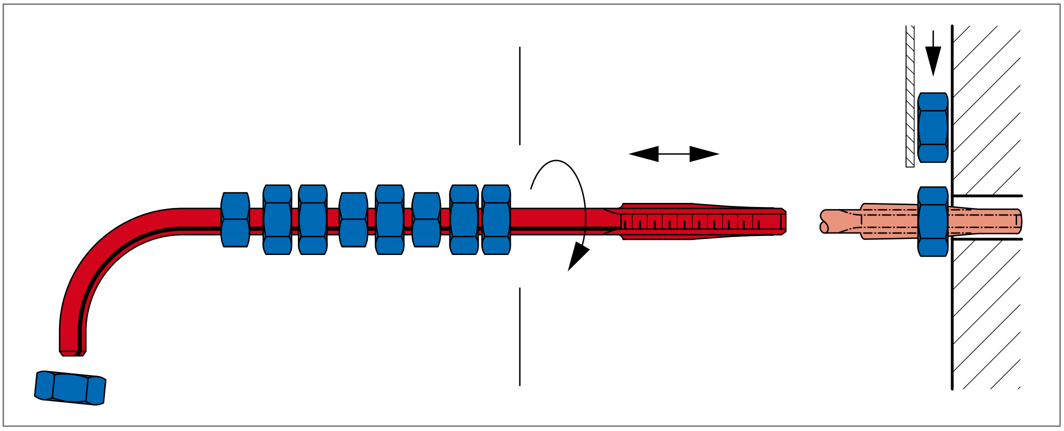


Figure 5.10 Tapping with a reduced-shank tap

Punching and bending

A threaded connection often also includes packers or screw accessories made from sheet metal or strips. Shaft locks and washers are also manufactured as punched parts. Cutting punches punch the desired shape out of a cutting plate. Bending parts are, for instance, parts made of profile wire or sheet metal that are formed into the desired shape by tools.

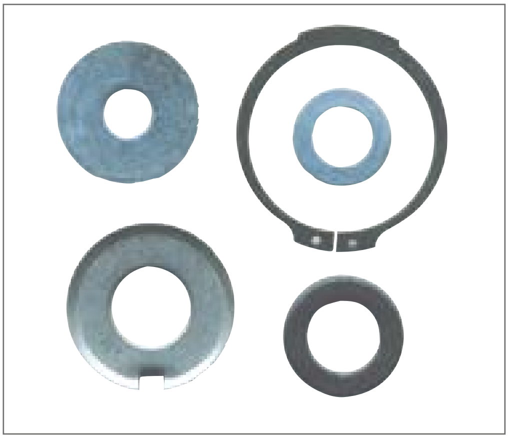


Figure 5.11 Punched parts

Figure 5.12 Bending parts

Heat treatment

The specifications for the mechanical properties of fasteners usually make heat treatment necessary. For this purpose, the manufactured product is subjected to heat treatment in a quenching and tempering facility.

Exception: Mill-finished rivets or fasteners and screws of strengths 4.8 or 5.8.

Figure 5.13 Quenching and tempering facility

In heat treatment, a distinction is drawn between the following processes:

- Annealing
- Hardening
- Heat treating
- Case hardening

Annealing relieves stresses that have arisen in the structure of the screws as a result of cold forming. By heating to approx. 500 °C and maintaining this temperature for a period of time, the part becomes low in residual stress, loses strength and increases in elongation. This is important for strength classes 4.6 and 5.6, for example, because a high fracture strain is required for these screws.

During hardening, the parts are heated to a temperature of approx. 800 °C. The absolute temperature is essentially based on the carbon content of steel. The structure changes due to the warming process. Subsequent quenching in oil or water makes the parts hard and brittle; they are now "hardened".

The parts are tempered (annealed) after hardening to achieve the required functional characteristics. The minimum tempering temperatures for high-strength screws are specified in DIN EN ISO 898 Part 1, Table 2, e.g. a minimum of 425°C for strength class 8.8. The parts then cool slowly at room temperature to achieve the required robustness. Hardening and subsequent tempering is called quenching and tempering.

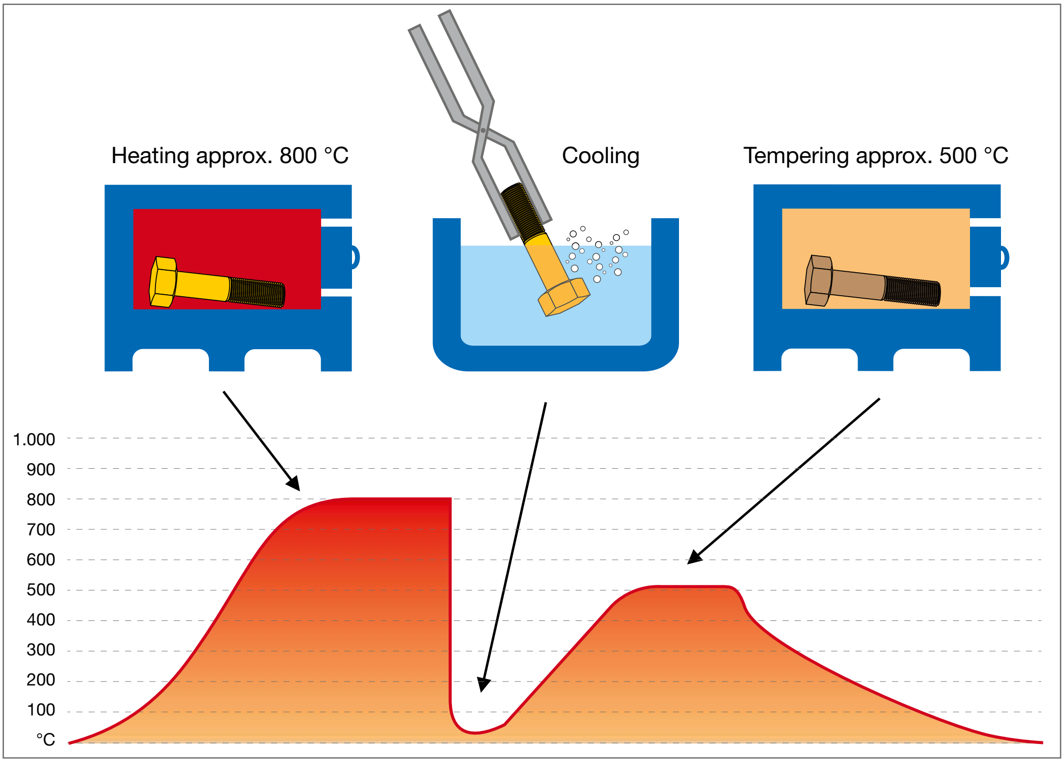


Figure 5.14 Quenching and tempering screws

In case hardening, carbon or nitrogen is added to the steel at hardening temperatures. These substances penetrate into the top layer of the parts and increase the hardness there. The surface is carburised.

This gives the parts a hard surface and a soft, tough core. These are the properties required for screws that cut or form their own threads (e.g. sheet metal screws or thread-forming screws).

The thread

The threads of the screw and nut must be dimensionally accurate and true to profile. This ensures that, after the application of a corrosion protection layer, the nut and screw can be screwed into each other without any problems and can transmit the calculated forces.

The thread has five dimensions that create the appropriate thread:

- The external or nominal diameter is the outer diameter
- The core diameter is the smallest diameter in the thread base
- The effective or flank diameter is the average diameter between the external diameter and the core diameter
- The thread pitch is the distance between the thread tips
- The flank angle is the angle of the thread tip

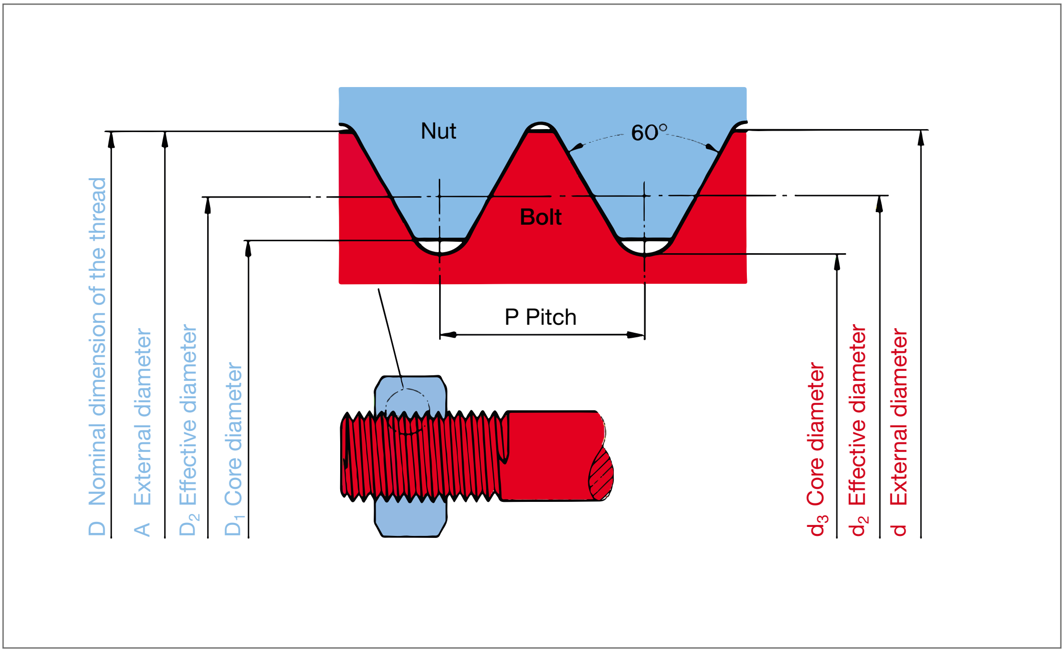


Figure 6.1 Thread profile without clearance

The nominal dimensions, e.g. for M 12 = 12 mm external diameter, are at the zero line.

If all of the dimensions were manufactured to these exact sizes, it would not be possible to screw the parts together with the counter thread.

A clearance is required between the thread flanks, and the threads can only be manufactured within certain tolerance limits. These tolerances, i.e. the dimensional clearances, are very small.

The example of a shaft and a bore (Figure 6.2) shows the required tolerances.

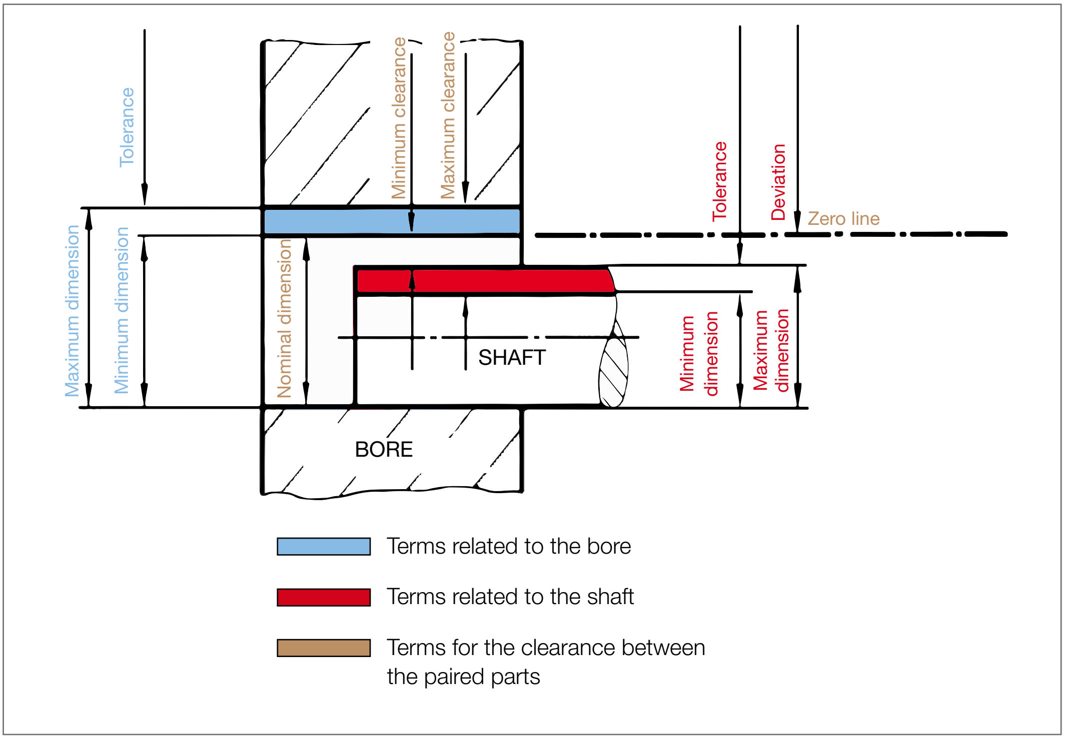


Figure 6.2 Free fit of shaft/bore

The combination must fit together even if the screw thread is manufactured at its maximum dimension and the female thread is manufactured at its minimum dimension. This means that no dimension may exceed the zero line or the nominal dimension; see Figure 6.3.

The **tolerance position** at the zero line is denoted by a capital H for internal dimensions and a lower-case h for external dimensions. The letters before h, i.e. from g to a, denote a larger dimension for male threads. The stud diameter is therefore smaller for tolerance position e than for g.

The number before the letter denotes the tolerance size, e.g. 6g. The larger the number, the larger the tolerance field. In addition, the dimensions of the tolerance fields change with the nominal diameter, i.e. the larger the nominal diameter, the larger the tolerance field. Diameter- and pitch-dependent tolerances for different degrees of tolerance can be found in DIN ISO 965 Part 1.

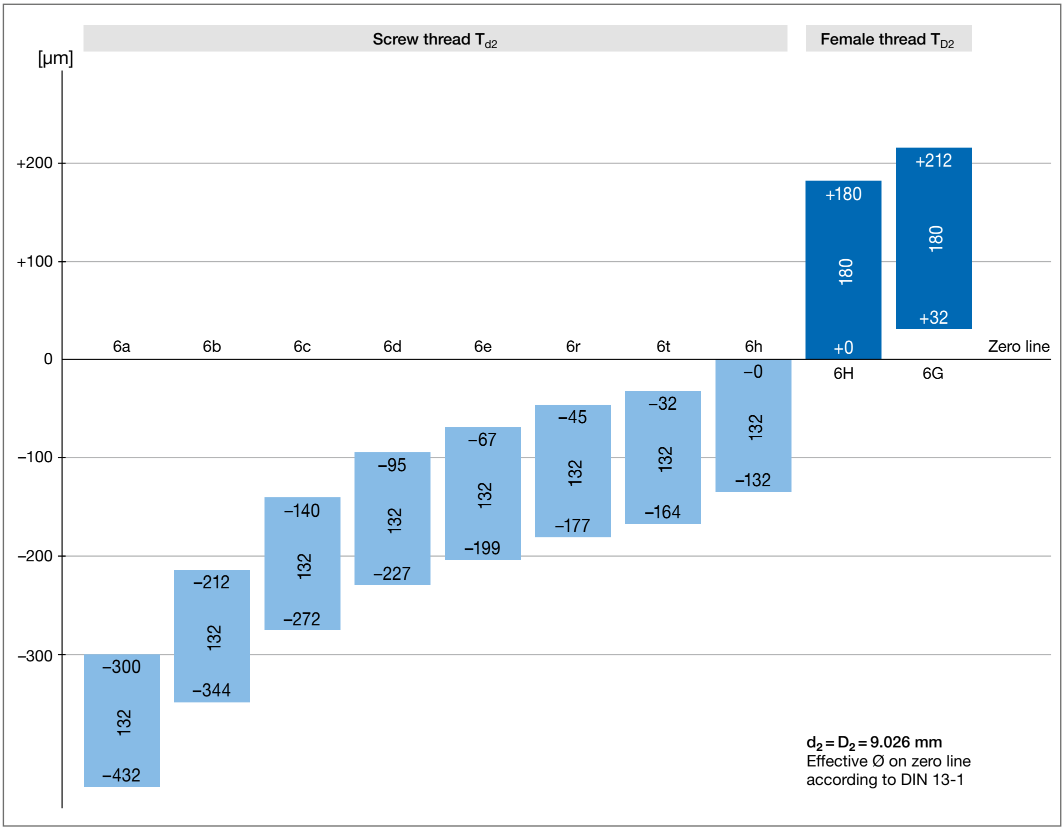


Figure 6.3 Tolerances T_{d2} and T_{D2} for the effective diameter d_2 (screw) and D_2 (nut) of an M10 × 1.5 thread.

If no special tolerance field is specified for screws, these parts are manufactured according to tolerance field 6g. This means that all commercially available screws have an undersize.

This minus tolerance allows a thin galvanic surface coating to be applied subsequently without exceeding the zero line of the thread in its finished state. If a thicker protective coating is required, a tolerance position with a smaller thread diameter is required, e.g. 6e for thicker galvanic coatings.

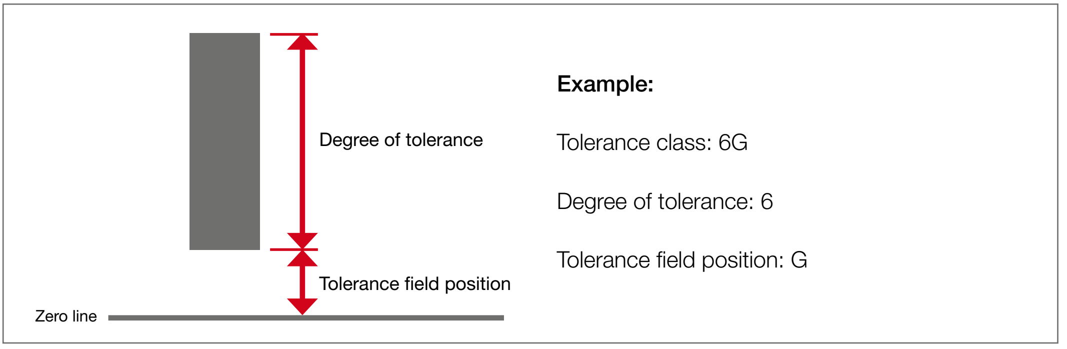


Figure 6.4 Tolerance system according to DIN ISO 965-1

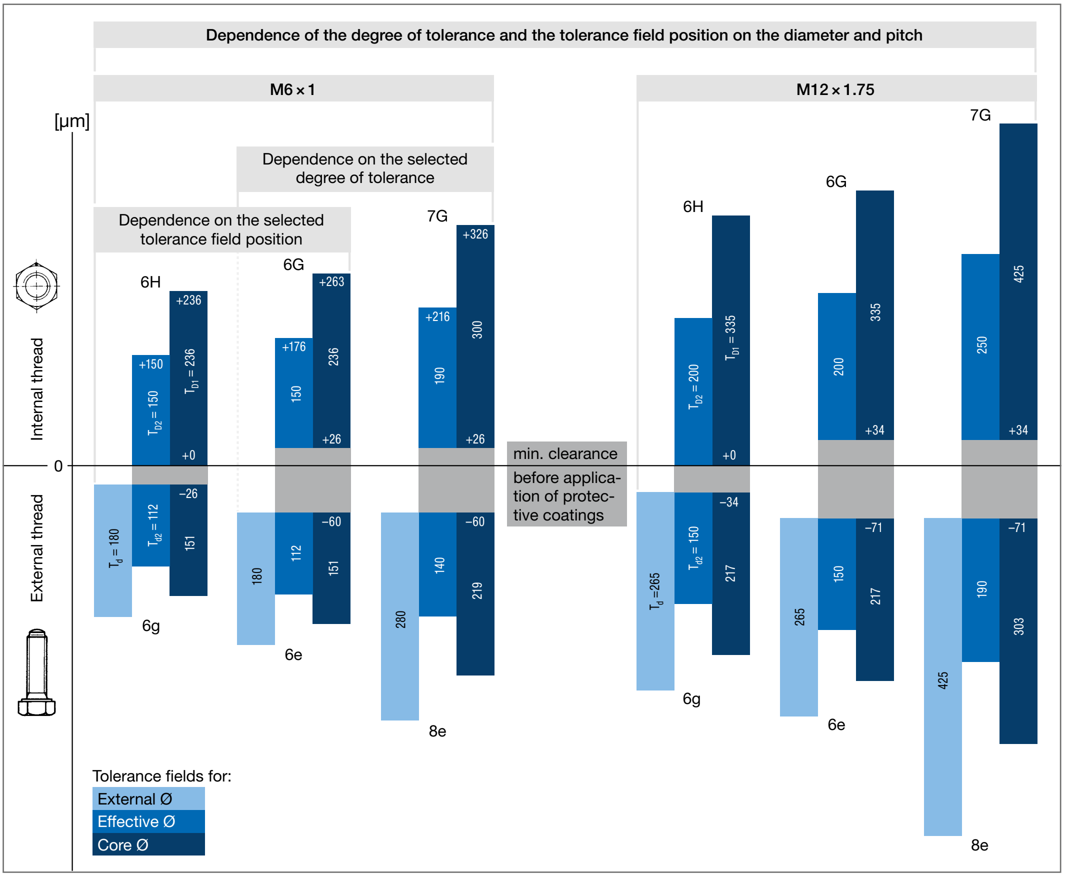


Figure 6.5 Dependence of the clearance between the screw and female thread on the tolerance field position and the degree of tolerance. Dependence of the degree of tolerance and the tolerance field position on the diameter and thread pitch.

