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European Assessment Document for

Threaded studs for connection of materials to structural steel and aluminium members



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This European Assessment Document (EAD) has been developed taking into account up-to-date technical and scientific knowledge at the time of issue and is published in accordance with the relevant provisions of Regulation (EU) No 305/2011 as a basis for the preparation and issuing of European Technical Assessments (ETA).

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1 SCOPE OF THE EAD

1.1 Description of the construction product

Threaded studs are used for the connection of non-structural components to structural steel and aluminium members (in the following referred to as threaded studs)- Threaded studs are mechanical fasteners made of steel for threaded connection with a minimum thread size of nominal 6 mm. The threaded studs can be used with grating fasteners or checker plate fasteners in accordance with clause 1.1.4 which are also covered by this EAD.

Subject to this EAD are the threaded studs as well as the nuts and washers.

This EAD applies to threaded studs subject to static or quasi-static actions (e.g., dead loads, wind loads) in tension, shear or combined tension and shear or bending. The threaded studs are not intended for re-use.

The material which is intended to be fixed (component I) is:

- non-alloy structural steel covered by EN 1993-1-1¹ (and the material codes given there) and EN 10346, or
- corrosion resistant steel according to EN 10088-2, or
- aluminium according to EN 755-2 or EN 485-2.

The threaded studs are not covered by a harmonised European standard (hEN).

Concerning product packaging, transport, storage, maintenance, replacement and repair it is the responsibility of the manufacturer to undertake the appropriate measures and to advise his clients on the transport, storage, maintenance, replacement and repair of the product as he considers necessary.

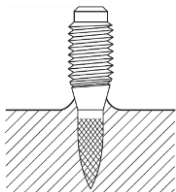
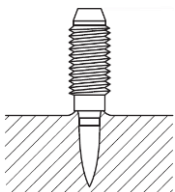
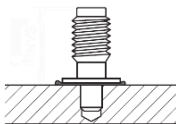
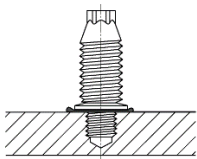
It is assumed that the product will be installed according to the manufacturer's instructions or (in absence of such instructions) according to the usual practice of the building professionals.

Relevant manufacturer's stipulations having influence on the performance of the product covered by this European Assessment Document shall be considered for the determination of the performance and detailed in the ETA.

1.1.1 Types of threaded studs

This EAD covers power-actuated and screw-in threaded studs. All types of threaded studs are subject to tension force, shear force and bending moment. Typical failure modes of the threaded studs are shown in Figure 2.2.1.1. Table 1.1.1.1 gives an overview on the different types of threaded studs as covered by this EAD.

Table 1.1.1.1: Types of threaded studs

sharp-tip threaded studs		blunt-tip threaded studs	
			
carbon steel with knurled tip ¹⁾	corrosion resistant stainless steel	corrosion resistant stainless steel	carbon steel or corrosion resistant stainless steel
without pre-drilling		with pre-drilling	
powder-actuated		powder-actuated or mechanically-actuated	screw-in
power-actuated			

¹⁾ tip knurling to the point

¹ All undated references to standards or to EADs in this EAD are to be understood as references to the dated versions listed in chapter 4.

Figure 1.1.1.1 gives an overview of the components of threaded stud connection: fixed material (component I) with the thickness t_I , base material (component II) with the thickness t_{II} , threaded stud with nut and washer (or with a flange nut combining washer and nut in one part). The maximum thickness of the fixed material t_I depends on the thickness and height of the used washers and nuts.

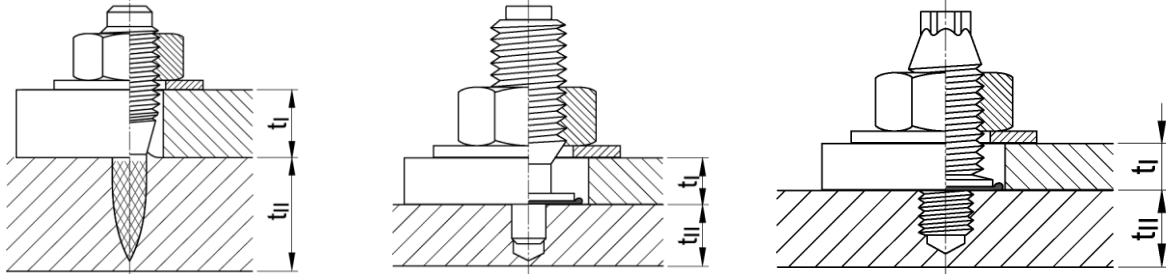


Figure 1.1.1.1: Components of threaded stud connection

1.1.2 Power-actuated threaded studs

Power-actuated threaded studs are mechanical fasteners made of corrosion resistant stainless steel or zinc plated carbon steel. The thread types can be metric size (e.g., M6, M8, M10) or other thread types (e.g., W6, W10). The nominal diameter d_s of the shank of the studs is in the range from 3,7 mm to 5,5 mm. Zinc plated sharp-tip threaded studs made of carbon steel have a ballistic tip which is knurled till its point (see Table 1.1.1.1). Stainless steel studs have a smooth shank.

Powder-actuated threaded studs have a sharp tip and are being driven by a powder-actuated fastening tool into the base material without any pre-drilling. The driving force of the fastening tool is provided by the power load of a cartridge. The powder-actuated sharp-tip threaded studs are assembled with a plastic washer and possibly with a plastic sleeve on the thread which work as guidance during the driving process.