The possible coating thicknesses for metric standard threads are specified for tolerance fields 6g and 6e in DIN EN ISO 4042.

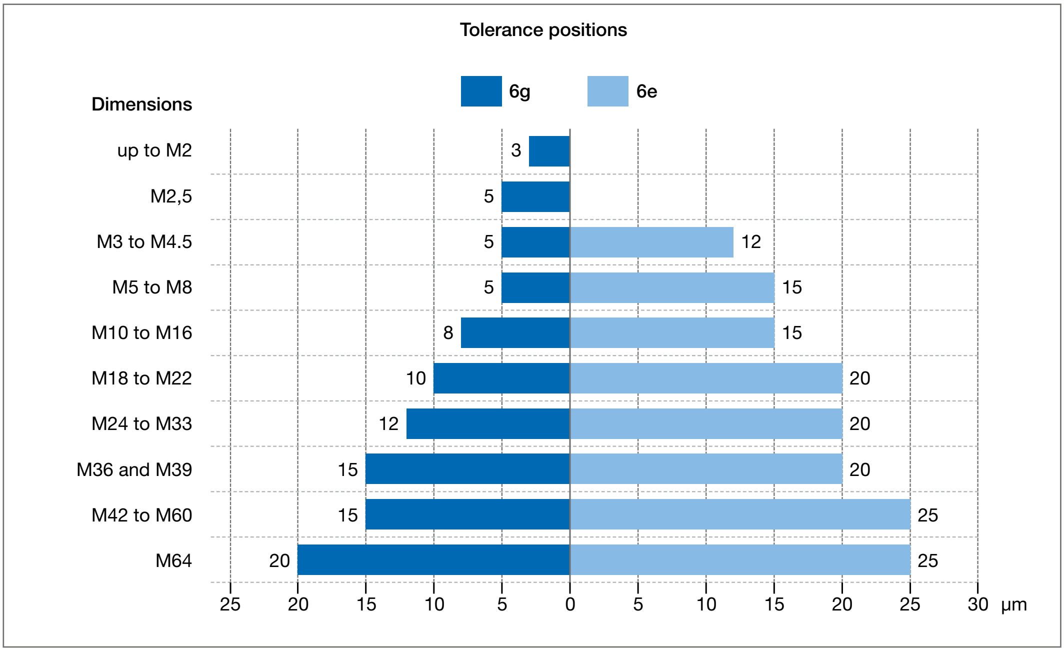


Figure 6.6 Maximum possible coating thicknesses on screws with a metric standard thread in accordance with DIN 13 (ISO 965) with maximum dimensions 6g and 6e (source: DIN EN ISO 4042)

The galvanically treated screw must not exceed the zero line at any point and is tested with a good ring gauge for tolerance position 6h.

The measuring points for the protective layer on the fasteners are defined according to DIN EN ISO 4042. Please see the table in the section on corrosion protection.

Female threads are usually manufactured with the tolerance field 6H, while for thicker protective layers this is correspondingly larger, e.g. 6G.

Threads for hot-dip galvanisation

The male threads for hot-dip galvanisation are manufactured according to tolerance position 6a. The zinc coating is at least 40 µm. The threads must not be recut after hot-dip galvanisation.

Due to the severe undersize, the diameter (tensile stress cross-section) is considerably reduced, so the load values are reduced (DIN EN ISO 10684).

When supplied as a set (screw and nut), it is up to the manufacturer to put the allowance the male thread or the oversize in the female thread.

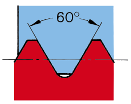
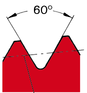
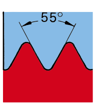
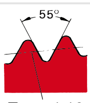
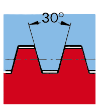
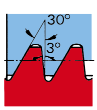
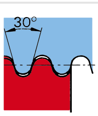
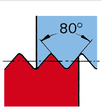
Thread types

The metric ISO thread is used worldwide. However, other threads are also required for special purposes and spare parts. The table below shows a selection and overview of common thread types.

Multifunctional thread types have been introduced according to manufacturer specifications and are commercially available. These include thread-forming threads for different materials and locking threads.

Common abbreviations for threads

M	Metric ISO thread
M..keg	Metric tapered external thread
Tr	Metric trapezoidal thread
S	Buttress thread
Rd	Round thread
Pg	Armoured conduit thread
G	Cylindrical pipe thread
R	External tapered pipe thread
Rp	Interior cylindrical pipe thread, sealing
St	Sheet metal screw thread
LH	(after the dimension specification) Left-hand thread
P	(after the thread pitch) Multi-start thread

	Thread name (abbreviation)	Example name	Standard	Range of applications
	Metric ISO thread (M)	M 08	DIN 14 0.3–M 0.9 mm	Watches and precision mechanics
	Metric ISO thread (M)	M 12	DIN 13 1–68 mm	General standard thread
	Metric ISO fine thread (M × Stg)	M 12 × 1.5	DIN 13 1–68 mm	General fine thread
	Metric thread for tight fit (M...Sk)	M 12 Sk6	DIN 13 + DIN 14	Threaded ends for engineer studs
	Thread with large clearance (M...DIN...)	M 24 DIN 2510	DIN 2510 12–180 mm	Threaded connections with anti-fatigue shaft
	Metric cylindrical internal thread (M...DIN...)	M 24 × 2 DIN 158	DIN 158 6–60 mm	Internal thread for screw plugs
 Taper 1:16	Metric tapered external thread (M... × P keg)	M 12 × 1 keg	DIN 158 6–60mm	Screw plugs and grease nipples
	Cylindrical pipe thread (G internal/external)	G 3/4 or G 3/4 A	DIN EN ISO 228.1 1/8 to 6 inch	Pipes and pipe connections
	Cylindrical pipe thread, internal (Rp)	Rp ¾	DIN 2999 1/16–6 inch DIN 3858 1/8–6 inch	Pipes and pipe connections
 Taper 1:16	External tapered pipe thread (R)	R ¾	DIN 2999 1/16–6 inch DIN 3858 1/8–6 inch	Pipes, fittings and pipe connections
	Metric ISO trapezoidal thread (Tr)	Tr 40 × 7	DIN 103 8–300mm	Transmission thread
	Buttress thread (S)	S 48 × 8	DIN 513 10–640mm	Transmission thread
	Round thread (Rd)	Rd 40 × 4	DIN 405 DIN 20 400	General round thread
	Armoured conduit thread (Pg)	Pg 21	DIN 40 430 Pg 7–Pg 48	Electrical engineering
	Left-hand thread (LH)	Tr 40 × 7 LH	LH = left hand	General

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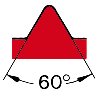
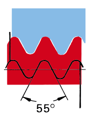
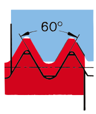
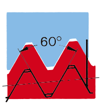
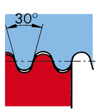
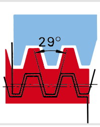
	Thread name (abbreviation)	Example name	Explanation	Spread
	Sheet metal screw thread	2.9	DIN EN ISO 1478	Sheet metal screws
	Wood screw thread	3.5	DIN 7998	Wood screws
	Multi-start thread (P...)	Tr 40 × 14 P7	14 : P7= 2 Start thread	General
	Whitworth thread, Coarse (BSW)	1/4-20 BSW	Standard BS 84	GB
	Whitworth thread, fine (BSF)	1/4-28 BSF	Standard BS 84	GB
	Unified coarse pitch thread (UNC)	1/4-20 UNC-2A	1/4-20 UNC-2A = a thread with 1/4 inch nominal diameter, 20 turns per inch	USA/GB/Canada
	Unified fine pitch thread (UNF)	1/4-28 UNF-3A		USA/GB/Canada
	Unified extra-fine pitch thread (UNEF)	1/4-32 UNEF-3A		USA/GB/Canada
	Unified special thread (UNS)	1/4-27 UNS		USA/GB/Canada
	Cylindrical pipe thread (NPSM/NPSM/NPSL/NPSH)	1/2-14 NPSM		USA
	Standard pipe thread, tapered (NPT)	3/4-18 NPT	1/4-20 UNC-2A = a thread with 1/4 inch nominal diameter, 20 turns per inch	USA
	Fine pipe thread, conical (NPTF)	1/2-14 NPTF Dryseal		USA
	Trapezoidal thread (ACME)	1 3/4 4 ACME-2G	1/4-20 UNC-2A = a thread with 1/4 inch nominal diameter, 20 turns per inch	USA
	Trapezoidal thread, flattened (Stub-ACME)	1/2-20 Stub-ACME		USA
	Buttress thread (Butt)	2.5-8 Butt-2A	Thread with ... inch N	USA

Table 6.1 Overview of common types of thread

Inches		Millimetres
1/64	0.015625	.397
1/32	0.03125	.794
3/64	0.046875	1.191
1/16	0.0625	1.587
5/64	0.078125	1.984
3/32	0.09375	2.381
7/64	0.109375	2.778
1/8	0.125	3.175
9/64	0.140625	3.572
5/32	0.15625	3.969
11/64	0.171875	4.366
3/16	0.1875	4.762
13/64	0.203125	5.159
7/32	0.21875	5.556
15/64	0.234375	5.953
1/4	0.25	6.350
17/64	0.265625	6.747
9/32	0.28125	7.144
19/64	0.296875	7.541
5/16	0.3125	7.937
21/64	0.328125	8.334
11/32	0.34375	8.731
23/64	0.359375	9.128
3/8	0.375	9.525
25/64	0.390625	9.922
13/32	0.40625	10.319
27/64	0.421875	10.716
7/16	0.4375	11.113
29/64	0.453125	11.509
15/32	0.46875	11.906
31/64	0.484375	12.303
1/2	0.5	12.700

Inches		Millimetres
33/64	0.515625	13.097
17/32	0.53125	13.494
35/64	0.546875	13.890
9/16	0.5625	14.287
37/64	0.578125	14.684
19/32	0.59375	15.081
39/64	0.609375	15.478
5/8	0.625	15.875
41/64	0.640625	16.272
21/32	0.65625	16.669
43/64	0.671875	17.065
11/16	0.6875	17.462
45/64	0.703125	17.859
23/32	0.71875	18.256
47/64	0.734375	18.653
3/4	0.75	19.050
49/64	0.765625	19.447
25/32	0.78125	19.844
51/64	0.796875	20.240
13/16	0.8125	20.637
53/64	0.828125	21.034
27/32	0.84375	21.431
55/64	0.859375	21.828
7/8	0.875	22.225
57/64	0.890625	22.622
29/32	0.90625	23.019
59/64	0.921875	23.415
15/16	0.9375	23.812
61/64	0.953125	24.209
31/32	0.96875	24.606
63/64	0.984375	25.003
1	1.0	25.400

Table 6.2 Conversion table: Inches (imperial) to millimetres

As already explained in detail, various influencing variables must be taken into account for screw connections. Along with an exact knowledge of all occurring forces and deformations, the defined tightening of the screw is crucially important.

The "Schrauben Vademecum" (Rasch Verlag, Bramsche, ISBN 3-935326-46-7) states: "*The preload force FM applied during assembly is critical for the operational safety of screw connections. This is set by twisting the screw and female threads that are engaged with each other. This twisting is applied to the connection during assembly by an externally applied torque through the action of the thread pitch.*"

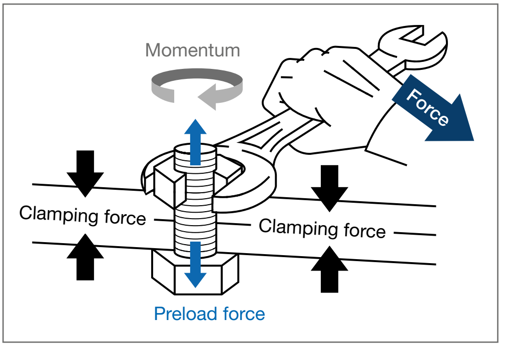


Figure 7.1 Force ratios when assembling a threaded connection

This assembly torque should be selected so that the resulting clamping force during operation results in a pure frictional connection between the components, while at the same time not overloading any of the tightened elements.

Control and monitoring variables in screw assembly

Unfortunately, the preload force as a physical quantity cannot be measured directly for most screw connections. For this reason, other methods are used in the assembly of screw connections to achieve the most precisely defined clamping of components. The externally applied assembly torque is relatively easy to measure and is directly proportional to the preload force, which is why this auxiliary variable is frequently used.

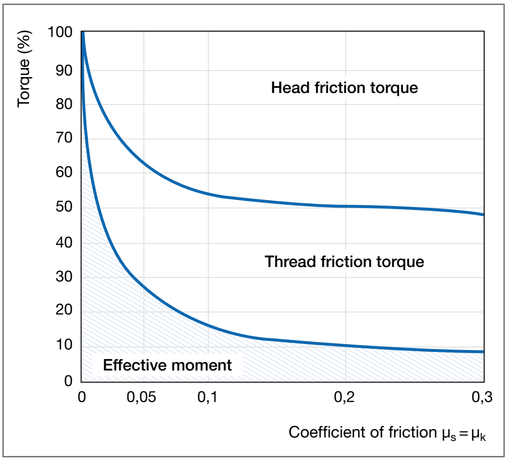


Figure 7.2 Effect of the coefficient of friction on the assembly process

The change in screw length can also be used as a measure of the preload force but is more complicated to measure. Above a certain minimum force level, the "twist angle" between the female and male threaded parts correlates with the elongation of the screw. Once a "trigger torque value" has been reached, this value can also be used as a measure of the preload force in the connection (if the clamped components have sufficient strength).

The section "Screw configuration and design principle for screw connections" explains how friction is a key aspect in the functioning of a screw connection. If we consider the efficiency of the screw assembly as a function of the friction coefficient μ, we can see that at a value of μ = 0.2 only 10% of the externally applied torque is converted into preload force. This ratio can change significantly if the friction conditions change.

This illustrates the influence that individual parameters can have on the assembly process. A systematic presentation of all significant influencing variables can be found in VDI/VDE-MT 2637-1 (see figure below).

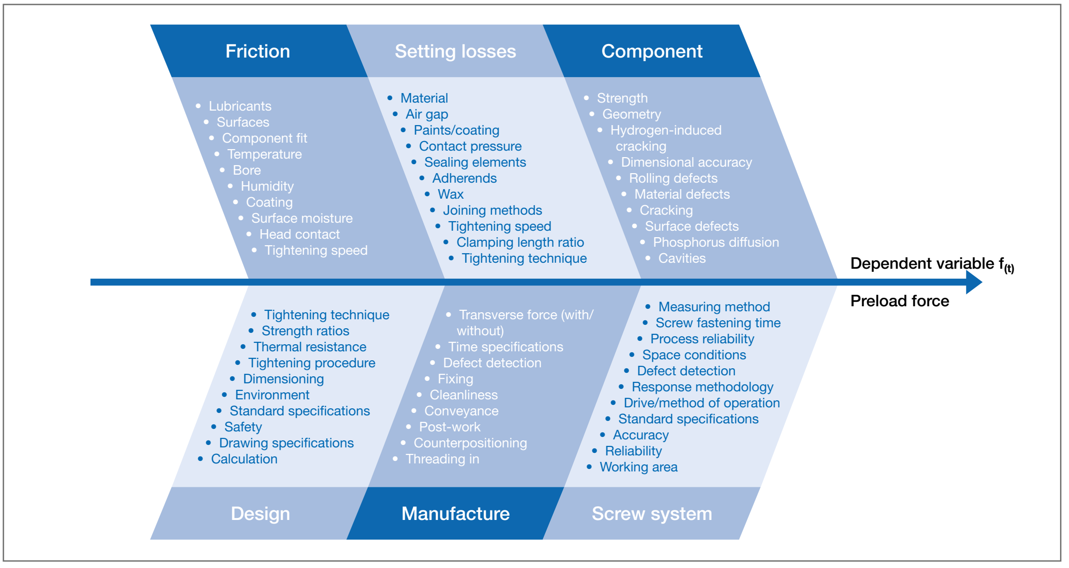


Figure 7.3 Influencing variables for the assembly of threaded connections

Classification of threaded connections

Various codes, standards and regulations (e.g. DIN 25201, VDI/VDE 2862) stipulate that it is the responsibility of the person responsible for the product to carry out a risk assessment for each screw site and to classify them as follows:

- Category A:
  Risk to life and limb and the environment
- Category B:
  Risk of functional failure
- Category C:
  Loss of comfort ("not class A or B")

Depending on classification into one of the three categories set out above, there are different requirements for the process capability of screw assembly. In Germany, compliance with these standards is regulated by law, including under the Product Safety Act (ProdSG) and the Ordinance on Industrial Safety and Health (BetrSichV).

Types of assembly

Some assembly methods for screws are set out here below:

- Manual assembly
- Torque-controlled assembly
- Angle-controlled assembly
- Gradient-controlled assembly
- Torsion-free assembly process

Manual assembly

If neither motor-driven nor measurement-displaying tools are used during assembly, this is referred to as manual assembly. The advantages of this method are the high availability of tools, the low preparatory effort required, and the high level of flexibility.

Empirical studies have shown that, depending on the type of screw, there are different size ranges in which screws can be assembled correctly "by feel", that small-format screws are almost always overtightened, and that screws of size M 14 and larger are generally not preloaded strongly enough.

Since control variables are not used and measurements are not recorded during purely manual assembly, this type of screw assembly is unsuitable for safety-relevant applications.

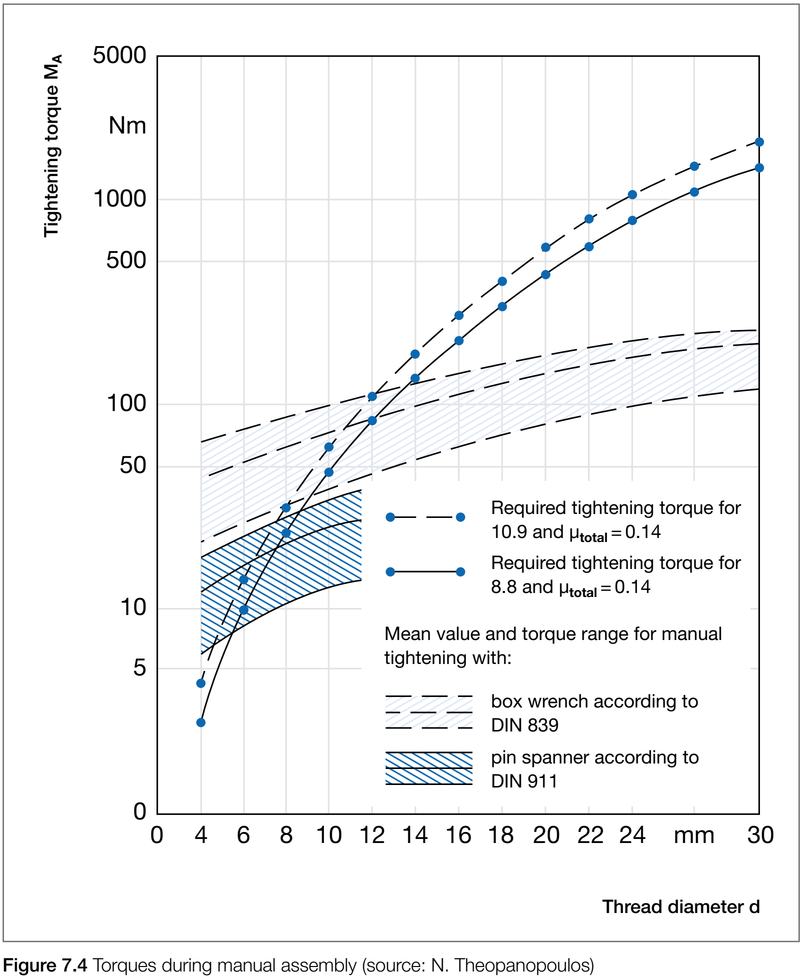


Figure 7.4 Torques during manual assembly (source: N. Theopanopoulos)

Torque-controlled assembly

Screw assembly using the assembly torque as a control variable is very common. Many screw systems offer the possibility of monitoring the angle of rotation as a control variable to detect possible defects during assembly. In most cases, this method involves tightening at high speed until a defined threshold torque is reached, then angle counting begins and tightening continues at low speed until the actual assembly torque (MA) is reached. This assembly method is usually used in the purely elastic range. The advantages of this method include the simple options for process control and the wide range of applications. However, the high influence of friction on the preload force to be achieved is a disadvantage.