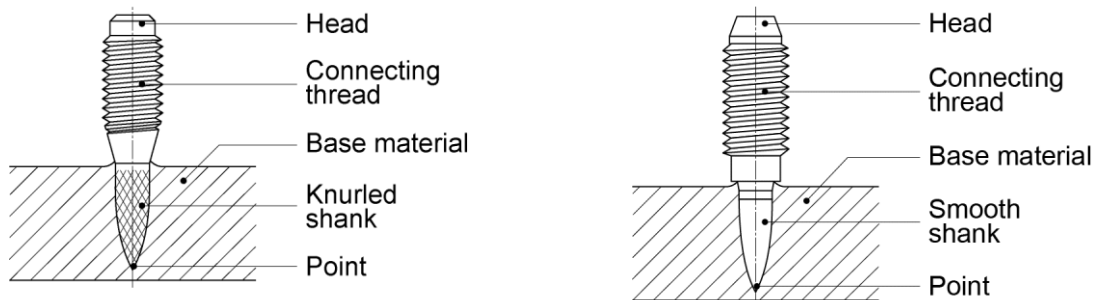


Figure 1.1.2.1: Examples and description of sharp-tip powder-actuated threaded studs

In contrast to this, blunt-tip threaded studs require a pre-drilled hole in the supporting steel in which they are driven by means of a power-actuated or mechanically-actuated fastening tool. For pre-drilling the hole, a special stepped drill bit is needed to achieve a defined hole geometry (hole depth and diameter). The driving force of the fastening tool is provided by the power load of a cartridge in case of powder-actuated tools or by mechanical energy in case of mechanically-actuated tools.

The power-actuated blunt-tip threaded studs can be equipped either with a plastic sleeve on the thread which works as guidance during the setting process and/or with a sealing washer. The sealing washer consists of a black chloroprene CR sealing ring with a Shore-A hardness greater than 63. The rubber of the sealing washer can be covered by a metal washer. The purpose of the sealing washer is to protect the pre-drilled location in the base material against corrosion.

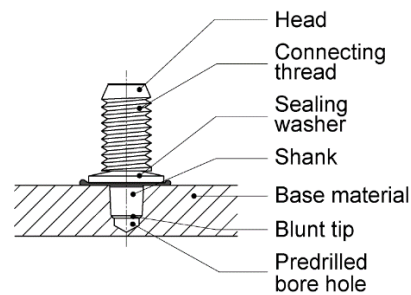


Figure 1.1.2.2: Examples and description of blunt-tip power-actuated threaded studs

1.1.3 Screw-in threaded studs

Screw-in threaded studs are mechanical fasteners made of corrosion resistant stainless steel or coated carbon steel with metric threads (e.g., M6, M8, M10) or other thread types (e.g., W6, W10) for attachment of supported materials on one end, and a threaded tip on the other end which taps its own internal mating threads for embedment into the supporting steel or aluminium. The nominal diameter d_1 (see Figure) of the threaded tip is in the range from 3,5 mm to 8,0 mm.

The screw-in threaded studs require a pre-drilled hole in the supporting steel or aluminium. The screw-in threaded studs are completed with a sealing washer, which consists of a black chloroprene rubber sealing ring with a Shore-A hardness greater than 63. The rubber may be covered by a metal washer. The purpose of the sealing washer is to protect the pre-drilled location in the base material against corrosion.

For pre-drilling the hole into the base material, a special stepped drill bit is needed to achieve a defined hole geometry (hole depth and diameter). In order to ensure the exact screw-in depth and a proper compressed sealing washer, the screw-in studs shall be installed with the appropriate installation tool.

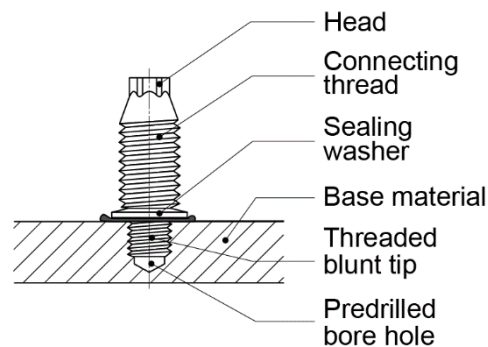


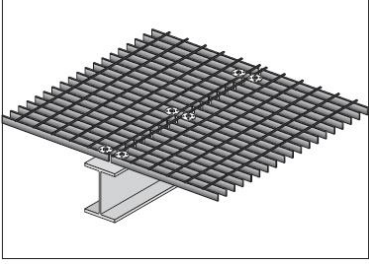
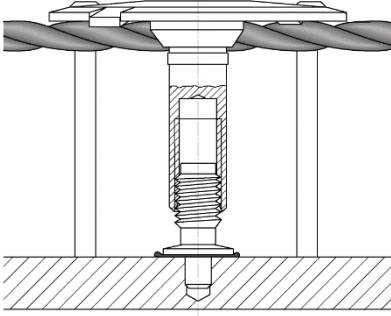
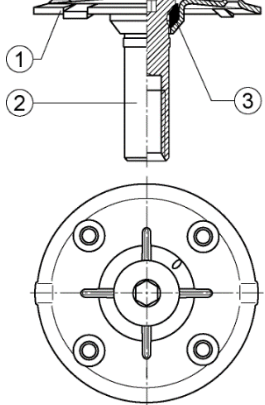
Figure 1.1.3.1: Example and description of screw-in threaded studs

1.1.4 Grating fasteners and checker plate fasteners

Grating fasteners and checker plate fasteners are made of metal and are designed to be used in connection with threaded studs to secure the position of gratings or checker plates. They are either made from corrosion resistant stainless steel or from zinc coated carbon steel. The zinc coating can be additionally protected by a reactive sealer. The grating fasteners consist of 3 parts as described in Table 1.1.4.1

The grating fasteners and checker plate fasteners are subject to tension forces.