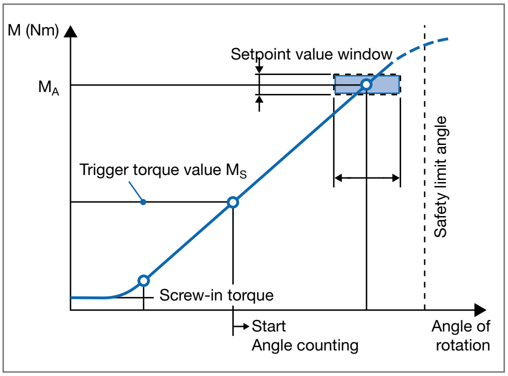


Figure 7.5 Torque curve over angle of rotation

Angle-controlled assembly

If the angle of rotation of the tool is used as a control variable for screw assembly, this is referred to as angle-controlled assembly. This method makes it possible to use the torque as a control variable to detect possible defects during assembly. With this method, pre-assembly is usually carried out at high speed up to a defined trigger torque value, whereupon angle counting begins and screw fastening continues at low speed up to the predefined final angle of rotation. This assembly method offers the most advantages for tightening up to the over-elastic range.

The torque curve in this range is almost horizontal because screws do not offer increased resistance to increasing elongation when reaching the yield point (Lüders elongation). If the angle of further rotation is selected in such a way that assembly ends shortly after the yield point is exceeded, the influence of friction is largely eliminated and the screw is only slightly plasticated although very highly prestressed. This method offers a high degree of process reliability but requires a great deal of care when determining the specific parameters for each type of screw used.

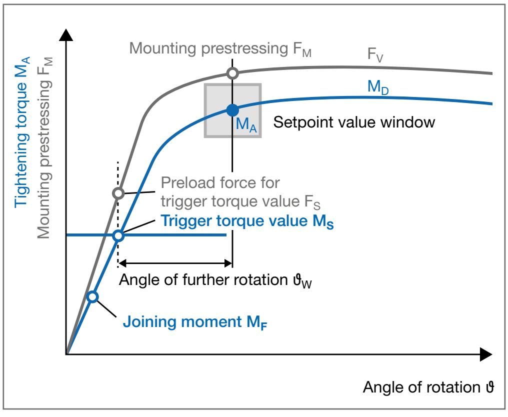


Figure 7.6 Preload force and preload torque curve over angle of rotation

Gradient-controlled assembly

It is possible to calculate a gradient from these two measured variables because much screwdriving equipment is now capable of recording and processing both torque and angle of rotation virtually in real time. As long as both values behave in a linear manner, the gradient remains constant. When the yield limit is reached, the angle of rotation continues to increase while the torque does not increase so the gradient drops.
This change in the gradient can be used as a control variable for a highly stable assembly process. The screw is loaded to its yield limit independently of friction and is only minimally plasticated. The material behaviour of the screw thus becomes the actual control variable for the assembly process. This means that both the angle of rotation and the torque can be used as additional control variables.

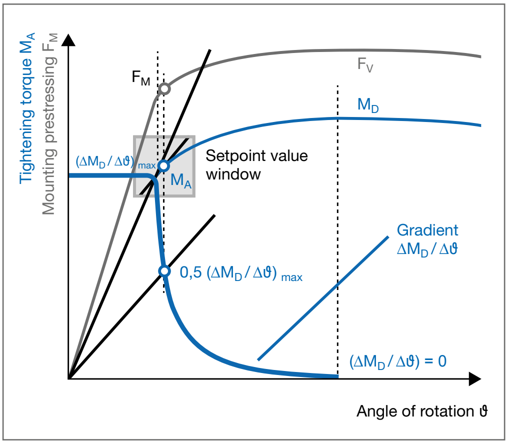


Figure 7.7 Course of M_A, F_V and gradient over angle of rotation

Torsion-free assembly process

Compared with the other variants, this type of screw assembly is very time-consuming, so it tends to be unsuitable for series applications. It is nevertheless used for very large screws that need to be tightened in a highly defined manner. In this process, the screw is prestressed without torsion by a tool acting from the outside. Only then is the nut screwed into its nominal position. The actual preload between the screw and the nut is only established when the tool is removed from the free end of the screw. The influence of friction is also largely eliminated in this process.

Note:
The manufacturer has a duty of care to select and monitor the appropriate assembly methods and screw fastening tools for their own production. As such, it should be noted that VDI/VDE Guideline 2862 is a set of rules that comprehensively describes the minimum requirements for the use of screw systems. Screw connections cannot function optimally without the application of a defined preload force!

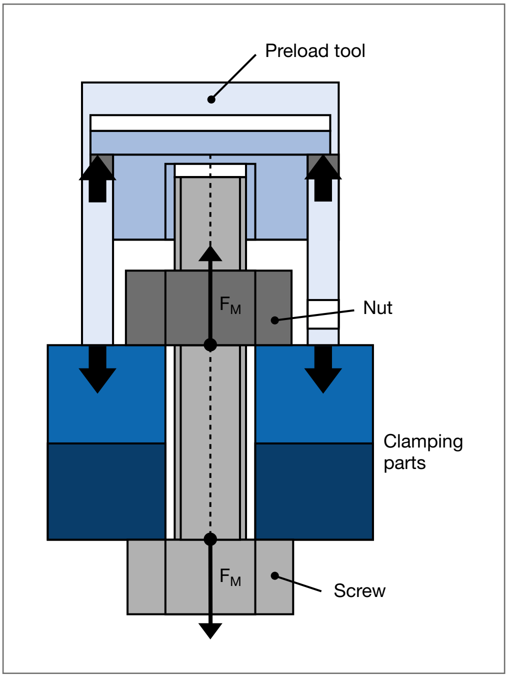


Figure 7.8 Torsion-free preloading of a threaded connection

Automated screw assembly

The larger the number of similar screw fastening positions in production, the more requirements for possible automation have to be considered. A wide range of aspects should be considered, relating to both equipment and to the fasteners themselves. With regard to screws, these criteria are listed below:

- Sorting criteria (missing parts, thread present, head diameter, etc.)
- Drive features (cam-out effect with cross recess, ISK with low force transfer)
- Finding aids (Dogpoint, Mathread, Navitight)
- Cleanliness (residual dirt, oil, surface coating [ZnFl unsuitable], adhesives)
- Reduced corrosion protection for vibrating conveyors
- Packaging
- Combined elements
- Length-diameter ratio (with automated feed) > 2

Sorting criteria

In the absence of special quality assurance measures, a deviation rate for critical characteristics of 800 ppm (parts per million) can be assumed for standard fasteners. This level of quality is insufficient for fully automated screw assembly. It is therefore advisable to ensure that the characteristics are relevant to the function by means of special sorting methods. These must be explicitly agreed by the supplier and user.

The quality objective of "zero defects" is not technically feasible at present; experience has shown that with automated sorting the remaining deviation rates for individual characteristics are 10 ppm on average.

Figure 7.9 Optical sorting of AMTEC®

Drive features

The tool engagement of screws has a significant impact on automation capacity during assembly. Both the threading of the tool into the drive and the transmission of the assembly torque should run as smoothly as possible. The cross-slots described in DIN EN ISO 4757, for example, are known for the "cam-out effect", when the shape of the tool engagement causes an axial force during assembly that can push the tool out of the drive. For high cycle rates, other drive features, like an internal hex socket in accordance with DIN EN ISO 10664, are much more suitable.

Figure 7.10 Internal hex socket drive in accordance with DIN EN ISO 10664

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Finding aids

In the case of long screws or screw positions that are difficult to access, it can prove beneficial for the thread to have an insertion pin or similar at the end to facilitate threading into the internal thread and to compensate for potential axial misalignments. Some variants of thread ends are described in DIN EN ISO 4753. Widely used, manufacturer-specific versions of finding aids are also available under the brand names Mathread and Navitight.

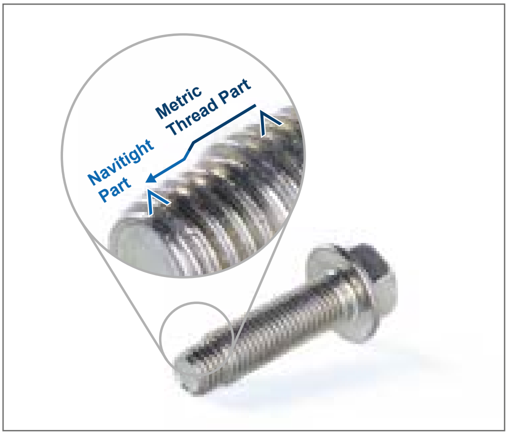

Figure 7.11 Screw tip suitable for assembly, Navitight®

Cleanliness

DIN ISO 8992 explains that fasteners for which no defined surface coating has been agreed are delivered in their manufactured state for products made of steel. This means that traces of the preceding manufacturing steps can be found on these products. High-strength screws, for instance, receive a final heat treatment, which can leave scaling and oil deposits on the surface.

These manufacturing residues tend to contaminate automatic feeders and assembly equipment, causing malfunctions. For this reason, the permissible residual dirt level for screws in mass production should be as low as possible.

Corrosion protection

Steel fasteners are often have surfaces that contain zinc to protect against corrosion. If these elements are fed in automatically, the corrosion protection can be impaired. For example, vibrating conveyors are often used in which the screws are constantly coming into contact with each other, which can cause damage to their surfaces.

Zinc flake coatings are often used on fasteners. This type of coating is not as adhesive as galvanic protective coatings, so they are less suitable for automatic feeders.

Packaging

A suitable form of packaging is also important for a smooth assembly process. It serves primarily as a container and means of transport, but should also protect the elements from damage, preserve their cleanliness and prevent them from mixing with foreign parts. The containers should not be too small, so as to avoid unnecessary packaging waste and unpacking procedures, but they should not be so heavy that they prevent easy handling. Taped elements represent a special type: here, the packaging also serves as a magazine for the screwdriver. This version is suitable if loosely poured elements are unwieldy or difficult to arrange.

Figure 7.12 Screws in a belt magazine

Combined elements

If fasteners are to be combined with washers during assembly, using combined elements can prove cost-effective. With this type of element, the individual parts are combined and made undetachable during manufacture. This eliminates the effort of threading during assembly itself, and the washer cannot be forgotten or misaligned.

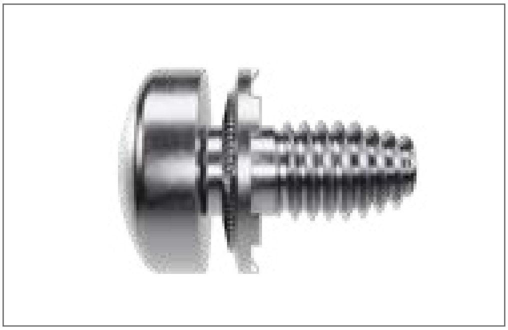

Figure 7.13 Combined element: Screw with captive washer

Length-to-diameter ratio for screws

If screws are to be automatically fed in right up to the joining point, for example by a hose feed, care must be taken to ensure that the orientation of the screws can be clearly maintained. For this purpose, it is worth having a sufficient ratio between length and diameter (guide value > 2).

Some basic tables are provided below to provide guidance with the selection of suitable parameters for an assembly-compatible design of a screw connection.

Slot	1
Cross-recess H	2
Combined cross-recess	3
Cross-recess Z	4
Square socket	5
Internal hex socket (DIN EN ISO 10664)	6
Internal hex socket with locking pin	7
Internal hex socket plus	8
Hexagon socket	9

Hexagon socket with locking pin	10
Two-hole drive	11
Tri-wing	12
Polygonal socket	13
Pentagon socket	14
Internal serration	15
Internal serration	16
One-way drive head	17

Figure 7.14 Drive types

Depending on the application, a wide range of options for selecting power drives allow rational assembly or offer additional features (e.g. anti-theft, anti-tampering, shear-off elements). Combinations of drive features are also possible for special requirements.

Friction coefficient class	Range for μ_G and μ_K	Selection of examples of typical Materials/surfaces	Selection of examples of typical Lubricants
A	0.04 – 0.10	Coatless metallic Black oxide Phosphated Galv. coatings, e.g. Zn, Zn/Fe, Zn/Ni Zinc flake coatings	Solid lubricants like MoS_2, graphite, PTFE, PA, PE, PI in bonded coatings, as top coats or in pastes Wax melts Wax dispersions
B	0.08 – 0.16	Coatless metallic Black oxide Phosphated Galv. coatings, e.g. Zn, Zn/Fe, Zn/Ni Zinc flake coatings Al- and Mg alloys	Solid lubricants like MoS_2, graphite, PTFE, PA, PE, PI in bonded coatings, as top coats or in pastes Wax melts Wax dispersions, greases, oils, manufacturing state
		Hot-dip galvanised	MoS_2, graphite, wax dispersions
		Organic coatings	with integrated solid lubricant or wax dispersions
		Austenitic steel	Solid lubricants or waxes, pastes
C	0.14 – 0.24	Austenitic steel	Wax dispersions, pastes
		Coatless metallic Phosphated	Manufacturing state (lightly oiled)
		Galv. coatings, e.g. Zn, Zn/Fe, Zn/Ni Zinc flake coatings Adhesive	None
D	0.20 – 0.35	Austenitic steel	Oil
		Galv. coatings, e.g. Zn, Zn/Fe Hot-dip galvanised	None
E	≥ 0.30	Galv. coatings, e.g. Zn/Fe, Zn/Ni Austenitic steel Al, Mg alloys	None

Table 7.1 Friction coefficient classes according to VDI standard 2230

This table assigns friction coefficient classes with guide values to various materials/surfaces and lubrication conditions for screw connections.
The friction coefficients to be aimed for are those in friction coefficient class B, in order to apply as high a preload force as possible with low scatter.

The table applies to room temperature and does not take any specific features into account.

Dimen-sions	Strength class	Assembly preload forces $F_{M\ Tab}$ in kN for μ_G =					Tightening torques M_A in Nm for μ_K =				
		0.10	0.12	0.14	0.16	0.20	0.10	0.12	0.14	0.16	0.20
M 5	8.8	7.4	7.2	7.0	6.8	6.4	5.2	5.9	6.5	7.1	8.1
	10.9	10.8	10.6	10.3	10.0	9.4	7.6	8.6	9.5	10.4	11.9
	12.9	12.7	12.4	12.0	11.7	11.0	8.9	10.0	11.2	12.2	14.0
M 6	8.8	10.4	10.2	9.9	9.6	9.0	9.0	10.1	11.3	12.3	14.1
	10.9	15.3	14.9	14.5	14.1	13.2	13.2	14.9	16.5	18.0	20.7
	12.9	17.9	17.5	17.0	16.5	15.5	15.4	17.4	19.3	21.1	24.2
M 7	8.8	15.1	14.8	14.4	14.0	13.1	14.8	16.8	18.7	20.5	23.6
	10.9	22.5	21.7	21.1	20.5	19.3	21.7	24.7	27.5	30.1	34.7
	12.9	26.0	25.4	24.7	24.0	22.6	25.4	28.9	32.2	35.2	40.6
M 8	8.8	19.1	18.6	18.1	17.6	16.5	21.6	24.6	27.3	29.8	34.3
	10.9	28.0	27.3	26.6	25.8	24.3	31.8	36.1	40.1	43.8	50.3
	12.9	32.8	32.0	31.1	30.2	28.4	37.2	42.2	46.9	51.2	58.9
M 10	8.8	30.3	29.6	28.8	27.9	26.3	43	48	54	59	68
	10.9	44.5	43.4	42.2	41.0	38.6	63	71	79	87	100
	12.9	52.1	50.8	49.4	48.0	45.2	73	83	93	101	116
M 12	8.8	44.1	43.0	41.9	40.7	38.3	73	84	93	102	117
	10.9	64.8	63.2	61.5	59.8	56.3	108	123	137	149	172
	12.9	75.9	74.0	72.0	70.0	65.8	126	144	160	175	201
M 14	8.8	60.6	59.1	57.5	55.9	52.6	117	133	148	162	187
	10.9	88.9	86.7	84.4	82.1	77.2	172	195	218	238	274
	12.9	104.1	101.5	98.8	96.0	90.4	201	229	255	279	321
M 16	8.8	82.9	80.9	78.8	76.6	72.2	180	206	230	252	291
	10.9	121.7	118.8	115.7	112.6	106.1	264	302	338	370	428
	12.9	142.4	139.0	135.4	131.7	124.1	309	354	395	433	501
M 18	8.8	104	102	99	96	91	259	295	329	360	415
	10.9	149	145	141	137	129	369	421	469	513	592
	12.9	174	170	165	160	151	432	492	549	601	692
M 20	8.8	134	130	127	123	116	363	415	464	509	588
	10.9	190	186	181	176	166	517	592	661	725	838
	12.9	223	217	212	206	194	605	692	773	848	980
M 22	8.8	166	162	158	154	145	495	567	634	697	808
	10.9	237	231	225	219	207	704	807	904	993	1,151
	12.9	277	271	264	257	242	824	945	1,057	1,162	1,347
M 24	8.8	192	188	183	173	168	625	714	798	875	1,011
	10.9	274	267	260	253	239	890	1,017	1,136	1,246	1,440
	12.9	320	313	305	296	279	1,041	1,190	1,329	1,458	1,685

Table 7.2 Preload forces and torques from VDI standard 2230

Maximum permissible tightening torques and resulting maximum preload forces for hexagon head screws ISO 4014 to 4018, hexagon socket screws ISO 4762 and for screws with analogous head strengths and head contact surfaces of strength classes 8.8–12.9 at 90% utilisation of the yield limit and a "medium" bore, in accordance with DIN EN 20273.

The table shows the permissible maximum values and does not cover any further safety factors. The application of the above values requires knowledge of the relevant guidelines and design criteria.

All direct screw connections use thread-forming fasteners that form their own threads when screwed into core holes and, depending on the type of screw connection, can also produce core holes.

In contrast, counter threads must be produced or nut elements used for metric screws.

Direct screwing increases productivity during assembly and reduces fastening costs.

The holding thread is formed by the screw thread. This is usually done by grooving. The precondition for this is that the screw threads must have a higher strength than the workpieces and the material being screwed in must be sufficiently ductile.

Figure 8.1 Thread-forming screw for plastics

Which screw for which application?

The most suitable screw type depends on the material. As a general rule:

coarse threads for soft materials, fine threads for hard materials.

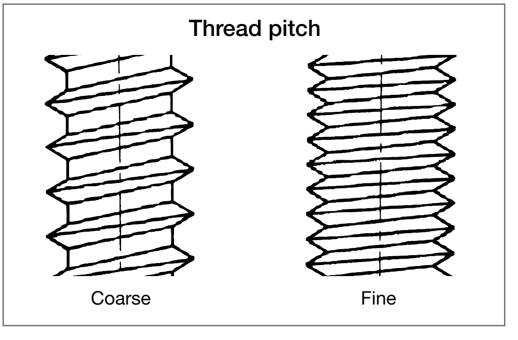

Figure 8.2 Thread-forming screw types

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Sheet metal screws

The threads of sheet metal screws are designated by the abbreviation ST (self tapping), e.g. St 3.5.
The sheet metal screw thread is standardised in DIN EN ISO 1478. The flank angle of the thread is 60°, as it is for metric screws. However, the thread has a coarser pitch. When screwed in, it acts like a forming tool and deforms the material without any shavings.