Table 1.1.4.1: Example of grating fastener

		
<p>Intended use Securing of position of gratings</p>	<p>Example of cross section of fixture: grating fastener in combination with blunt-tip power-actuated fastener</p>	<p>Grating fastener consisting of 3 parts: 1...disc 2 ... screw with internal thread 3 ... thermoplastic polyurethane</p>

1.2 Information on the intended use(s) of the construction product

1.2.1 Intended use(s)

The power-actuated and screw-in threaded studs are intended to be used for redundant multiple fastening and group fastening of non-structural components.

Examples:

- Multiple fastening applications: Fastening of non-structural components in mechanical and electrical installations (e.g., pipes, electric conduits, installation channels etc.)
- Group fastenings (base plates of consoles or footings or other members e.g., electrical switchbox)
- Fastening floor gratings and floor plates in conjunction with grating fasteners or checker plate fasteners

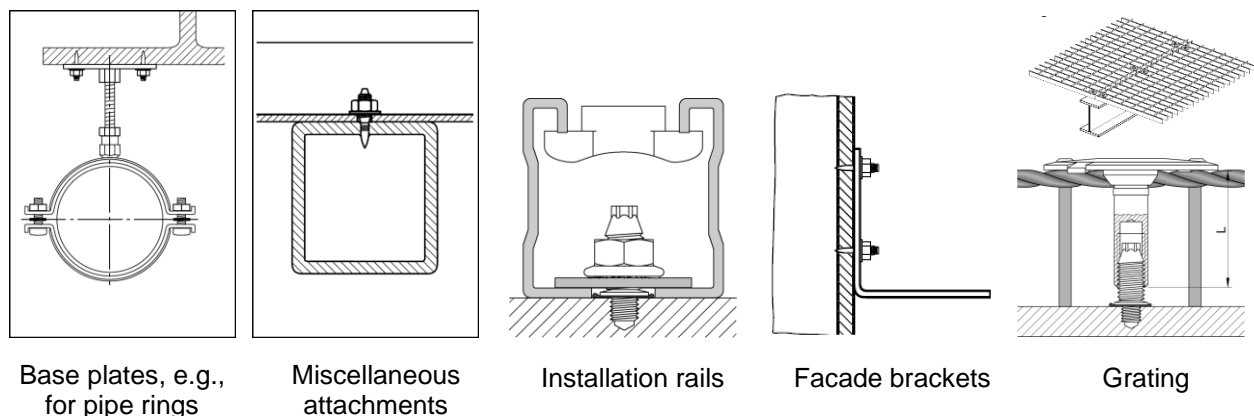


Figure 1.2.1.1: Examples of threaded stud connection

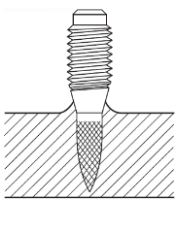
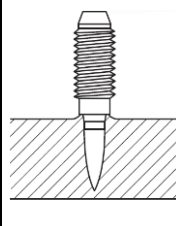
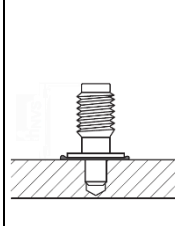
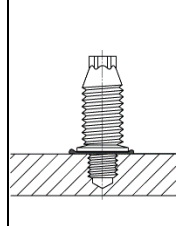
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The threaded studs are intended to be used for

- non-alloy structural steel covered by EN 1993-1-1 and the material codes given there, and/or EN 1993-1-12 and/or EN 10025-6 with a maximum coating according to Table 1.2.1.1 or
- aluminium following EN 1999-1-1 and the material codes given there as base materials (component II).

The minimum thickness t_{II} and the minimum tensile strength $f_{u,II}$ of the base material are given in Table 1.2.1.1, as applicable. The test programme addresses the use of typical standard coating thickness e.g., hot-dipped galvanized or off-shore coated base materials with a maximum thickness of 0,5 mm. Thicker coatings, e.g., fire protection layers, are applicable provided supplemental testing is done according to clauses 2.2.2 and 2.2.3.

Table 1.2.1.1: Characteristics of the base material (component II)

	Studs with sharp tip		Studs with blunt tip	
				
Base material (component II)				
Steel: thickness t_{II} [mm]	≥ 4	≥ 4	≥ 4	≥ 3
Steel: tensile strength R_m [N/mm ²]	≥ 340			
Aluminium: thickness t_{II} [mm]	-	-	-	≥ 5
Aluminium: tensile strength R_m [N/mm ²]	-	-	-	≥ 270
Minimum Edge distance c_{min} [mm]	15		6	
Standard coating thickness t_c [mm]	0,2 to 0,5 ⁽¹⁾		0,2 to 0,5 ⁽¹⁾	
Maximum thickness of coating $t_{c,max}$ [mm]	4,0		1,0	

(1) Maximum standard coating t_c can be selected within that range

The intended use comprises threaded studs and connections for indoor and outdoor applications. Threaded studs, grating fasteners and checker plate fasteners made from galvanized carbon steel are intended to be used in dry internal environment. The minimum zinc coating thickness of carbon steel threaded studs, grating fasteners and checker plate fasteners amounts to 5 μm .

Threaded studs, grating fasteners and checker plate fasteners made from stainless steel are intended to be used in environmental conditions according to EN 1993-1-4, Table A.1, dependent on the corrosion resistant class (CRC – depending on the material number, see EN 1993-1-4, Table A.3).

The threaded studs, grating fasteners and checker plate fasteners are intended to be used in the temperature range from -40 °C to +100 °C.

Figure 1.2.1.2 shows the definition of the geometric parameters.

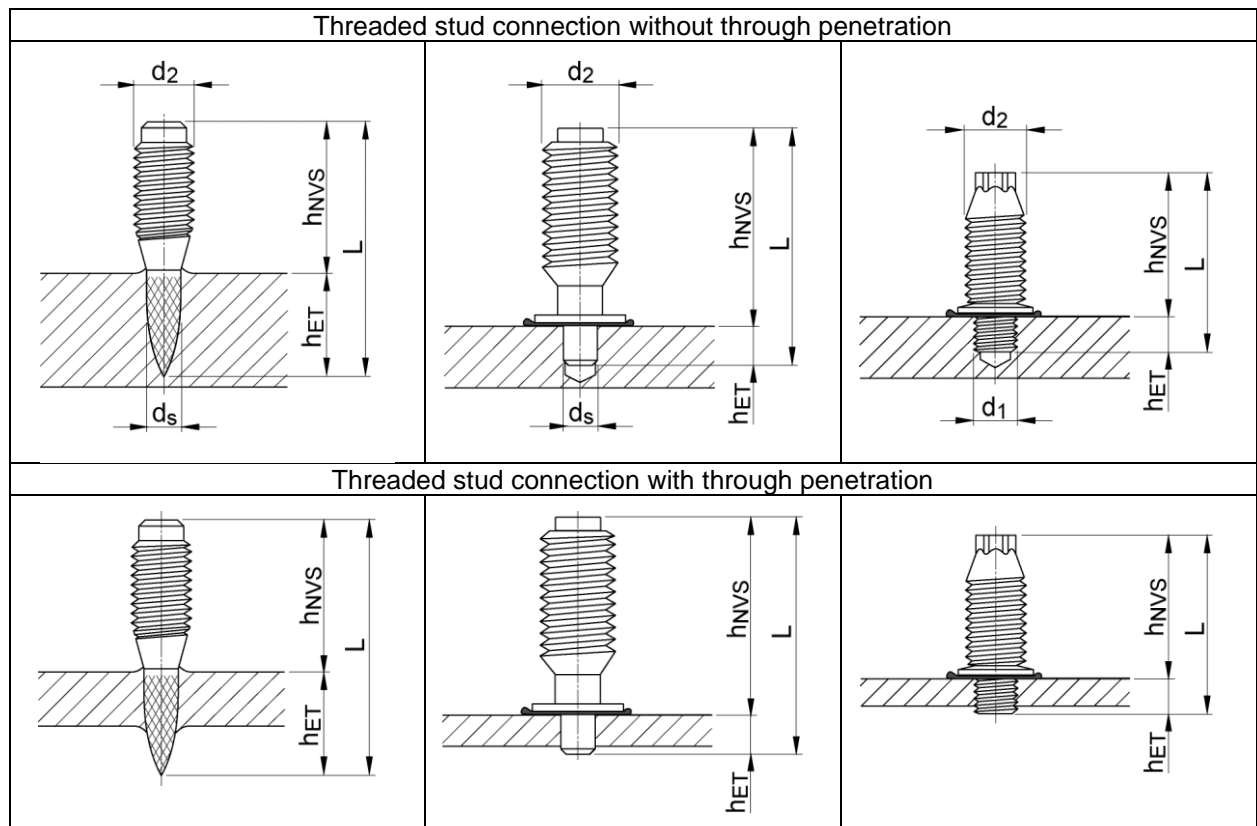


Figure 1.2.1.2: Definition of geometric parameters during installation and quality control

In case of a group fastening a rigid fixture is assumed. The actions on each stud are calculated assuming elastic force distribution. Within a group only studs of the same type, size and length shall be used. A group fastening consists of minimum 2 fasteners. Examples of stud groups are shown in Figure . Other stud arrangements, e.g., in a triangular or circular pattern, are also possible.

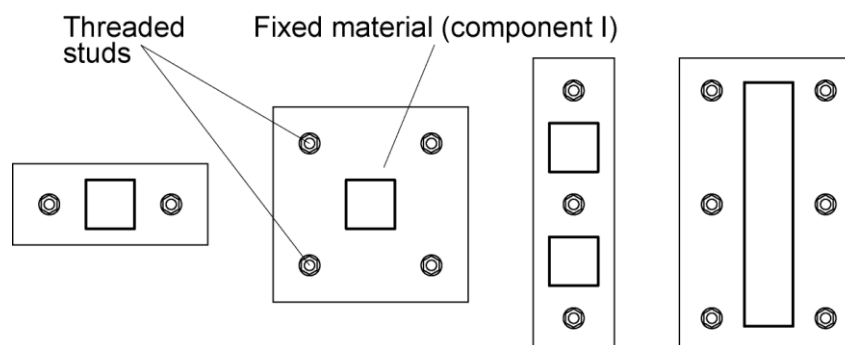


Figure 1.2.1.3: Examples of group fastening patterns

The shear resistance of a group of studs needs to be verified by means of group tests in dependence on the hole diameter d_c in the fixed material, see Figure and clause 2.2.4.