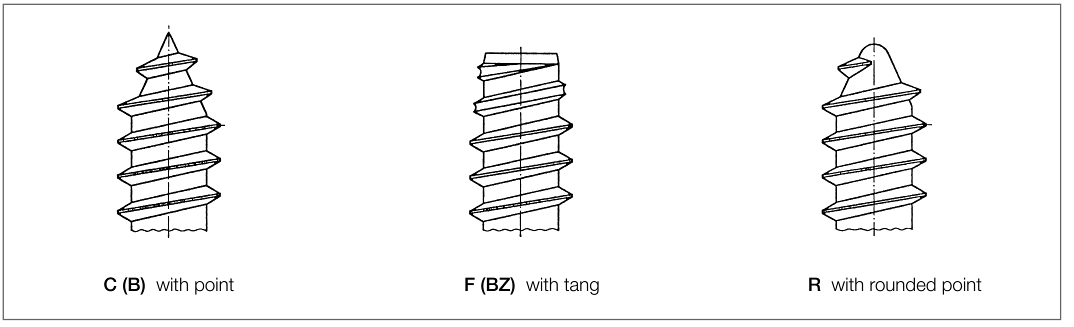


Figure 8.3 Thread ends according to DIN EN ISO 1478

1. Sheet metal screws

Sheet metal screws for use with steel materials are case-hardened. This gives the screws a high surface hardness and a tough core.

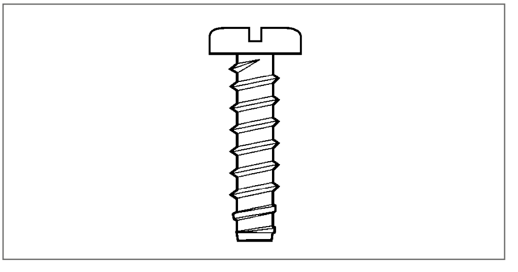


Figure 8.4 Sheet metal screw with tang

2. Sheet metal screws with drill bit

The threads correspond to those of sheet metal screws with an additional drill point.

Advantages of self-drilling screws
- No centre-punching
- No borehole
- No hole mismatch
- No tolerance issues

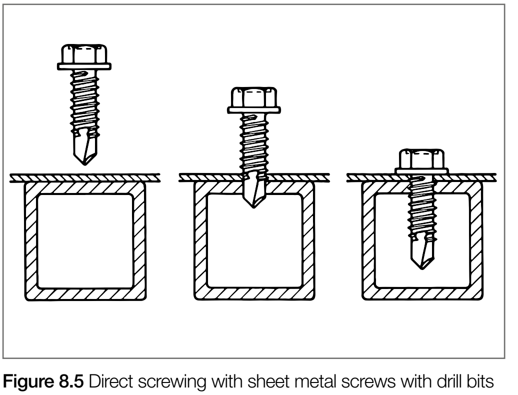


Figure 8.5 Direct screwing with sheet metal screws with drill bits

3. Thin sheet screws

If the screwed-in parts (sheets) are thinner than the thread pitch of the sheet metal screws according to DIN EN ISO 1478 (wobble limit), additional joining elements must be used because otherwise a tight direct connection with sheet metal screws is not possible. Thin sheet screws are a cost-effective alternative. These form a passage through a metal sheet, after which a metric thread is grooved.

This gives the mounting hole a more favourable overall height at the screw connection point and the thread pitch is finer, so there is sufficient coverage of the formed metric thread flanks.

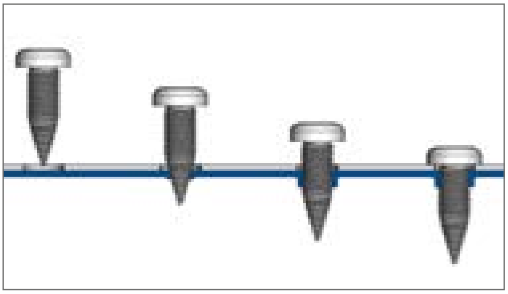


Figure 8.6 Screw fastening with thin sheet screws

Applications without a pilot hole are also possible. There is no need for additional nut elements.

4. Thread-forming screws, DIN 7500 design, Form Duo

Thread-forming screws are screwed into a pre-drilled hole in solid metal components. The hole diameter is between the core diameter and the pitch diameter of the thread.* The threaded end of the screw is tapered to facilitate thread forming. The counter thread is pushed into the mounting hole due to its non-circular shape (lobulation).

A group of thread-forming screws is standardised in DIN 7500. In addition to the Form Duo screw shown, there are different designs for the thread forming zone. Different principles may be adopted, depending on the type of production. The screw thread itself has an oversize.

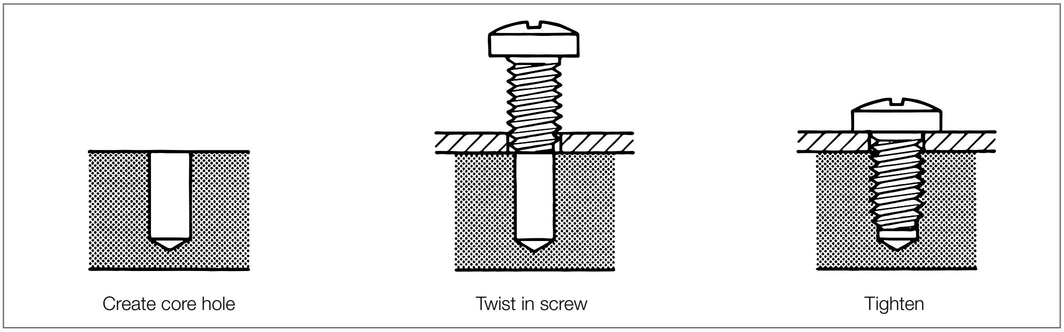


Figure 8.7 Applying direct screw fastening to solid metal components

Thread-forming screws can be used in the following materials, among others:

- Steel up to a tensile strength of 450 N/mm²
- Aluminium
- Copper alloys
- Zinc die-cast

No chips are produced during the machining of thread-forming screws. The grooved thread is hardened and is compatible with metric ISO screw threads, so in case of repair, for instance, a normal metric screw can be used.

* For design information, please refer to our eShop or the product standards.

Advantages of thread-forming screws in metallic materials.

- No thread cutting/no chips
- No locking elements required
- Good vibration resistance
- High pull-out resistance

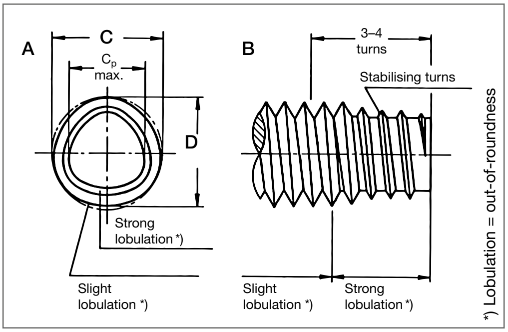


Figure 8.8 Thread according to DIN 7500 Form Duo design

Cut thread

- Low flank coverage
- Cut fibre flow
- Chips
- Flank clearance

Grooved thread

- Large flank coverage
- Undisturbed fibre flow
- Hardened surface
- No chips

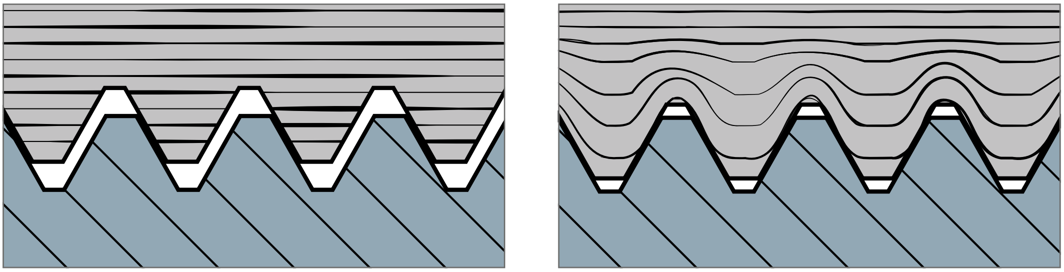


Figure 8.9 Comparison between cut and grooved threads

5. Thread-forming screw in special designs and factory standards.

In addition to the screws according to DIN 7500, various screws with optimised flank geometry are also available, which are especially designed for connection with light metals.

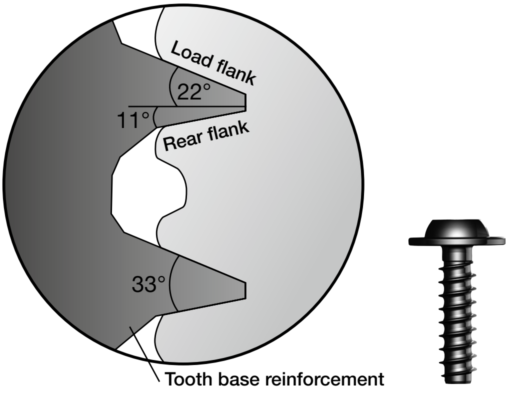


Figure 8.10 Direct screw fastening with an ALtracs® screw in light metal

6. Self-tapping screws for plastics

For direct screw fastening to thermoplastics, low screw-in torques, high overtightening torques and high pull-out forces are required. AMTEC® screws (Böllhoff standard B 52004 ff.) with a 30° thread flank have proven beneficial in such cases. These have a relatively large pitch and a small core diameter. The screw connection has self-locking properties and can be re-screwed up to ten times.

Figure 8.11 Direct screwing into thermoplastic material

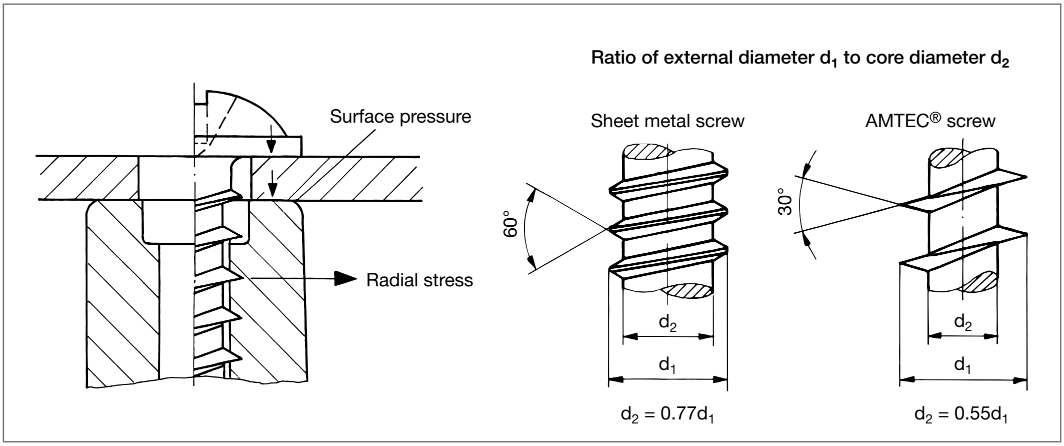
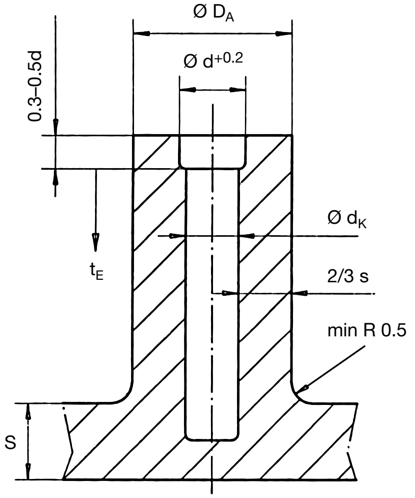


Bild 8.12 Direct screw fastening with an AMTEC® screw in plastic

This method is especially economical because a nut element would generally also have to be embedded for a metric thread. However, it is essential to observe the design notes* for proper use.

* see the product brochure or our eShop



Materials	Hole diameter d_K	External diameter D_A	Screw-in depth t_E
ABS	0.80 × d	2.00 × d	2.00 × d
ABS PC Blend	0.80 × d	2.00 × d	2.00 × d
ASA	0.78 × d	2.00 × d	2.00 × d
PA 4.6	0.73 × d	1.85 × d	1.80 × d
PA 4.6 GF 3.0	0.78 × d	1.85 × d	1.80 × d
PA 6	0.75 × d	1.85 × d	1.70 × d
PA 6 GF 30	0.80 × d	2.00 × d	1.90 × d
PA 6.6	0.75 × d	1.85 × d	1.70 × d
PA 6.6 GF 30	0.82 × d	2.00 × d	1.80 × d
PBT	0.75 × d	1.85 × d	1.70 × d
PBT GF 30	0.80 × d	1.80 × d	1.70 × d
PC*	0.85 × d	2.50 × d	2.20 × d
PC GF 30*	0.85 × d	2.30 × d	2.00 × d
PE-LD (soft)	0.70 × d	2.00 × d	2.00 × d
PE-HD (hard)	0.75 × d	1.80 × d	1.80 × d
PET	0.75 × d	1.85 × d	1.70 × d
PET GF 30	0.80 × d	1.80 × d	1.70 × d
PMMA	0.85 × d	2.00 × d	2.00 × d
POM	0.75 × d	1.95 × d	2.00 × d
PP	0.70 × d	2.00 × d	2.00 × d
PP TV 20	0.72 × d	2.00 × d	2.00 × d
PPO	0.85 × d	2.50 × d	2.30 × d
PS	0.80 × d	2.00 × d	2.00 × d
PVC (hard)	0.80 × d	2.00 × d	2.00 × d
SAN	0.77 × d	2.00 × d	1.90 × d

Figure 8.13 Recommended tube design for direct screw fastening with AMTEC® screws

The Delta PT screw is available as an advanced fastener, especially for thermoplastic, highly reinforced synthetic materials.

Features
❶ Advanced flank geometry
❷ Enlarged core cross-section
❸ Reduced pitch
❹ Reinforced head geometry
❺ High-quality screw material

Result
- High torsional and tensile strength
- High dynamic safety
- Good heat dissipation
- Low radial stress
- Low surface pressure

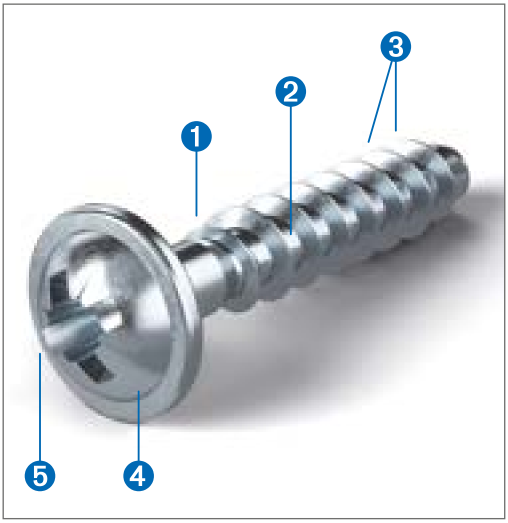


Figure 8.14 Delta PT screw for direct screw connections in thermoplastics

Applications in thermosets with the Delta PT screw with cutting edge.
- Thermoset components are not plastically deformable
- Very brittle materials with low elongation capacity require a cutting aid

Cutting edge
- Milled ¼ circle
- Length: 3 – 4 × thread pitch

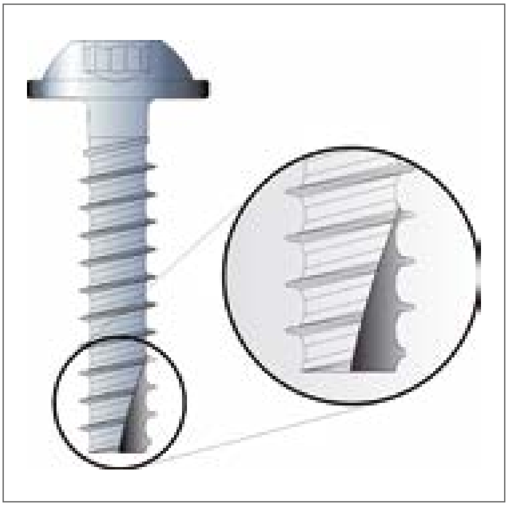


Figure 8.15 Delta PT screw with cutting edge for direct screw connections in thermosetting plastics

Technical advantages and economic benefits of direct screw connections

- Higher loadable internal threads due to strain hardening with metal direct screw connection
- More reliable and less expensive process, as fewer operations are required
- High resistance to loosening because the thread has a tight fit

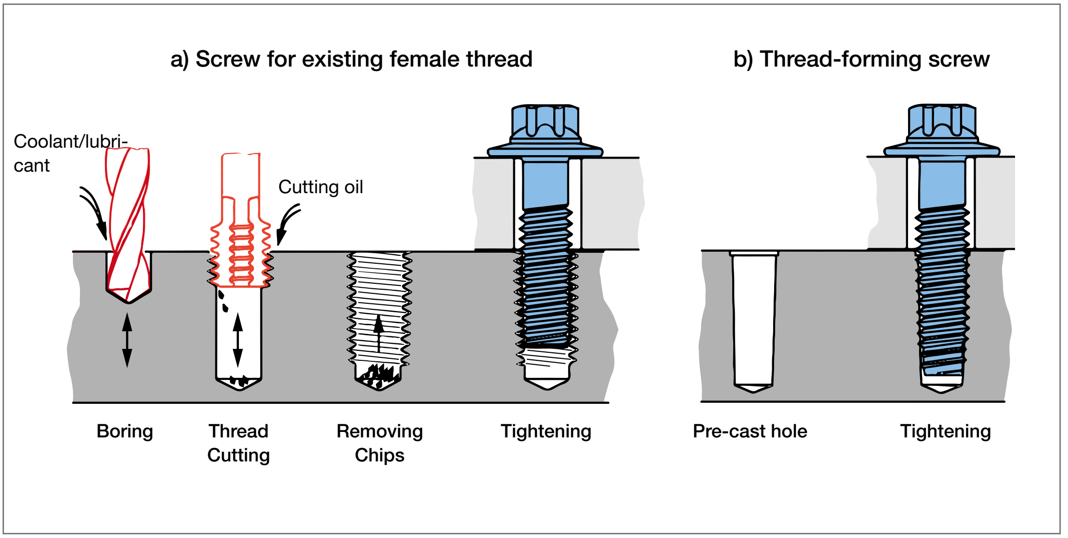


Figure 8.16 Comparison between a convention screw connection and a direct screw connection

Important technical note

When using the optimum direct screw fastening method, it is important to follow the design notes and installation guidelines. Matching – in terms of components, screw type and assembly – is hugely important. It is recommended to carry out assembly tests with original components and to check and determine the assembly parameters prior to series production.

Böllhoff's Application Technology department will be happy to help you determine the screw connection characteristics you need.

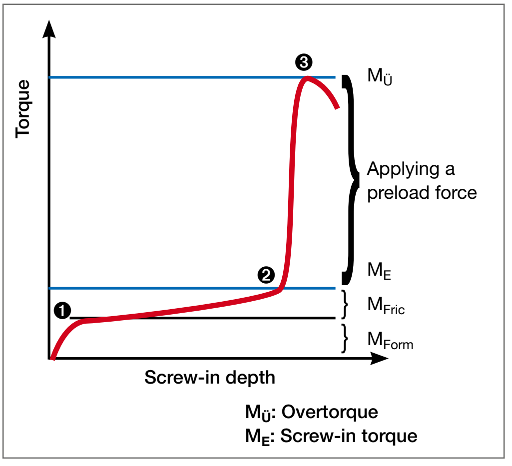


Figure 8.17 Screw-in curve for a direct screw fastening in a blind hole

Direct fastening

The growing use of lightweight and low-cost materials means that the use of direct screw fastenings will continue to increase.

When does thread grooving not work?

- If there are small differences in strength between the screw material and the component material
- If the materials are too brittle
- If very high pretensioning forces are required

Securing threaded connections

A screw connection is understood to be a connection that can be detached multiple times, that joins two or more components together by means of a preload force generated during assembly. This connection should consistently behave as one part, even under the influence of an external operating force. To this end, the preload force generated by the assembly tightening torque, which causes the frictional connection between the components, must be maintained as far as possible. Otherwise, the components may come apart, the screws may loosen or the screws may be subjected to unacceptable shear strain. If a screw connection is designed correctly, the frictional resistance in the thread and under the screw head is sufficiently high to prevent automatic loosening even under a vibration load. In this case, the connection is self-locking. The automatic loosening of a screw connection always begins with an unintentional drop in the preload force and is caused in particular by dynamic loads. When this happens, the preload force can be partially or completely lost.