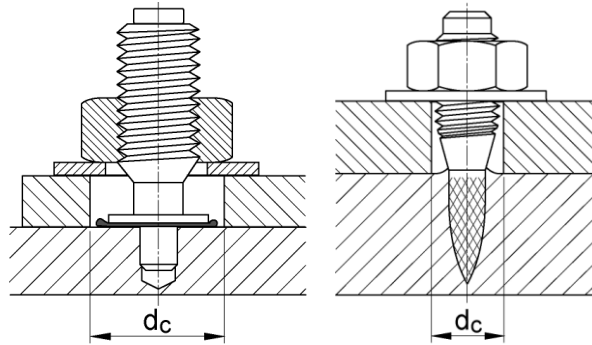


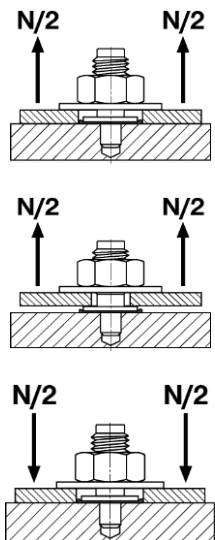
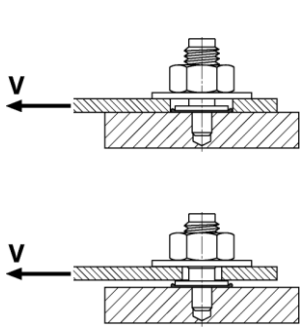
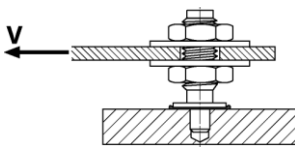
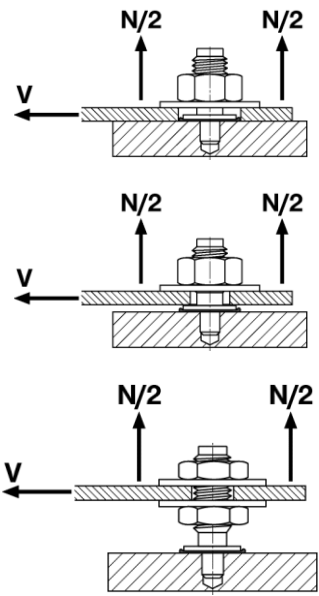
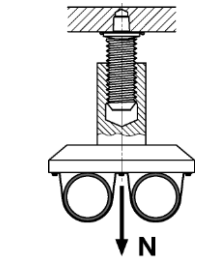
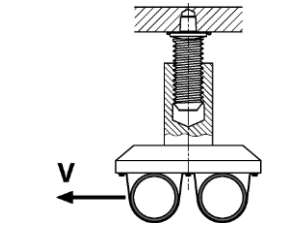
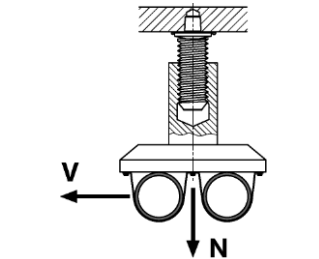
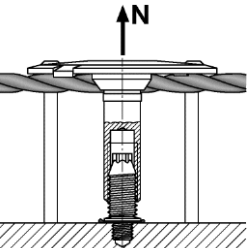
Figure 1.2.1.4: Clearance hole

Table 1.2.1.2: Shear load introduction into threaded studs

<p>Shear load introduction via the stud: The stud bears directly against the fixed material (component I)</p>	<p>Load transmission via thread</p>
<p>Shear load introduction via the sealing washer: Metal washer bears against the fixed material (component I). $t_{f,max} = 15$ mm.</p>	<p>Load transmission via washer</p>

Table shows the different types of connections as well as the respective loading conditions.

Table 1.2.1.3: Types of connection and corresponding loading conditions

Connections of steel sheets or plates to supporting material with nut and washer			
<p>Tensile / pressure loading</p> 	<p>Lateral shear loading</p> 	<p>Bending loading</p> 	<p>Interaction</p> 
Connection of components in mechanical and electrical installations			
<p>Tensile loading</p> 	-	<p>Bending loading</p> 	<p>Interaction</p> 
Connections of grating fastener discs and floor plate fastening discs to supporting material			
<p>Tensile loading</p> 	-	-	-

1.2.2 Working life/Durability

The assessment methods included or referred to in this EAD have been written based on the manufacturer's request to take into account a working life of the threaded studs for the intended use of 25 years when installed in the works (provided that the threaded studs are subject to appropriate installation (see 1.1 and 1.2.1)) These provisions are based upon the current state of the art and the available knowledge and experience.

When assessing the product, the intended use as foreseen by the manufacturer shall be taken into account. The real working life may be, in normal use conditions, considerably longer without major degradation affecting the basic requirements for works².

The indications given as to the working life of the construction product cannot be interpreted as a guarantee neither given by the product manufacturer or his representative nor by EOTA when drafting this EAD nor by the Technical Assessment Body issuing an ETA based on this EAD, but are regarded only as a means for expressing the expected economically reasonable working life of the product.

1.3 Specific terms used in this EAD (if necessary in addition to the definitions in CPR, Art 2)

General

Fixed material (component I) = component to be fixed to the base material

Base material (component II) = member made from steel or aluminium, into which the threaded studs are driven or screwed-in

The notations and symbols frequently used in this EAD are given below. Further particular notation and symbols are given in the text.