The diagram below shows the interrelationships on which a reliable screw connection depends*.

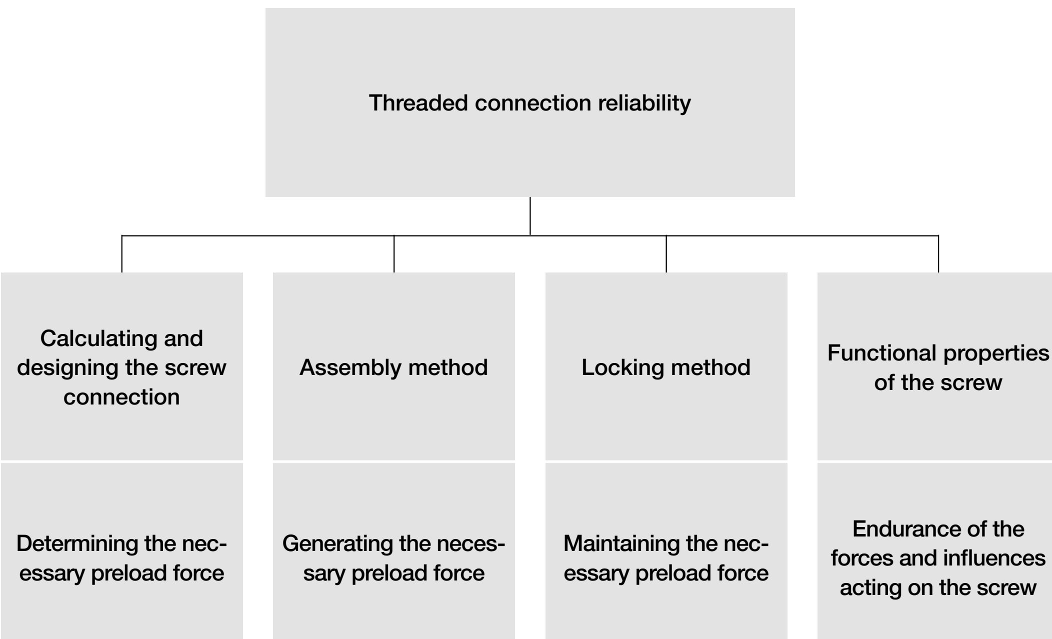


Bild 9.1 Interrelationships that affect the reliability of a screw connection

* From data sheet 302: A well designed screw connection that has been tightened under monitoring does not usually require additional screw-locking.

In practice, design measures cannot always ensure sufficient security in the screw connection. So to prevent screw connections from loosening or even falling apart, screw-locking elements are used in such cases.

For this purpose, the individual measures are divided into the following groups according to their mode of operation:

- setting locks
- locking devices
- anti-rotation locks

The table compares causes with the operating principles of individual screw-locking elements.

Cause of loosening	Classification of locking elements according to		
	Function	Operating principle	Example
Loosening due to settling or creep	Setting lock	Reducing the surface pressure	Screw-and-washer assembly, e.g. DIN EN ISO 10644 Flange screw DIN EN 1665
		Co-tensioned, resilient elements	Disc springs DIN 2093 Safety washers DIN 6796 and B 53072 Screw-and-washer assemblies DIN 6900-5 Nut-and-washer assemblies B 53010
Turning loose by releasing the self-locking effect	Captive lock	Positive locking elements	Castle nuts DIN 935 and DIN 979 Screws with split pin hole DIN 962 Wire locking device Lock washers
		Clamping elements	All-metal nuts with clamping part, e.g. DIN 6927 Nuts with plastic insert, e.g. DIN 6926 Screws with plastic coating in the thread, e.g. B 53081 Self-tapping screws DIN 7500 HELICOIL® screwlock B 62000
	Anti-rotation lock	Locking elements	RIPP LOCK® lock washers, ratchet screws and nuts, e.g. B 158
		Locking, tensioning elements	Wedge locking washers B 53074
		Adhesive elements	"Microencapsulated screws", e.g. B 53084

Table 9.1 Classification of locking elements according to their function and method of operation

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A basic distinction is drawn between two mechanisms for automatic loosening – loosening and turning loose:
With loosening, dynamic or static loads, especially in the axial direction, cause permissible stresses to be exceeded, resulting in settling and creep. This reduces the remaining clamping length and thus the applied preload force.

In contrast, when the screw is turned loose, dynamic loads act transversely to the screw axis and thus displace the clamped components relative to each other.

If the limits on this displacement are exceeded so that the acting transverse forces are greater than the static friction between the clamped components caused by the preload force, then this can result in a wobbling motion about the screw axis. This relative movement generates an internal loosening torque that can lead to a complete loss of the preload force and, in extreme cases, even to the disintegration of the connection.

Unlike locking devices, anti-rotation locks prevent the screw connection from loosening. These include locking elements with profiling on the contact surface.

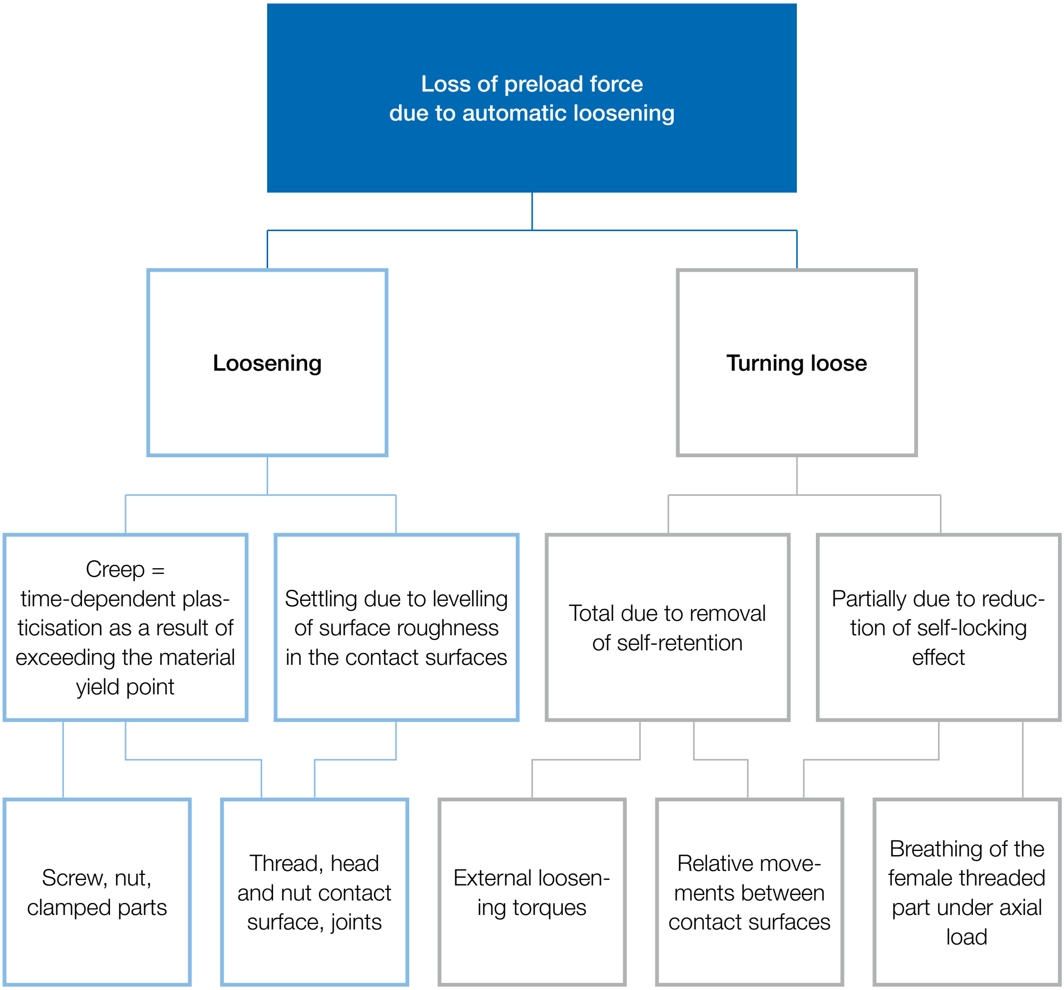

Figure 9.2 Causes that can lead to self-loosening of screw connections under dynamic loading (source: data sheet 302: Sicherungen für Schraubverbindungen [Locking devices for screw connections], O. Strelow; Beratungsstelle für Stahlverwendung, Düsseldorf)

Countermeasures against loosening

In order to keep the influences that lead to the loosening of screw connections to the minimum, these connections must be carefully calculated and correctly assembled. Large screw head diameters reduce the surface pressure and thus the tendency for settling and creeping on the contact surfaces. Screw-and-washer assemblies and flange screws are well-established as suitable fasteners in such cases.

"Co-tensioned, resilient locking elements" exist to reduce the loss of preload caused by settling and creep. Clamping discs or disc springs with high rigidity are suitable for some applications. Spring rings and serrated lock washers do not have a sufficiently high spring effect, so they are unsuitable as screw locking devices and the corresponding standards were withdrawn in 2003.

Countermeasures against turning loose

The best measures against unintentional turning loose have always been of a design nature. The basic rule is to prevent relative movements in the joints and on the thread flanks. To this end, the components to be connected should be as rigid as possible, while the associated screw connection should be as flexible as possible. This is achieved by using high-strength screws with great resilience, long clamping lengths and small shaft diameters.

Additional measures include the use of clamping elements as locking devices or adhesive components as anti-rotation locks. In contrast to pure locking devices, anti-rotation locks prevent a significant loss of preload force.

Locking elements

Although locking devices permit the partial loosening or turning loose of the connections, they still prevent them from coming apart completely. This means that locking devices are by no means comparable to effective screw-locking devices, which prevent the connection from loosening in the first place.
Locking elements such as nuts with plastic inserts, screws with plastic coating in the thread or all-metal nuts with or without additional clamping part and special thread flank geometries are used as locking devices.

Unlike locking devices, anti-rotation locks prevent the screw connection from loosening. These include locking elements with profiling on the contact surface.

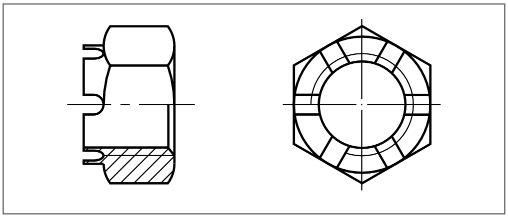

Figure 9.3 Castle nut

The best-known, albeit not recommended, "positive locking" elements include castle nuts, screws with split pin holes and wire locking devices.

Toothed elements

The function of this locking method is based on impressed, usually asymmetrical, teeth that are aligned so that the steeper flank faces the unscrewing direction. During tightening, these shape elements dig into the component and create a form fit that must be overcome during loosening (Figure 9.4). The surface finish and the strength of the clamping parts are crucially important to this function.

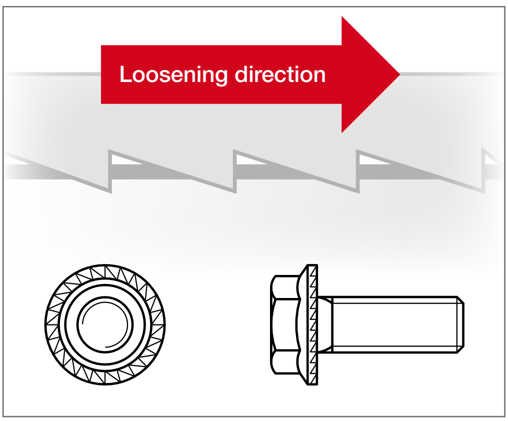

Figure 9.4 Fasteners with serrations on the bearing surface

Elements with locking ribs

A ribbed profile is suitable for sensitive surfaces. In this case, plastic deformation and hardening of the bearing surface increase the loosening torque.

RIPP LOCK® screw locking device

This screw locking device from Böllhoff is based on radial ribs. The pitch angle of the ribs is greater than the thread pitch of the screw. As a result, an excellent locking effect is achieved both with the lock washer (B 53065) and with the screws with locking function (B 158, B 251) and nut (B 193). During assembly of the fastener, the radial ribs of the RIPP LOCK® lock washers imprint themselves in the respective opposing position due to the preload force applied.
The resulting tight fit reliably prevents the connection from loosening by itself, even under extreme vibrations or strong dynamic loads.

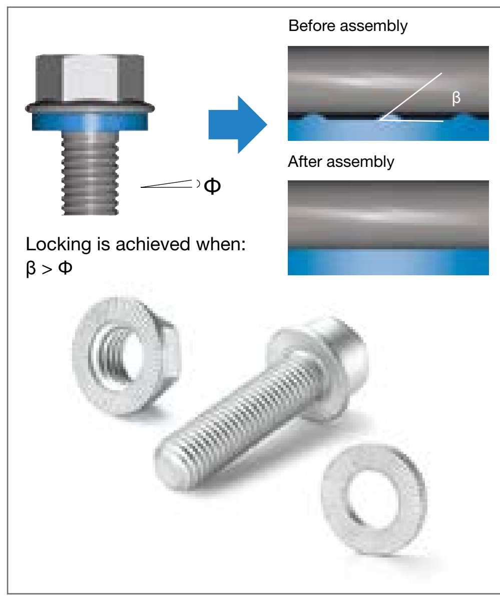

Figure 9.5 Fasteners with ribbings on the bearing surface

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Screws/nuts with a locking profile from our product range

The advantage of this locking method is that it is integrated into the screw or nut, so it cannot get overlooked. These locking elements have not yet been standardised.

The following Böllhoff standards are available from stock:

- B 53085 Hexagonal self-locking screws
- B 53012 Self-locking nut with flange
- B 151 and B 196 Locking elements with serrations
- B 158, B 251 and B 193 RIPP LOCK® Locking elements with ribbings

NORD-LOCK® wedge locking washers

The washers, which are bonded in pairs, are placed with their radial ribs under the screw head and/or the nut. Standard screws and nuts can be used for this purpose. When the screw and/or nut is tightened, the radial ribs of the washer pair are imprinted into the mating surface and a tight fit is achieved.

The figure below shows what happens when the screw is loosened:

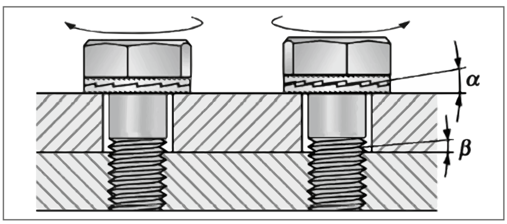


Figure 9.6 Locking effect of NORD-LOCK® washers

The pair of washers is firmly in place and movement is now only possible between the wedge surfaces. Even the slightest rotation in the loosening direction causes an increase in the clamping force due to the wedge effect, so that the screw locks itself. Wedge locking washers effectively secure against the turning loose of transversely loaded, vibration-stressed and vibrating screw connections.

Figure 9.7 NORD-LOCK® Wedge locking washers, Böllhoff standard B 53074

Chemical screw-locking devices

Chemical thread-locking devices (adhesive – clamping – sealing). These products are sold either as liquid adhesive coatings (anaerobic curing) or as pre-coatings. The latter has the advantage that the coating no longer has to be applied manually during assembly but is applied in a process-secure manner to the fasteners before delivery. This is also possible for bulk materials.

Description

Chemical thread locking can be divided into adhesive and clamping thread lockings. They are used as a precoat to ensure a reliable process (no forgetting or uneven application of the products):

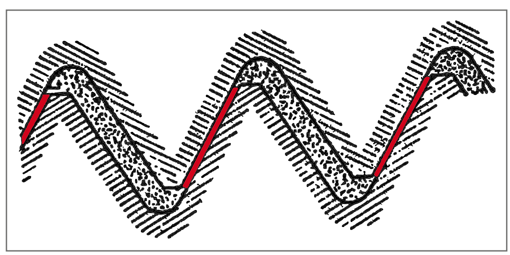


Figure 9.8 Chemical thread locking

DIN 267 Part 27 – Adhesive coating

Microencapsulated adhesives: When screwed in, the micro-capsules are destroyed by pressure and/or shear stress. The adhesive contained in the capsules is released. A chemical reaction (polymerisation) occurs when it is mixed with the hardener. This causes the adhesive to set (material closure) and brings about the desired locking effect. The assembly process should be completed after about 5 minutes (hardening). Depending on the product, different setting times must be observed (effectiveness of the adhesive locking effect).

DIN 267 Part 28 – Clamping coating

Clamping thread locking material: In this case, a polyamide is applied to a threaded section. A clamping effect is produced when the screw is screwed in. The axial clearance between the screw and nut thread is filled by the coating and also produces an increased surface pressure on the opposite uncoated thread flanks. The desired clamping locking effect occurs.
Locking devices cannot prevent partial turning loose, but can prevent complete loosening of the screw connection.

Procedure for adhesive and clamping locking devices

Unless otherwise specified, coating should be carried out in accordance with DIN 267 Part 27/28.
Length: 1,5 d +/- 2P for P < 1
1,5 d +/- P for P ≥ 1
measured from the screw end.

The first two to three thread turns should be largely free of coating material to facilitate screwing in. Thread locking can be designed as internal coatings (nuts) or as external coatings (screws). At the same time, the coating can also be used on different materials and surfaces, according to the product. Different temperature resistances of the products must be taken into account. In addition, chemical thread locking can provide a sealing function. Care should be taken to ensure that the coating is applied all over and that the additional requirements are defined.

Figure 9.9 Different chemical thread locking systems

Characteristics / Product	Adhesive: DIN 267, T 27					
	Precote 30 yellow	Precote 80 red/green	Precote 80-3red/ green	Precote 85 turquoise	3M Scotch Grip 2353 blue	3M Scotch Grip 2510 orange
Temperature resistance	– 60 to + 150 °C	– 60 to + 170 °C	– 60 to + 170 °C	– 60 to + 170 °C	– 30 to + 110 °C	– 30 to + 150 °C
Weak acids pH > 4 at RT	1	1	1	1	1	1
Alkaline solutions pH > 11 at RT	1	1	1	1	1	1
Oils and greases	1	1	1	1	1	1
Antifreeze	1	1	1	1	1	1
Brake fluids	1	1	1	1	1	1
Solvents	1	1	1	1	1	1
Petrol	1	1	1	1	1	1
Water	1	1	1	1	1	1
DVGW approval (DIN 30600 Drinking water)	no	no	no	no	no	no
Breakaway and loosening torques	medium	high	high	high	high	high
Reusable	no	no	no	no	no	no
Dimension range	M 4–M 60	M 3–M 60	M 3–M 60	M 3–M 60	M 2–M 60	M 2–M 60
Anti-rotation lock	yes	yes	yes	yes	yes	yes
Meets requirements according to DIN 267, T 27	yes	yes	yes	yes	yes	yes
Meets requirements according to DIN 267, T 28	no	no	no	no	no	no
Screw-in thread free of oil and grease	yes	yes	yes	yes	yes	yes
Processing time after fastening	max. 5 min.	max. 5 min.	max. 5 min.	max. 5 min.	max. 5 min.	max. 5 min.
Minimum temperature for setting	– 20 °C	– 20 °C	– 20 °C	– 20 °C	+ 5 °C	+ 5 °C
Coefficient of friction in thread	0.10–0.15	> 0.25	0.25–0.28	0.10–0.16	0.10–0.16	n/a
Setting time	6 hours	6 hours	0.5 hours	6 hours	24 hours	72 hours

1 = very good · 2 = good · 3 = satisfactory· 4 = sufficient · n/a = not applicable

Table 9.2 Overview of different chemical screw-locking solutions (all data subject to change)

Clamping: DIN 267, T 28							Sealing			
Polyamide spot Plas-bolt blue/red	Polyamide complete Plasbolt blue/red	Clemm-Loc brown	VC 3	Polyamide spot, complete, tempera-ture-resist-ant, orange	Precote 6 white	Precote 9 red brown/white	Precote 4 white/blue	Precote 5 white/blue	Thread sealant 4291	Loctite 5061 light blue
– 50 to + 90 °C	– 50 to + 90 °C	– 60 to + 130 °C	– 30 to + 90 °C	– 50 to + 200 °C	– 60 to + 110 °C	– 60 to + 180 °C	– 60 to + 180 °C	– 60 to + 160 °C	– 50 to + 150 °C	– 50 to + 150 °C
1	1	1	3	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1	1
1	1	1	4	1	1	1	1	1	1	1
1	1	1	3	1	1	1	1	1	1	1
1	1	1	1	1	1–2	1–2	1–2	1–2	1–2	1–2
yes	yes	yes	no	yes	no	no	no	no	no	yes
high	high	high	low	high	high	medium	low	low	low	low
2 ×	2 ×	5 ×	2 ×	5 ×	2 ×	2 ×	1 ×	1 ×	1 ×	1 ×
M 3–M 24	M 3–M 24	M 2–M 24	M 1–M 24	M 2–M 60	M 2–M 60	M 2–M 60	M 2–M 60	M 2–M 60	M 4–M 55	M 4–M 60
no	no	no	no	no	no	no	no	no	no	no
no	no	no	no	no	no	no	no	no	no	no
yes	yes	yes	no	yes	yes	yes	no	no	no	no
no	no	no	no	no	no	no	no	no	no	no
unlimited	unlimited	unlimited	unlimited	unlimited	unlimited	unlimited	unlimited	unlimited	unlimited	unlimited
n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
0.10–0.15	n/a	0.10–0.15	0.10–0.20	0.10–0.15	0.25–0.30	0.10–0.15	0.10–0.23	0.12–0.18	0.10–0.15	n/a
none	none	none	none	none	none	none	none	none	0.5–1 hour	none

Position of coating

Unless otherwise specified, the coating must be applied at the specified length (see Figure 9.10).