Threaded stud and threaded stud connections

L	=	total length
d_2	=	thread diameter of stud
d_1	=	nominal diameter of threaded tip screwed-in to the base material
h_{ET}	=	driving distance of power-actuated fasteners in the base material, screw-in distance of screw-in studs in the base material
h_{NVS}	=	fastener standoff (distance from top of the stud to the surface of either coated or uncoated base material)
c	=	edge distance
c_{min}	=	minimum allowable edge distance
s_{min}	=	minimum allowable spacing
e	=	lever arm
T	=	installation torque

Fixed material (component I) and base material (component II)

t_I	=	thickness of fixed material
$t_{I,max}$	=	maximum thickness of fixed material
$t_{I,max,V}$	=	maximum thickness of fixed material for shear forces
t_{II}	=	thickness of base material
t_c	=	standard coating thickness of base material

² The real working life of a product incorporated in a specific works depends on the environmental conditions to which that works is subject, as well as on the particular conditions of the design, execution, use and maintenance of that works. Therefore, it cannot be excluded that in certain cases the real working life of the product may also be shorter than referred to above.

$t_{c,max}$	=	maximum coating thickness of base material
d_c	=	diameter of the clearance hole in the fixed material (component I)

Tests / Assessment

$F_{5\%,t}$	=	5%-fractile of the test results per test series ($N_{5\%,t}$, $V_{5\%,t}$, $M_{5\%,t}$)
α	=	Load angles
α_R	=	correction factor to consider minimum specified strength and thickness
α_T	=	correction factor to consider the effect of maximum installation torque T
α_g	=	correction factor to limit the effect of grating deformations
k_s	=	statistical factor
s	=	standard deviation of test series
v	=	coefficient of variation of test series
$N_{Rk,II}$	=	characteristic tension resistance stated in ETA, addressing pull-out and fastener failure
$N_{Rk,I}$	=	characteristic tension resistance stated in ETA, addressing failure of component I
$N_{Rk,pl}$	=	characteristic tension resistance related with failure of plastic components (thread or nut)
$N_{Rk,g}$	=	characteristic tension resistance of grating or checker plate fastener
$V_{Rk,II}$	=	characteristic shear resistance stated in ETA, addressing failure of component II and fastener failure
$V_{Rk,I}$	=	characteristic shear resistance stated in ETA, addressing failure of component I
M_{Rk}	=	characteristic bending resistance stated in ETA
$N_{Rd,II}$	=	design tension resistance, addressing pull-out and fastener failure
$N_{Rd,I}$	=	design tension resistance, addressing pullover failure of component I
$N_{Rd,g}$	=	design tension resistance of grating or checker plate fastener
$V_{Rd,II}$	=	design shear resistance stated in ETA, addressing failure of component II and fastener failure
$\alpha(n)$	=	performance reduction factor stated in ETA considering group effects test value / reference value
n	=	number of studs of a group of fasteners
$V_{Rd,I}$	=	design shear resistance stated in ETA, addressing failure of component I
M_{Rd}	=	design bending resistance stated in ETA
$\Delta\sigma_c$	=	characteristic fatigue strength at $N = 2 \cdot 10^6$ cycles; fatigue category
m	=	slope of fatigue strength curve
R	=	constant stress ratio $R = \sigma_{min} / \sigma_{max}$ in constant amplitude fatigue tests
γ_M	=	partial factor for the material
γ_{MII}	=	partial factor for considering base material variations
γ_{Mf}	=	partial factor for fatigue strength $\Delta\sigma_c$

2 ESSENTIAL CHARACTERISTICS AND RELEVANT ASSESSMENT METHODS AND CRITERIA

2.1 Essential characteristics of the product

Table 2.1 shows how the performance of threaded studs is assessed in relation to the essential characteristics.

Table 2.1.1 Essential characteristics of the product and methods and criteria for assessing the performance of the product in relation to those essential characteristics

No	Essential characteristic	Assessment method	Type of expression of product performance
Basic Works Requirement 2: Safety in case of fire			
1	Reaction to fire	2.2.8	Class
2	Resistance to fire	2.2.9	Level, (k_{ue} [-])
Basic Works Requirement 4: Safety and accessibility in use			
3	Tension Resistance for threaded studs and Tensions Resistance for grating fasteners	2.2.2	Level ($N_{Rk,II}$ [kN]) Level ($N_{Rk,g}$ [kN])
4	Shear Resistance of individual threaded studs	2.2.3	Level (V_{Rk} [kN])
5	Shear Resistance of groups of threaded stud connections	2.2.4	Level ($V_{Rk,II,g}$ [kN])
6	Bending moment resistance	2.2.5	Level (M_{Rk} [Nm])
7	Resistance in case of combined loading (interaction)	2.2.6	Level ($Z_{m,\alpha}$ [kN])
8	Fatigue classification of base material	2.2.7	Level (Fatigue category)

2.2 Methods and criteria for assessing the performance of the product in relation to essential characteristics of the product

This chapter is intended to provide instructions for TABs. Therefore, the use of wordings such as “shall be stated in the ETA” or “it has to be given in the ETA” shall be understood only as such instructions for TABs on how results of assessments shall be presented in the ETA. Such wordings do not impose any obligations for the manufacturer and the TAB shall not carry out the assessment of the performance in relation to a given essential characteristic when the manufacturer does not wish to declare this performance in the Declaration of Performance.