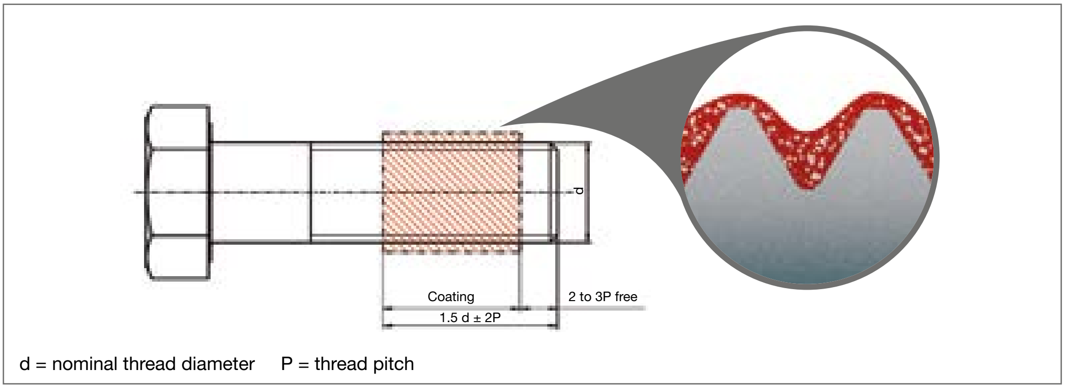


Figure 9.10 Position of coating, e.g. for a hexagon head screw

Notes for assembly

- Defined position and length of coating
- Tolerance 6g/6h after electroplating
- Optimal thread start according to DIN 76, free from burrs, countersink 1.05 × nominal diameter
- For sealing applications, coat at least four threads and assemble with overlapping

Locking effect under dynamic load

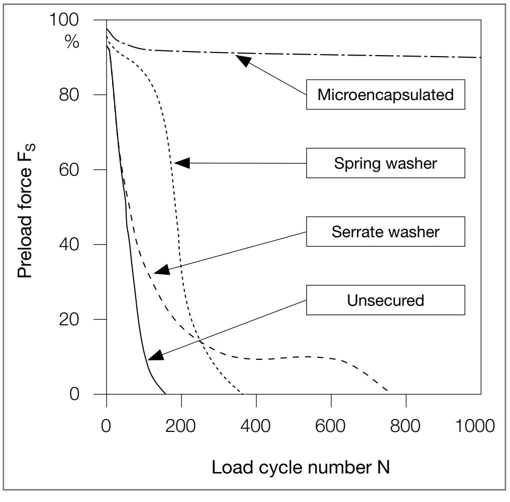


Figure 9.11 Junkers vibration test according to DIN 65151

Other chemical thread locking and seals are available at any time on request.

We advise our customers on the best technical and most cost-effective solution and implement their specific requirements.

Locking screw connections

This remains a key issue, as often the design of the connection does not factor in all of the influencing parameters, yet increased product liability and safety requirements have to be taken into account. At the same time, each screw-locking element has an effect on the fastening situation and must be taken into account during assembly planning.

Aspects such as reuse, temperature influences, material pairings and locking specific locking or additional properties are key when choosing an appropriate locking component. The question of reusability must also be considered.

Unsuitable screw-locking devices

Some of these are still widely used today, although they no longer conform to the latest standards. The corresponding product standards have been withdrawn. Such elements have been incorrectly assigned as "anti-rotation locks" and "setting locks". Co-tensioned resilient elements are ineffective in high-strength screw connections with a high preload. In poor circumstances, they can even promote the settling effect and facilitate a drop in the preload force. These are as follows:

- Spring rings in accordance with DIN 127 (withdrawn in 1992), DIN 128 and DIN 6905
- Spring washers in accordance with DIN 137 and DIN 6904
- Serrated lock washers in accordance with DIN 6798 and DIN 6907
- Lock washers in accordance with DIN 6797
- Locking plates in accordance with DIN 93, DIN 423 and DIN 463
- Safety cups in accordance with DIN 526
- Self-locking nuts in accordance with DIN 7967

It has been shown that the intended locking effect is not achieved because, for example, the washer elements are already flattened at relatively low preload forces and do not produce a spring effect, or the desired mechanical function is not met with these products.

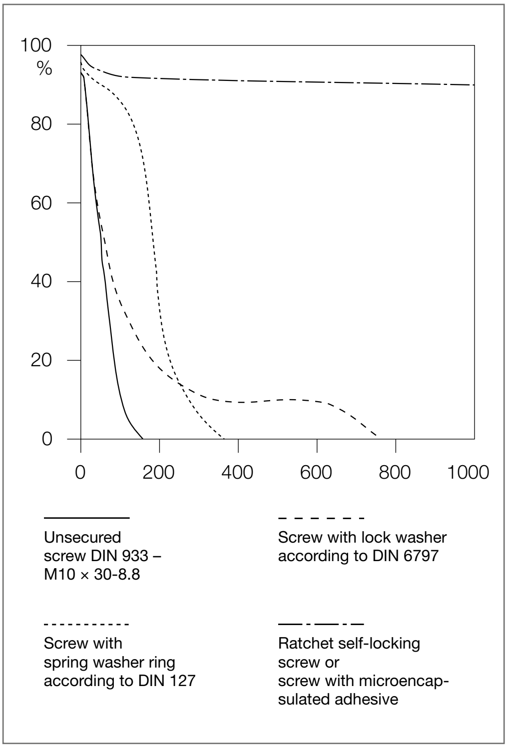


Figure 9.12 Loosening curves of various screw connections subject to dynamic transverse loading

09

Sealing technology is used in almost every industrial sector and is an important field in design engineering. It focuses on preventing leakage, avoiding contamination, ensuring fault-free operation of machines, preventing corrosion and protecting the environment. The aim is to use sealing technology to prevent or reduce the transport of liquid or gaseous substances between two spaces, as shown in the diagram in Figure 10.1.

There is no such thing as absolute tightness in the physical sense; it must always be defined in the context of the elements that require sealing. The most important general criteria when specifying a seal are safety, reliability and cost-effectiveness. The following parameters are particularly important: Installation conditions, pressure, density, temperature, viscosity, and pH value of the medium to be sealed. Sealing functions can be achieved using conventional sealing elements, constructive designs and connecting elements with additional sealing functions.

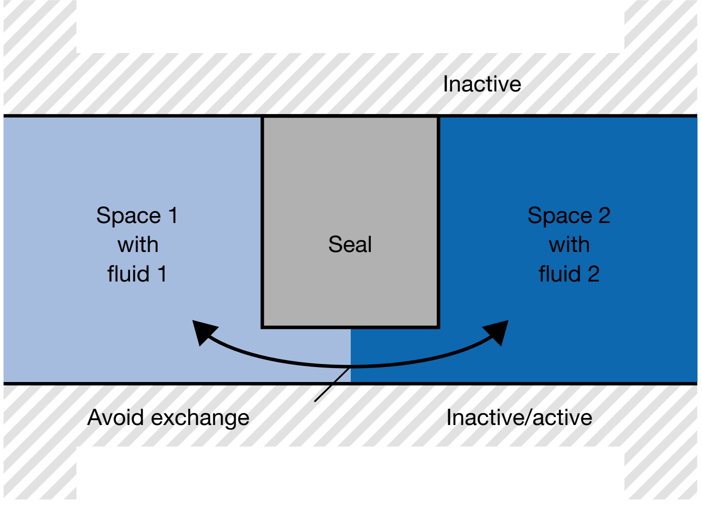


Figure 10.1 The function of a seal

Sealing points can be categorised as static or dynamic. At static sealing points, there is no relative movement between the sealing surfaces, whereas with dynamic seals, there is function-related relative movement of the sealing surfaces in relation to one another.

This relative movement can be rotational, as with shaft seals, or translational, as with rod seals and piston seals. In the case of dynamic seals, tasks such as force transmission and guidance should not be performed by the seal.

10

Overall, there is a vast array of sealing elements. We have set out an overview of the sealing elements below, to help you with their classification and specification. We have focused primarily on static sealing points.

Figure 10.2 shows a breakdown of static sealing points. If the sealing point needs to be detachable for maintenance, then a screwable element is usually used. For permanent sealing of bores, on the other hand, sealing plugs or adhesive or welding techniques are often used.

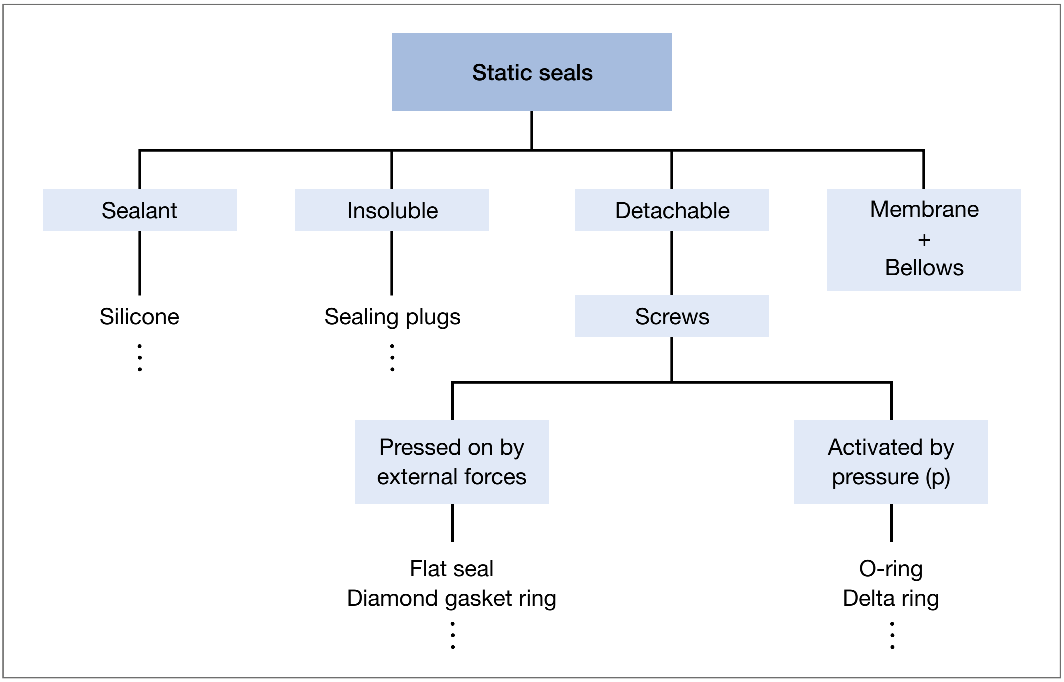


Figure 10.2 Classification of static seals

Detachable seals on screw connections

Sealing via a screw has the advantage of creating a detachable connection. Depending on the application, this can achieve a pure sealing function, while additional force can be applied via the screw, and the sealing element can be replaced without great effort. A simple screw already provides a certain degree of sealing and reduces the exchange of media. The mode of operation is similar to a labyrinth seal.

However, the sealing effect of the screw alone is often insufficient, so additional measures are used to increase the tightness. In this case, the usual measures here are as follows:

- Use of sealing rings
- Use of sealing coatings on the underhead
- Use of sealing coatings on the thread
- Use of conical threads
- Use of special threads

Sealing rings

Sealing rings are available in a wide range of designs, shapes and materials. One advantage is that they can be used directly in combination with standard screws. This means that screws can be adapted very well to the areas to be sealed.

To achieve the greatest possible sealing effect, the sealing surface should be machined. Table 10.1 compares widely used sealing rings.

O-rings	USIT rings	Sealing rings
Various standards available, e.g. DIN 3771, DIN 3601	Rubber-metal composite seal	DIN 7603
Various materials	Steel or stainless steel washer	Various materials
Good chemical resistance	Rubber bead in NBR or Viton	Good chemical resistance
Non-reactive	Simple, fast assembly (loss-proof)	High mechanical strength
Seals against liquids and gases	Secure, self-reinforcing sealing and suitability for high pressures if copper rings are not suitable	Seals against liquids and gases
Screws should have undercut		Screws should be adapted for the application

Table 10.1 Overview of common sealing rings

Coating

For larger series, it is possible to improve or achieve a tight screw connection by means of an under-head coating or by coating the thread.

In the case of an underhead seal, plastic is melted onto the underhead side of the screw. This can achieve a very effective seal against gases and liquids, with no damage to the workpiece surface.

The screws can still be dealt with as bulk material and are reusable to a limited extent. Machining the workpiece surface is useful for enhancing the sealing effect, but is not necessary in all cases. There are a large number of possible coatings for applications with different parameters. Three commonly used products are shown in Table 10.2.

Nylon ring	GESI seal	Precote 200
Multi-use (5x)	Multi-use (5x)	Limited reuse (2x)
Sealing effect up to 150 bar	Sealing effect up to 70 bar	Sealing effect up to 10 bar
Storage life: at least 4 years	Storage life: at least 4 years	Storage life: at least 4 years
Usable at –40 to +140 °C	Usable at –40 to 90 °C	Usable at –40 to 150 °C
Can be designed to suit the application	Good resistance to weather and chemicals	Dry, non-sticky sealing film
Seals immediately after installation	Good electrical insulation properties	Excellent chemical resistance

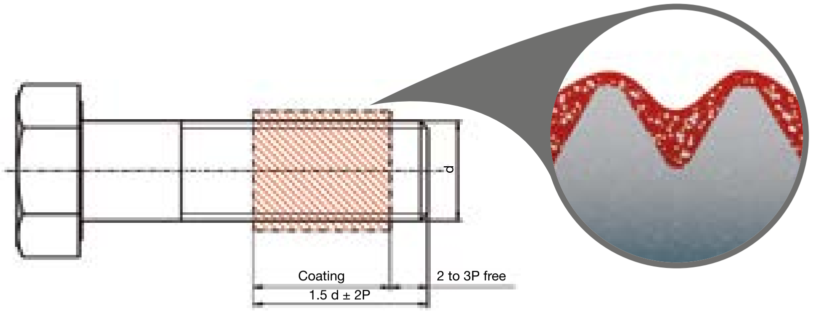
Table 10.2 Overview of common underhead coatings

In a thread coating, plastic or a microencapsulated material is applied to the thread as an all-over coating. The advantage of precoating is that it is applied to fasteners in a process-safe manner before delivery, rather than manually during assembly.

Adhesive microencapsulated precoatings consist of encapsulated adhesive and hardening agent. When screwed in, compressive and shear stress acts on the capsules. The capsules open. The adhesive and hardening agent are released and polymerisation occurs. The adhesive sets and forms a material bond.

In a locking precoating, a polyamide spot is sprayed onto a threaded section. The axial clearance between the screw and the internal screw thread is filled by the coating, creating high surface pressure between the thread flanks. An all-over coating should be applied to achieve a sealing effect.

The coating position should be specified for both processes in such a way that the sealing surface lies in the counter thread, see Figure 10.3. Care should be taken to ensure that the degree of filling is sufficient to compensate for thread tolerances. In addition to the sealing function, a precoated screw offers increased security against self-turning loose. An example of a precoated screw is shown in Figure 10.4.



d = nominal thread diameter P = thread pitch

Figure 10.3 Position of thread coating according to standard DIN 267–27

Figure 10.4 Screw with microencapsulated precoating

Geometry

The geometry of the screw can be adapted to increase the tightness in the underhead and in the thread area. Special geometries are used in the thread to compensate for thread clearance and ensure complete contact in the counterthread. First and foremost, tapered or conical threads and self-tapping threads are suitable for this purpose.

In tapered threads, the diameter increases from thread run to thread run, thereby reducing the thread clearance. The thread flanks compress and thus seal. Due to thread tolerances, it is sometimes necessary to use an additional sealant. The Whitworth pipe thread is an example of a standardised conical thread. This consists of a cylindrical internal thread and a conical external thread. It is used for fittings and threaded pipes.

Self-tapping screws displace the material of the component and thus produce the respective counterthread themselves. The resulting connection has no flank clearance, so the thread is tight. Further information on thread-forming screws can be found in the "Direct screw fastening" section.

Screws that are explicitly used for closing service bores are called screw plugs. Figure 10.5 shows standardised screw plugs. Various standards specify head shape, thread form and additional sealing elements. Besides the metric thread, the pipe thread and the gas thread are also very common. Examples of the different forms include:

- DIN 906: Screw plug with internal drive, tapered thread M 8x1 to M 48x2, R1/8 to R2
- DIN 908: Screw plugs with collar and hexagon socket, cylindrical thread M 8x1 to M 48x2, G1/8 to G1 1/2, form A (without seal, form AC with copper seal), form AA with aluminium seal
- DIN 910: Screw plug with collar and external hexagon, M 10x1 to M 52x1.5 and G1/8 to G2

Figure 10.5 Screw plugs DIN 906, DIN 908, DIN 910 (from left to right), (Source: Böllhoff eShop)

Sealing of bores

Non-detachable fasteners are generally used when the application involves permanently sealing a bore. Along with welding, soldering and adhesive joints, various fasteners can be pressed on or in. These are described below.

Like ball elements, parallel pins and taper pins are low-cost elements used for small diameters. Sealing plugs are often used for applications that are highly important for the function or safety. Pins are inserted into a bore in order to achieve a tight fit. A stepped bore allows for precise positioning. Tests are required to determine the safe pressure range, and considerable stresses are sometimes introduced into the material.

Balls are inserted into components by hammer, air hammer or a press. The ball is approx. 0.2 mm larger in diameter than the bore. A stepped bore allows the ball to be placed in position. With the ball, it is also necessary to determine the safe pressure range and to keep an eye on the stresses that are introduced into the component. A sealing effect only takes place via the ball circumference in contact. This can lead to leakage in materials with cavities or bore grooves.

Sealing caps, e.g. according to DIN 443 or DIN 470, are often used in gears and motors in the lower pressure range and for large diameters. The elements are only suitable for low pressures, as there is no crimping in the base material.

Sealing plugs are suitable for process-safe, replicable sealing of auxiliary bores. These are based on the push-expansion principle or on the pull-expansion principle. A distinction is drawn between four types of sealing plugs. Three are shown in Figure 10.6.

Figure 10.6 Sealing plugs

- One-piece sealing plugs like BB blockers
- Ball expanders
- Mandrel expanders
- Pull expanders with internal thread

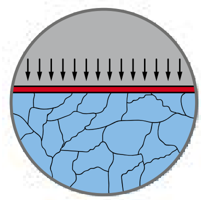
Ball sealing plugs function according to the push-expansion principle. In this process, the ball is pressed into the sleeve and causes it to expand. Mandrel expanders and PULLPLUGS™ function according to the pull-expansion principle. The mandrel or pin is pulled into the sleeve and causes it to expand. Sealing plugs feature a ribbed profile on the outside of the sleeve that anchors the sealing plug into the installation material during expansion. The ease of installation in the existing borehole makes this method particularly efficient, as there is no need to cut a thread. Furthermore, it does away with the need for additional sealants. Sealing Plugs are suitable for small- and large-scale production alike, as they can be installed manually, semi-automatically or fully automatically.

The design criteria for sealing plugs are maximum pressure, temperature, fluid to be sealed, material and geometry of the component, and processing technique. The common pressure application range goes up to 500 bar, while bursting pressure of the elements ranges from 1000 to 1500 bar. The one-piece B-blockers and sealing plugs with a short lateral surface are suitable for low pressures below 100 bar.

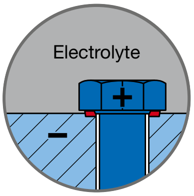
DIN 50900 Part 1 describes corrosion as "the reaction of a metallic material with its environment, which causes a measurable change in the material and can lead to impairment of the function of a metallic component or an entire system".

Most screw damage is caused by corrosion. Corrosion is unavoidable, however, so corrosion protection should be understood as a measure that controls and delays the development of corrosion.

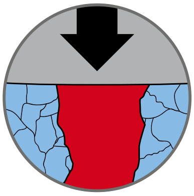
Of the many types of corrosion, those that are pertinent to the subject of fasteners are shown in Figure 11.1.



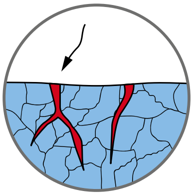
Surface corrosion is the even removal of attacked surfaces.



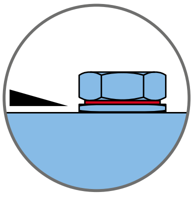
Contact corrosion occurs when different metals come into contact with an electrolyte.



Pitting corrosion occurs in localised areas, including via damage to protective coatings.



Stress corrosion cracking results from exposure to a corrosive medium and simultaneous stress.



Crevice corrosion occurs in gaps in the material or between joined components.

Figure 11.1 Different types of corrosion

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Fasteners are parts of a corrosion system that must be considered by the user within the overall context.

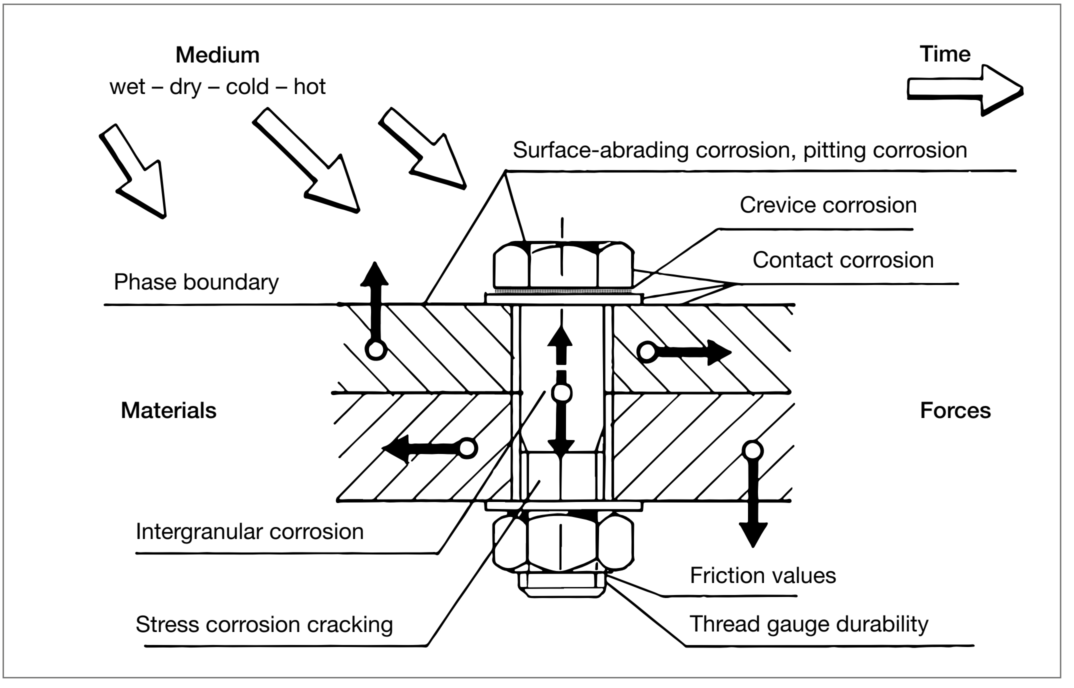

Figure 11.2 Screw connection corrosion system

A distinction is drawn between active and passive corrosion protection.

If fasteners made of materials that are largely corrosion-resistant are used, this is called **active protection**. This includes, for instance, rust- and acid-resistant steels and non-ferrous metals.

If steel fasteners are provided with a protective surface, then this is called **passive corrosion protection**. This includes all types of surface treatment.

Some examples of these common surface coatings for fasteners can be found on the following page.

Common surface coatings

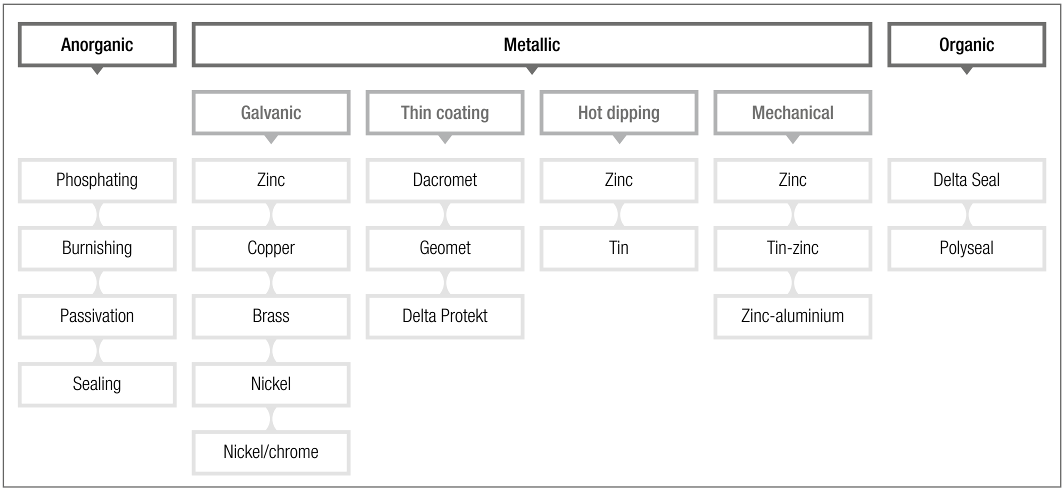

Figure 11.3 Overview of different surface coatings

In metallic protective coatings, a distinction is drawn between:

- **anodic** surfaces, such as zinc
- **cathodic** surfaces, such as nickel and chromium.

Zinc is very frequently used in different types of coatings. Zinc is coarser than the steel of the fastener. If part of the zinc coating is damaged, then the damaged area is closed again by the reaction of the zinc.

This is explained by the anodic effect, in which zinc "sacrifices" itself for the steel part and dissolves before the base metal.

This reaction is also used in underground piping and steel ship hulls with sacrificial anodes. The bare threads of hot-dip galvanised nuts are also protected by the zinc coating on the male threads.

The most common surface coating is electrolytic or galvanic (electroplated). The designation systems for galvanic surfaces are regulated according to DIN EN ISO 4042.

Surfaces for fasteners

These surfaces are much more than just corrosion protection coatings; they are systems with multi-functional properties that protect against corrosion and a whole lot more.

In the case of fasteners, special attention is normally paid to corrosion protection. In practice, a relatively small number of failures are due to mechanical loads; a far higher number are due to deterioration as a result of corrosion. In this context, it is particularly important to bear in mind that the fasteners of a component should not represent a weak point.

In addition to the design requirements, the selection of a suitable corrosion protection coating necessitates a complex approach (see Figure 11.4).

To this end, it is also necessary to consider current market developments in order to ensure that new products introduce
a) current, sustainable,
b) permanently available, and
c) cost-effective surface systems
to the market.
After all, any change to existing products that have been introduced into series production costs a lot of money and can lead to bottlenecks and quality issues.

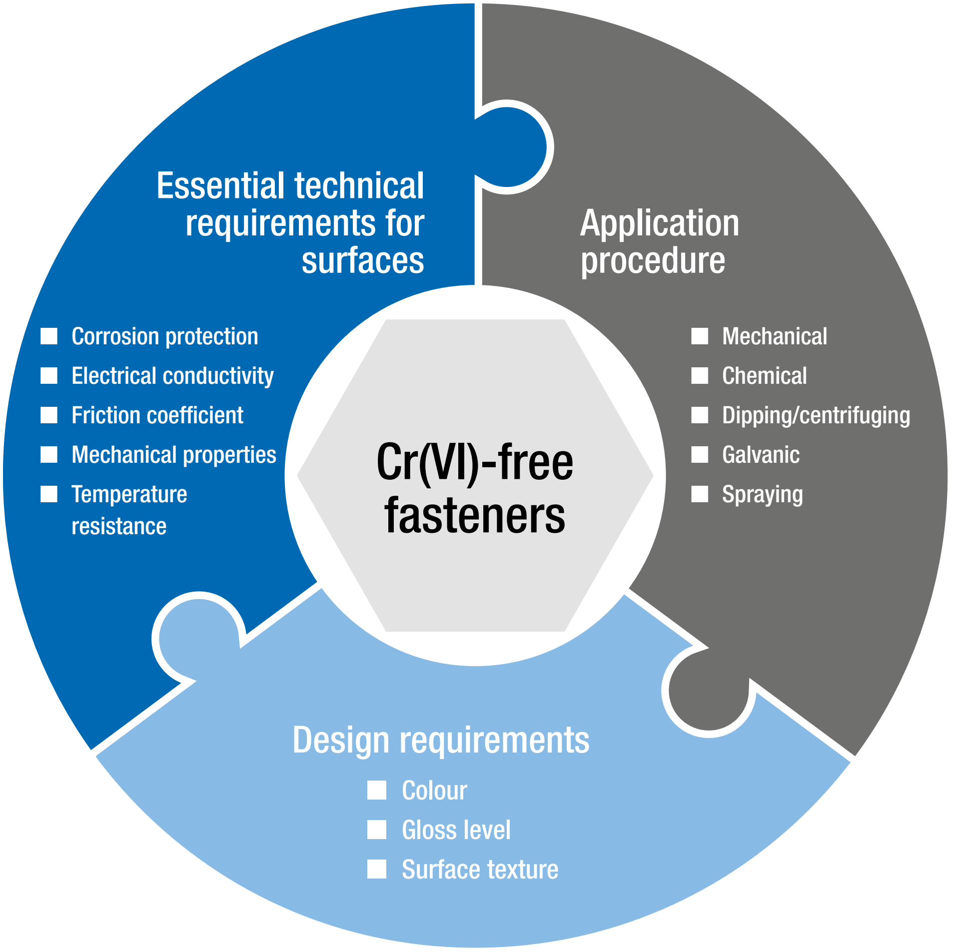

Figure 11.4 Surface coating system requirements

One of these market developments is the ban on chromium(VI) introduced in the key sectors of the automotive and electrical industries that supplier companies and electroplating companies have had to put into place.

Following the VDA and DIN EN ISO 3613, the detection limit of Cr(VI) is 0.1 µg/cm^2.

The following chromium(VI) content in coatings can be considered as a basis, in accordance with the VDA:

Coating	Approx. content in µg/cm^2
Chromated yellow	10
Chromated olive	15
Chromated black	16
Zinc flake coatings in accordance with DIN EN ISO 10683 flZnyc (e.g. Dacromet)	20

Table 11.1 Chromium(VI) content in different coatings

Product-specific advantages and disadvantages of the different systems are opposed to each other. In some cases, chromium(VI)-free systems require seals due to the lack of a self-healing effect. However, the switch to chromium(VI)-free coatings is inevitable in the medium term for all users and industries, and is environmentally sound.

Our recommendations when selecting a surface coating are based on modern "toxin-free" systems.

New chromium(VI)-free standard

Böllhoff offers a new standard as a replacement for yellow chromating that meets high technical requirements. This is a galvanised surface with a coating thickness of ≥ 5 µm for fasteners from thread size M5. In addition, this surface is thick-film passivated and adjusted to the friction coefficient window μ_{tot} of 0.12–0.18 µm for high-strength external threaded parts.

Sealing is available as an option.
With 144 h corrosion resistance to red rust, the defined VZD surface offers improved protection compared to the galvanised, 8 µm yellow chromated version (A3C) and, due to the low layer thickness, can be used for various screws and accessories.

Cr(VI)-containing reference surface, according to DIN EN ISO 4042 (with min. 8 µm coating thickness)	Zinc corrosion h	Base metal corrosion h	Name
Zn, chromated yellow	72	120	A3C
ZnFe, chromated black	72	360	R3R

The data in the above table are standard values determined for fasteners in the barrel process. Corrosion protection depends on dimensions and geometry. Requirements for other functional properties and assembly conditions must also be assessed.

Table 11.2 Chromium(VI)-containing surface coatings (selection)

Corrosion resistance of Cr(VI)-free surfaces in salt spray test

Coating	Layer thickness µm min	DIN EN ISO 9227 SS white rust h	SS red rust h	Böllhoff surface
Zn (thin-film) passivated **without** seal	5	12	36	C1
	8	24	72	C2
Zn black passivated **with** seal	8 ❷	12	72	C9
Zn thick-film passivated **with/without** seal	5	72	144	VZD standard surface ❶
Zn thick-film passivated **with** seal	5	96	168	V4
	8	96	240	V5
ZnFe black **with** seal	5	120	168	E8
	8	120	360	E9
ZnFe transparent **without** seal	5	72	168	E0
	8	72	360	E1
ZnFe transparent **with** seal	5	120	240	E3
	8	120	360	E4
ZnNi transparent **without** seal	5	120	360	N0
	8	120	600	N1
ZnNi transparent **with** seal	5	144	480	N3
	8	144	720	N4
ZnNi black passivated **without** seal	8 ❶	24	360	N7
ZnNi black passivated **with** seal	5	120	480	N8
	8	120	720	N9
Zinc flake coating e.g. DIN EN ISO 10683 flZn/nc/480h	~8	–	480	Examples: G1 = Geomet 321 A L0 = Delta Protekt KL 100
Zinc flake coating e.g. DIN EN ISO 10683 flZn/nc/L/720h	~10	–	720	Examples: G7 = Geomet 321 B+VL L2 = Delta Protekt KL100+VH 301 GZ
Zinc flake coating e.g. DIN EN ISO 10683 flZn/nc/TL/480h	~10	–	480	Examples: G9 = Geomet 500 A L8 = Delta Protekt KL105
Zinc flake coating e.g. DIN EN ISO 10683 flZn/nc/480h black	~8	120	480	Examples: L4 = Delta Protekt KL 100 + Delta Seal black L9 = Zintek 300 + Techseal SL

The values are guide values for barrel-plated goods immediately after coating.

❶ With lubricant additive for high-strength screws (> 8.8), coefficient of friction VZD = 0.12 – 0.18 µ total, also possible with coefficient of friction B2 = 0.09 – 0.14 µ total (according to VDA).

❷ Minimum recommended coating thickness.

Table 11.3 Chromium(VI)-free surface coatings (selection)

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Marking for electroplated coatings according to DIN ISO 4042

Coating metal/alloy		Identification letter
Abbreviation	Element	
Zn	Zinc	A
Cd ❶	Cadmium	B
Cu	Copper	C
CuZn	Copper-zinc	D
Ni	Nickel	E
Ni Cr ❷	Nickel-chromium	F
CuNi	Copper-nickel	G
CuNi Cr ❷	Copper-nickel-chromium	H
Sn	Tin	J
CuSn	Copper-tin	K
Ag	Silver	L
CuAg	Copper-silver	N
ZnNi	Zinc-nickel	P
ZnCo	Zinc-cobalt	Q
ZnFe	Zinc-iron	R

❶ The use of cadmium is partially restricted for reasons of environmental protection.
❷ Chrome layer thickness = 0.3 µm

Table 11.4 Galvanically applied coatings

Layer thickness (total layer thickness) in µm		Number
One coating metal	Two coating metals ❶	
No layer thickness specified	–	0
3	–	1
5	2 + 3	2
8	3 + 5	3
10	4 + 6	9
12	4 + 8	4
15	5 + 10	5
20	8 + 12	6
25	10 + 15	7
30	12 + 18	8

❶ The thicknesses specified for the first and second coating metals apply to all combinations of coatings, with the exception of chromium as the top layer, which always has a thickness of 0.3 µm.

Table 11.5 Thickness of the metal coatings

Gloss level	Passivation by chromating Colour ❶	Identification letter
matt	no colour	A
matt	bluish to iridescent bluish	B
matt	yellow to yellowish brown, iridescent	C
matt	olive green to olive brown	D
coatless	no colour	E
coatless	bluish to iridescent bluish	F
coatless	lustrous yellow to yellowish brown, iridescent	G
coatless	olive green to olive brown	H
glossy	no colour	J
glossy	bluish to iridescent bluish	K
glossy	lustrous yellow to yellowish brown, iridescent	L
glossy	olive green to olive brown	M
highly glossy	no colour	N
optional	according to B, C or D	P
matt	brownish black to black	R
coatless	brownish black to black	S
glossy	brownish black to black	T
all levels of gloss	without chromating	U

Zinc, zinc alloy coatings and cadmium coatings are passivated. Some colours are only possible with zinc coatings.
❶ Cr(VI)-free passivation has not yet been addressed in standards. For that reason, these must be designated and ordered separately, e.g. as Cr(VI)-free thin- or thick-film passivated products. See the overview on page 115.

Table 11.5 Chromium(VI)-containing surface coatings

Example of the marking for a 5 µm zinc-plated, bluish matt passivated screw:	A 2 B

Notice:

In 2018, in the course of updating the standard, a new description system was defined that includes the corresponding element at the beginning of the description. The electroplated coating, the coating thickness, the conversion coating and the lubrication condition are then listed.

EXAMPLE 3: A fastener with an electroplated coating (ISO 4042) of zinc (Zn) and a required coating thickness of 12 µm, with a chromium(VI)-free iridescent conversion coating (Cn), with subsequent post-sealing with or without integrated lubricant (T2) is designated as follows

[Fastener Description] – **ISO 4042/Zn12/Cn/T2**

Figure 11.5 Example from standard data sheet ISO 4042

Galvanising

Fasteners are degreased, pickled and electrolytically plated with the coating metal in baths. For fasteners and small parts, this is mainly done in barrel plating systems. Large fasteners and bulky parts are galvanised as racks to avoid damage due to their high weight.

Metal deposition on a steel surface is not uniform. Protruding areas are coated more heavily, while recesses and indentations are coated more lightly.

For this reason, fixed measuring points are provided for measuring coating thickness, see Figure 11.6.

Problems with gauge retention can occur during galvanisation of long, thin screws due to the uneven layer thickness.

A wide variety of metals can be applied through galvanising. The most common coatings are zinc, nickel, chromium, copper, brass and tin.

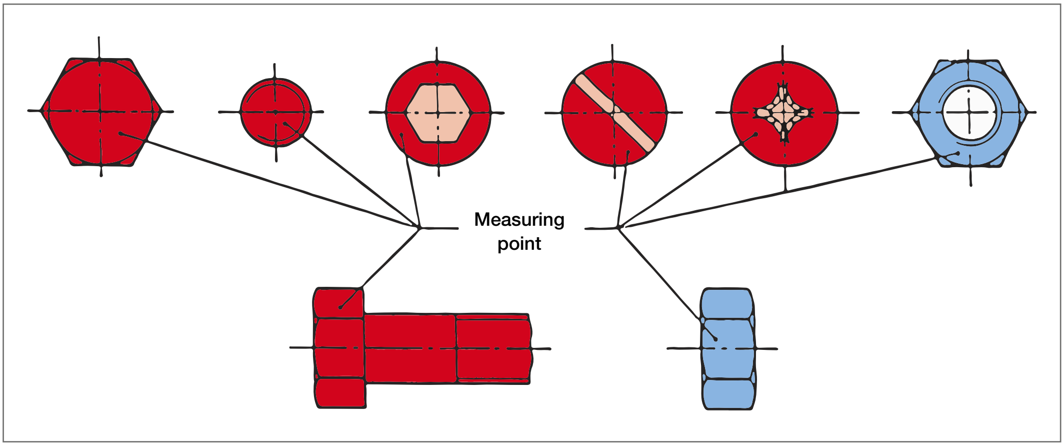

Figure 11.6 Measuring points for coating thickness measurements

Zinc

Zinc is well suited to galvanic surface coating because of its anodic effect.