2.2.1 General survey and failure modes

The assessment of the load-bearing capacity of the threaded studs, grating fasteners, fixed material (component I) and the base material (component II) are part of this EAD. The fastening tools for power-actuated threaded studs (either powder-actuated or mechanically-actuated direct fastening tool including cartridge), the installation tool for screw-in threaded studs (e.g., cordless screw driver including depth stop) and the stepped drill bit for threaded studs with blunt tip are an integral part of this assessment with regards to its effect on the capacity of the connection.

For fixed material (component I) made of steel or aluminium the loading capacities, which are governed by the properties of fixed materials, are to be determined by tests according to this EAD (reference method) or, alternatively, by calculation using the formulas from EN 1993-1-3 or, respectively, EN 1999-1-1. The load-bearing capacity of the threaded studs (tension, shear, bending) shall be determined by tests according to this EAD. Bending tests shall be carried out with threaded studs installed in the supporting material with the minimum edge distance c_{min} . The minimum edge distance c_{min} and the minimum spacing s_{min} in the base material (component II) shall be determined by tests according to this EAD.

Test procedures are described in Annex A. Example of test setups are also shown in Annex A for the respective type of tests. All tests are to be performed at ambient room temperature.

The following Table shows a general survey of the required tests.

Table 2.2.1.1: General survey of tests for assessing the performance of the product

		Fixed material (component I)		Base material ⁽¹⁾ (component II)		Purpose
		t _I	R _m	t _{II}	R _m	
Fixed material	Static tension tests (optional)	Each relevant thickness	Lower tolerance	optional	optional	Pull-through resistance
	Static shear tests (optional)					Shear resistance
Threaded stud	Static tension tests	-	-	Each relevant thickness and coating	Lower tolerance	Static pull-out and resistance of the stud & fastener fracture check
	Static tension tests – edge distance	-	-	Minimum thickness	Lower tolerance	Effect of edge distance on static pull-out
	Static shear tests	optional	optional	Each relevant thickness and coating	Lower tolerance	Static shear resistance
	Static shear tests – edge distance	optional	optional	Minimum thickness	Lower tolerance	Effect of edge distance on static shear
	Static shear tests – group tests	optional with maximum hole clearance		Relevant thickness	Relevant strength	Static shear resistance of groups
	Bending tests	-	-	Each relevant thickness	Lower tolerance	Bending resistance of the stud
	Power-actuated studs: application limit test	-	-	Each relevant thickness	Upper application limit	Verification of driving operation and pull-out resistance at the upper application limit
	Screw-in studs: Thread forming torque, upper application limit	-	-	Each relevant thickness	Upper application limit	Verification of installation at the upper application limit
Grating or checker plate fastener	Tension test	Each relevant disc type and grating bar spacing		optional	optional	Tension resistance of the disc
Base material	Fatigue tests (optional)	-	-	Each relevant thickness	Each relevant strength	Fatigue category of base material with stud

(1) Coated or uncoated as applicable

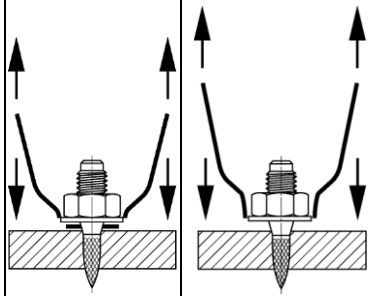
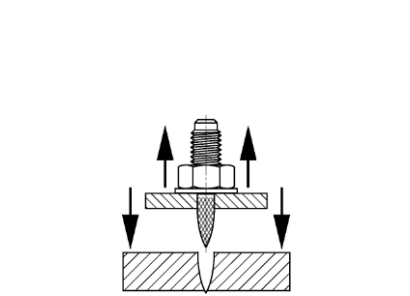
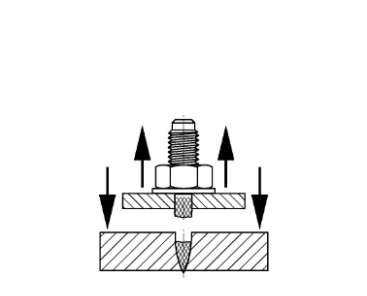
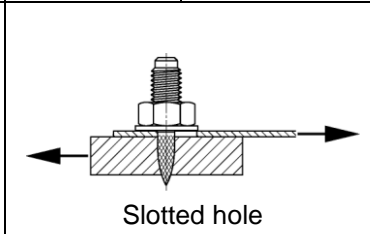
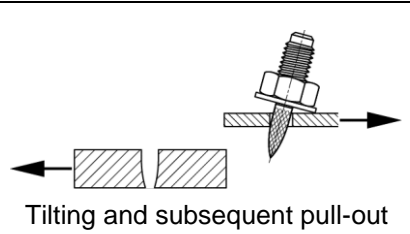
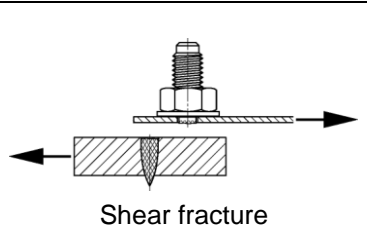
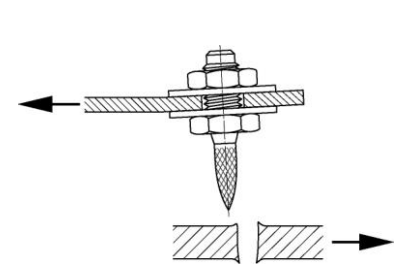
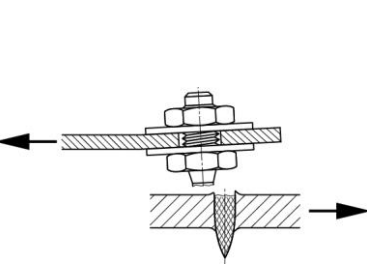
	Failing component		
Type of loading	Fixed material (component I)	Base material (component II)	Threaded stud
Tensile loading	 <p>Punching Pull-through</p>	 <p>Pull-out of threaded stud</p>	 <p>Tension fracture (1)</p>
Lateral shear loading	 <p>Slotted hole</p>	 <p>Tilting and subsequent pull-out</p>	 <p>Shear fracture</p>
Shear load with lever arm (bending moment)	<p>-----</p>	 <p>Tilting and subsequent pull-out</p>	 <p>Bending fracture</p>