Due to Faraday's law, the amount of zinc deposited on the fastener and thus the coating thickness can be measured by varying the electroplating time and current intensity.

Typically, fasteners are zinc-plated and passivated at 5 – 7 µm.

Zinc alloy coatings

This process is characterised by zinc-based alloy coatings with other elements. Transparent or black passivation can be applied afterwards.

ZnFe contains 0.3% to 1% iron. ZnNi contains 8 % to 15 % nickel.

Zinc alloy coatings are becoming increasingly important due to the low corrosion products of the alloy layer.

Nickel and chromium

Nickel and chromium, unlike base metals like zinc, provide protection with their hard coating. These metals are finer than steel. When the surface is damaged, the coating metal rusts underneath and dissolves.

Both metals are used for decorative purposes.

The chromium surface is particularly hard, resistant to abrasion and does not tarnish.

Chrome finishes are not usually applied directly to steel surfaces. The steel part is copper-plated, then nickel-plated, and only then chromium-plated.

Chromium electroplating is usually applied as a rack finish.

Copper

Copper surfaces serve as intermediate layers between nickel and chrome surfaces and also have high electrical conductivity.

Brass

Fasteners are mainly brass-plated for decorative purposes.

Tin

Parts with a tin surface are easier to solder.

Figure 11.7 Barrel plating

Post-treatment of galvanically applied zinc coatings

Post-treatment to improve corrosion resistance is commonly required for galvanically applied coatings.

Passivation

This conversion coating, formed by a post-dip solution, is technically practicable and increases corrosion resistance.
Passivations completely cover the galvanic protective layer. They are applied chemically. This also closes the pores of the zinc surface.
Thin-film passivation is available as a Cr(VI)-free version. This standard post-treatment is based on Zn, ZnFe and ZnNi. **Thick-film passivation** offers greater protection against the susceptibility of the zinc coating to corrosion. This is based on Cr(III) values, so it meets the legal requirement to be free of Cr(VI). Passivation layers are silvery blue and iridescent or can come in additional colours.
Chromating ❶. Passivation with Cr(VI) content. Yellowish to black with increasing Cr(VI) content. Yellow chromated surfaces offer good corrosion protection, but chromates are only resistant up to approx. 70 °C.

Depending on the industry, surfaces containing chromium(VI) have either already been replaced by chromium(VI)-free passivated surfaces or are currently being replaced. It is expected that chromium(VI)-containing surfaces will be replaced by chromium(VI)-free surfaces in all industries in the future.

Top coats

These are usually additional film-forming layers to increase corrosion protection or provide different colouration.

Seals

Usually silicate-containing substances to increase corrosion protection, which are interlaced through passivation. The seals consolidate the appearance of the passivation layers and can alter the friction coefficient.

❶ The most common method of chromating in the past is no longer permitted in certain industries due to EU directives on protecting humans and the environment. This means that it is also necessary to select an alternative treatment or coating system for fasteners. Cr(VI)-free passivations with or without sealing are available here.

Potential surface structure

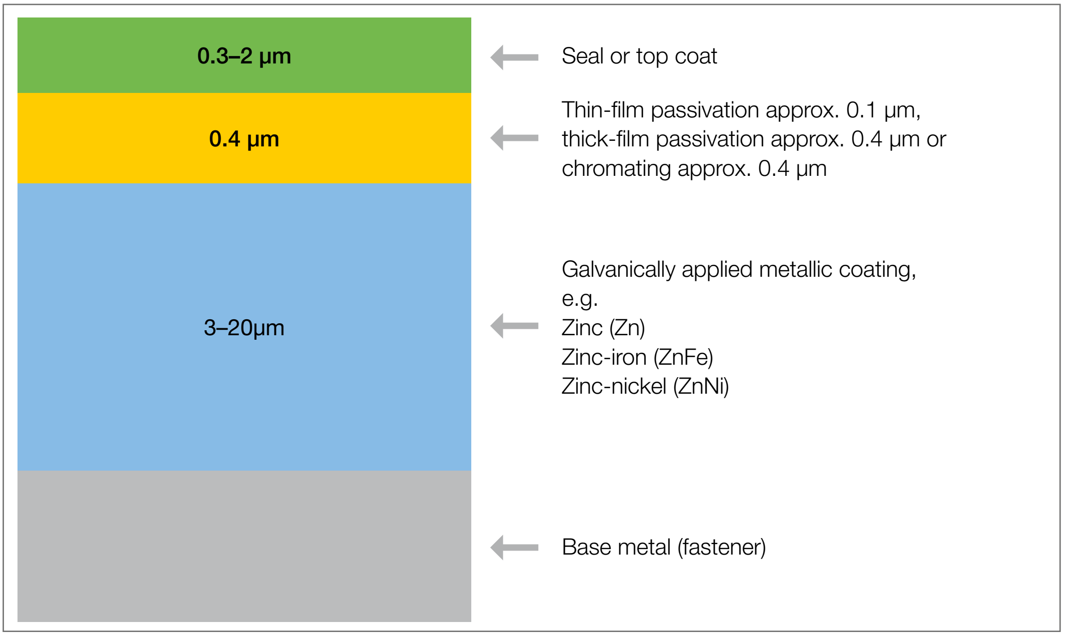

Figure 11.8 Schematic diagram of a galvanic surface structure

Hydrogen embrittlement

In the Standards Committee for Fasteners (FMV), users and manufacturers agreed on important formulations for this complicated technical process, which have been incorporated into DIN EN ISO 4042:

Hydrogen-induced brittle fracture
"... is the failure of components due to the interaction of atomically absorbed hydrogen and residual tensile stresses or tensile load stresses ...".

The risk of hydrogen embrittlement
In the processes deployed today for the deposition of metal coatings from aqueous solutions, hydrogen-induced, delayed brittle fracture cannot definitively be ruled out for screws made of steel with the minimum alloying constituents or minimum tempering temperatures specified in DIN ISO 898 Part 1. This applies to parts made of steel with tensile strengths of Rm ≥ 1000 N/mm², corresponding to 300 HV. This can usually be avoided by selecting a material that is particularly suitable for the application of galvanic surface protection using modern surface treatment processes, including appropriate post-treatment.

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There is an increased risk of brittle fracture for accessories with resilient properties and with hardening greater than 400 HV. Special measures are therefore required with regard to material selection, heat and surface treatment.

For other mechanical fasteners, the risk of hydrogen embrittlement should be determined on a case-by-case basis. If such risk is apparent, suitable measures must be taken to prevent hydrogen embrittlement.

How does the hydrogen get into the steel?
Damaging hydrogen can be absorbed by the steel during pickling, galvanising and corrosion.

Sensitivity to hydrogen embrittlement increases as the strength of the steel increases. Susceptibility to brittle fracture can be largely avoided by selecting a sufficiently ductile material with a minimum tempering temperature of +500 °C and suitable surface treatment processes, including appropriate post-treatment. (Appropriate post-treatment means heating to +190 °C to +200 °C with hold times of two to four hours).

This means that screws which, in terms of material and tempering temperature, only meet the minimum requirements for strength classes 10.9 and 12.9 in DIN ISO 898 Part 1 cannot subsequently undergo galvanic surface treatment without risk.

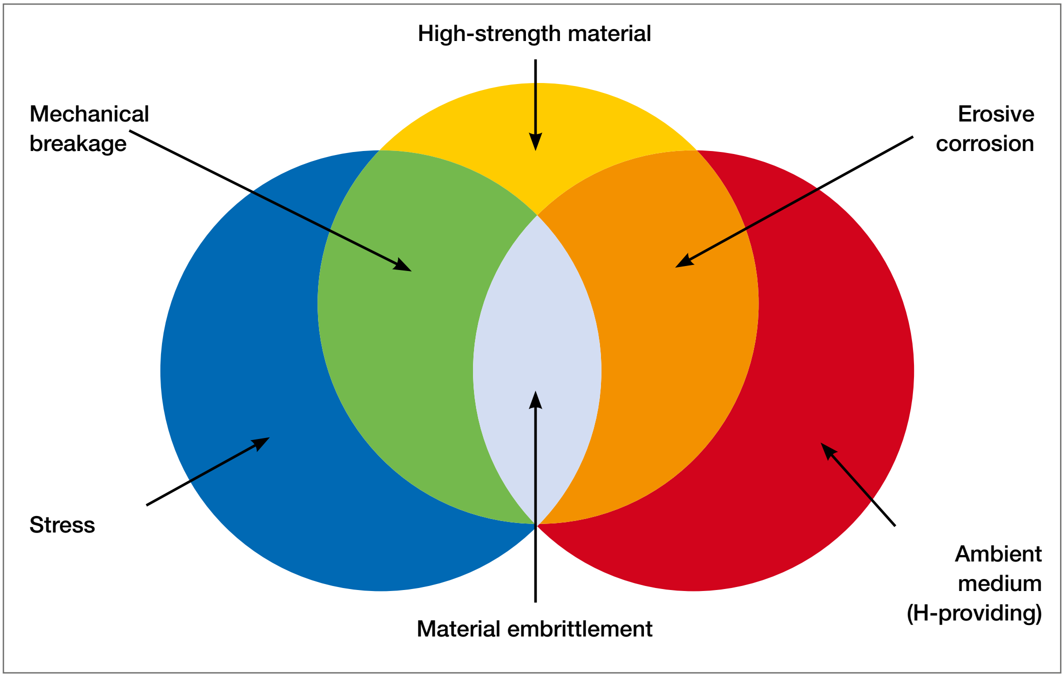

Figure 11.9 Interplay of conditions for hydrogen-induced delayed brittle fracture.*

* K. Kayser: Kritische Betrachtung zum Korrosionsschutz an Schrauben, VDI-Z Vol. 126 no. 20

Zinc flake coatings

After cleaning and degreasing the surface, the parts are immersed in an aqueous or solvent dispersive solution containing a mixture of zinc and aluminium flakes.

The parts are then centrifuged to remove excess coating metal.

For large and unwieldy parts, the surface coating is sprayed on.

The applied coating is then baked at 180 °C or 300 °C.

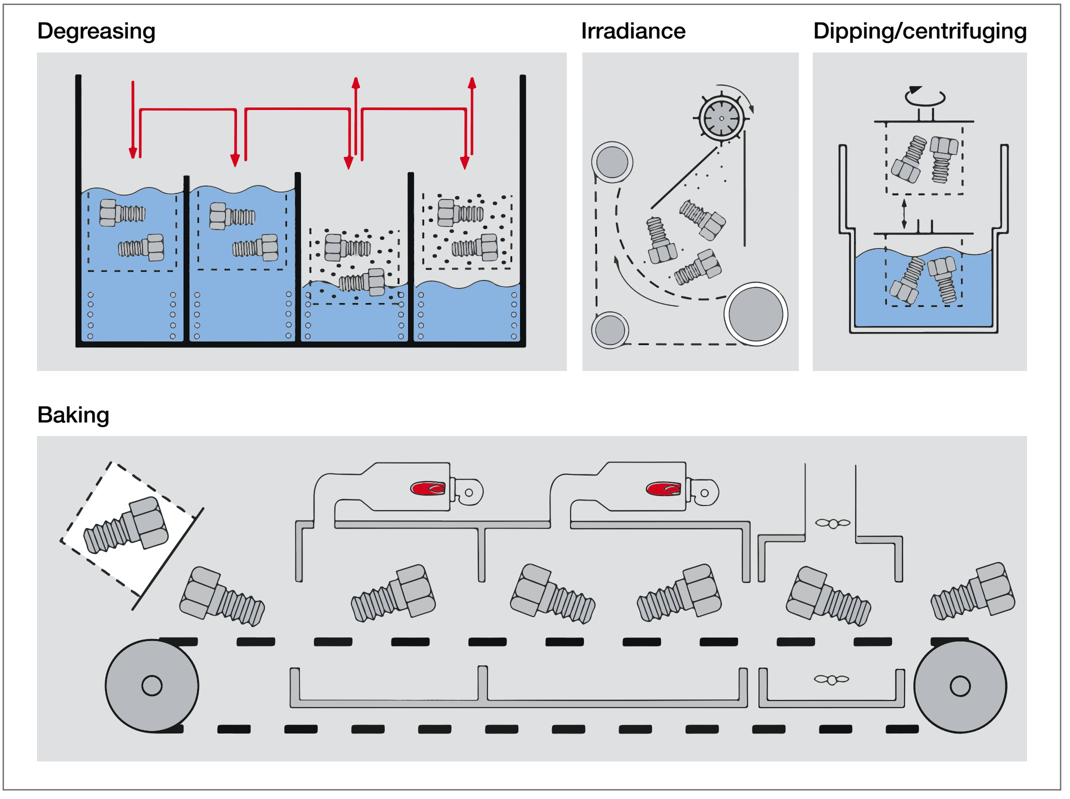

Figure 11.10 Coating sequence when applying a zinc flake coating

After one cycle, the coating thickness is approx. 4 µm. At least two layers are applied, so the coating is 8–10 µm and is therefore not suitable for screws with a small thread diameter.

Parts treated with a dispersion coating are matt grey and have a high level of corrosion protection – considerably higher than that for electrogalvanised parts.

Seals or **top coats** can be applied subsequently. Lubricants can be integrated into a coating or applied as a final post-treatment. Friction coefficients can be set relatively accurately.

This coating process eliminates the risk of **hydrogen embrittlement**.

Zinc flake coatings are also known as thin coatings or **dispersion coatings** and are sold under brand names including Dacromet, Geomet and Delta-Protekt.

DIN EN ISO 10683 describes these coatings as non-electrolytically applied **zinc flake coatings.**

The standard designation is **flZn.** The times required for the salt spray test are also specified. After this test period, the parts must not show any red rust.

flZn / 480 h
Zinc flake coating with a test duration of 480 hours

flZnL / nc / 480 h
Zinc flake coating with a test duration of 480 hours and an integrated lubricant, without Cr(VI)

flZn / nc / 720 h / L
Zinc flake coating without Cr(VI) with a test duration of 720 hours and a subsequently applied lubricant

flZn / nc / 480 h
Zinc flake coating with a test duration of 480 hours, without Cr(VI)

flZn /nc / Tn / L / 720 h / C
Zinc flake coating with a test duration of 720 hours, without Cr(VI), with a top coat without lubricant, with additional lubricant with a specified friction coefficient

Specifying the test duration gives you the coating thickness. A coating thickness (flZn) of 5 µm with Cr(VI), or of 8 µm without Cr(VI) is required for a resistance of 480 hours in the salt spray test.

In the case of subsequent coating of stock items, the thread tolerances and their possible coating thicknesses must be observed (see Section 6, p. 68).

Thin lacquer coatings (top coat)

Top coat consisting of an organic compound applied in a liquid state. The fasteners are immersed or the top coat is sprayed on and then heated to 200 °C. This causes the lacquer coating to set.

This protective layer can be applied in many colours on top of another surface coating. Lubricants can be incorporated into this protective layer to provide constant favourable friction coefficients for the screw connection.

These processes are known under brand names including Delta-Seal and Polyseal.

Hot-dip galvanising

Thermal galvanising (tZn) is carried out in a bath of liquid zinc at a temperature of approx. 500 °C. Due to the high temperature, zinc and iron react to form a zinc/iron alloy layer. This layer is not damaged during machining.

After dipping, excess zinc is removed from the fasteners by centrifuging. The screw threads must not be recut.

DIN EN ISO 10684 prescribes a coating thickness of at least 40 µm for hot-dip galvanised parts. This thick protective layer and the underlying zinc/iron layer provide very high corrosion protection.

The thick coating must be taken into account in the thread design if the threads are to remain screwable in their galvanised state. As such, the screw thread must be manufactured with a larger undersize before galvanising.

However, this reduces the tensile strength cross-section and therefore the flank coverage. For this reason, different test loads apply to hot-dip galvanised screws than to parts with galvanic coatings (DIN EN ISO 10684).

For the above reasons, it is also not advisable to hot-dip galvanise screws classified below M 8. Female threads are not cut until after hot-dip galvanising takes place, so they are not galvanised. The zinc on the male thread also protects the female thread.

Please comply with DIN EN 14399 (until September 2007 also DIN 18800) for hot-dip galvanised HV connections.

Phosphating or bonderising

The dark grey to black surface protection is created by dipping in a zinc phosphate solution. Paint coatings and lubricants adhere well to this phosphate layer. Phosphating is also frequently used to obtain better sliding properties during cold forming.

Phosphate coatings offer only slight corrosion protection.

Burnishing

Bare ferrous materials are immersed in an oxidising solution at approx. 140 °C. A brownish-black iron oxide layer is formed on the surface. The burnished parts are then oiled or waxed.

The level of corrosion protection is very low.

Blackening

High-strength screws are cooled in an oil emulsion during heat treatment after tempering. The oil burns into the surface and gives the part a black colour.

This treatment provides slight corrosion protection for storage and transportation.

Chemical nickel plating

Coating is executed without electricity, in a nickel salt solution. Very uniform coating thicknesses are achieved in this process, even on edges and in bores, and in the micro range.

This coating is therefore suitable for small and complicated parts. The surface hardness is high due to the nickel coating metal.

Mechanical coatings

By moving in a drum, metal particles are pressed (plated) onto the fasteners by a glass bead mixture. The mixture of glass beads depends on the size and profile of the parts.

This process is also known as mechanical plating or 3M galvanising.

Service life in years until red rust forms in corrosive atmospheres					
Country climate	Urban climate	Industrial climate	Marine climate	Surface protection	Layer thickness µm
03 – 08	1 – 04	below 1	1 – 3	galvanised, passivated	5 – 8
05 – 12	2 – 06	1 – 2	1 – 4		12
10 – 20	5 – 10	2 – 3	2 – 5		20
05 – 13	1 – 07	1	1 – 5	galvanised, chromated yellow / thick-film passivated	5 – 8
08 – 20	3 – 10	1 – 3	1 – 7		12
17 – 34	8 – 17	3 – 5	3 – 8		20
50	25	5	7	hot-dip galvanised (from M 8)	60

Table 11.6 Guide values for the lifespan of various surface treatments

ECOTECH = **ECO**nomic **TECH**nical Engineering

How can cost savings be achieved through optimised joining technology? The manufacturing costs of a new product are already largely determined in the design phase. How economical the joining technology is only minimally dependent on the price of the joining elements.

Much more important are the process costs for preparing and assembling the components to be joined. The major cost drivers in the process are design, procurement, quality assurance, logistics, warehousing, assembly preparation, final assembly and capital commitment.
In contrast, the part price of the fastener is comparatively low, accounting for about 20%.

The earlier ECOTECH specialists are involved, the more positive the impact on the entire value chain.

20% parts price vs.
80% system costs
Optimisation pays off!

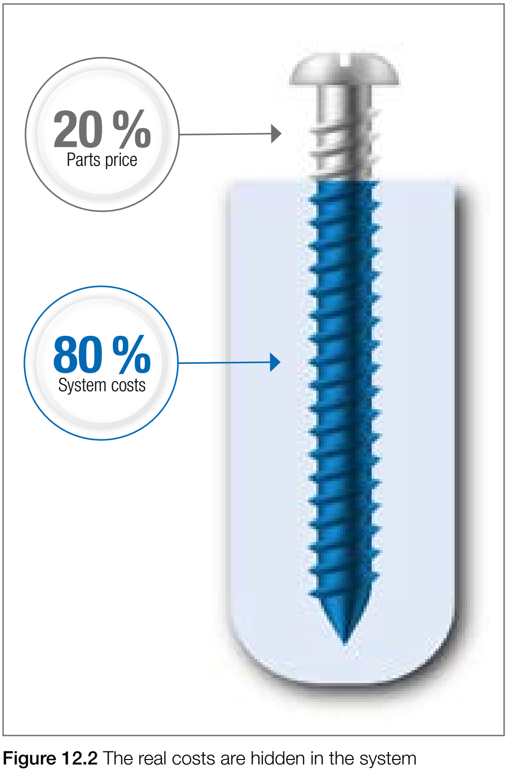

Figure 12.2 The real costs are hidden in the system

Our services for you at a glance

Figure 12.3 Our service cycle

Comprehensive services

Do you have a finished product or are you still in the middle of development? We will analyse your product and its joining technology down to the very last detail. ECOTECH aims to identify potential for optimisation.

Our service modules interlock perfectly: from the specific technical solution to research and development to optimisation during series production and knowledge transfer, each of our modules is individually tailored to your needs within the framework of our joint project, for the perfect 360° range of products and services.

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Passion for successful joining.

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