Figure 2.2.1.1: Failure modes

2.2.2 Tension Resistance

2.2.2.1 Test procedure and tension failure modes

The possible failure modes of a threaded stud connection under tensile load are:

- Pull-out failure (pull-out of threaded stud from base material (component II))
- Failure of fastener (tensile fracture of threaded stud or grating fastener)
- Pull-through of the fixed material (component I)

The test program addresses the different possible failure modes.

The test load shall be increased until failure (pull-out, fracture of the stud, failure of the grating fastener or pull-through of fixed material). The respective failure modes as well as the material properties of the base material, the threaded fastener and the fixed component used for the tests shall be documented. Furthermore, the load-displacement curves shall be documented. The measurement of the piston or cross-head displacement of the test engine is in general sufficient. The material properties shall be documented by means of inspection documents 3.1 according to EN 10204. The material properties shall correspond to the material specifications supplied by the manufacturer.

Examples of tension test setups are shown in Annex A.3.

2.2.2.2 Pull-out tests

The test series given in Table , Table and Table are necessary in combination with all types of fastening tools / installation tools to be assessed for setting the power-actuated or screw-in threaded studs. The right setting of the power-actuated and screw-in threaded studs is essential for a correct load-bearing connection.

At least 10 tension tests shall be carried out per test series.

Sharp-tip powder-actuated threaded studs

Table shows the pull-out tests to be performed with sharp-tip threaded studs. The steel grade of the base material (component II) is S235 according to EN 10025-2. The tensile strength R_m of the base material with the thickness t_{II} shall be at the lower limit according to EN 10025-2. For qualification of minimum edge distances less than 15 mm tension test number 5 shall be to be performed.

Table 2.2.2.2.1: Pull-out tests with sharp-tip studs

Test number	Base material		Objective	Steel surface
	Thickness t_{II}	Edge distance c		
1	Minimum	≥ 15 mm	Pull-out resistance at minimum base material thickness	Black, mill scale
2	10 mm		Pull-out resistance at 10 mm base material thickness	Black, mill scale
3	Maximum		Pull-out resistance at maximum base material thickness ⁽¹⁾	Black, mill scale
4	Minimum ⁽³⁾		Influence of paint coating on pull-out resistance with standard coating thickness t_c	Paint coating ⁽⁵⁾
5	Minimum ⁽³⁾		Influence of hot-dip galvanized coating on pull-out resistance with standard coating thickness t_c	Hot-dip galvanized coating or duplex coating ^{(2) (5)}
6 (optional)	Minimum ⁽⁴⁾	c_{min}	Pull-out resistance at minimum base material thickness with minimum edge distance.	Black, mill scale or coated
7 (optional)	Minimum	≥ 15 mm	Pull-out resistance at minimum base material thickness with maximum coating thickness $t_{c,max}$	Coated with maximum coating thickness
8 (optional)	Maximum		Pull-out resistance at maximum base material thickness with maximum coating thickness $t_{c,max}$	Coated with maximum coating thickness

(1) If unlimited base material steel thickness is to be covered, the maximum thickness $t_{II,max}$ needs to exceed ($h_{ET,max} + 5$ mm).

(2) Duplex coating is a hot-dip galvanized coating plus paint layers as top coating.

(3) Or thickness with the least resistance from Test 1, 2 or 3.

(4) Or thickness and coating with the least resistance from Test 1, 2, 3, 4 and 5.

(5) Examples of coating specifications see Annex A.3.3.

Blunt-tip power-actuated threaded studs

Table 2.2.2.2.2 shows the pull-out tests to be performed for blunt-tip threaded studs. The steel grade of the base material (component II) is S235 according to EN 10025-2. The tensile strength of the base material with the thickness t_{II} shall be at the lower limit according to EN 10025-2. For qualification of minimum edge distances less than 10 mm tension test number 4 and 5 shall be performed.

Table 2.2.2.2: Pull-out tests for blunt-tip studs

Test number	Base material		Objective	Steel surface
	Thickness t_{II}	Edge distance c		
1	Minimum	≥ 10 mm	Pull-out resistance at minimum base material thickness without through penetration	Black, mill scale ⁽²⁾
2	Maximum		Pull-out resistance at maximum base material thickness without through penetration ⁽¹⁾	Black, mill scale ⁽²⁾
3	Minimum		Pull-out resistance at minimum base material thickness with through penetration	Black, mill scale ⁽²⁾
4	Minimum ⁽³⁾⁽⁴⁾		Influence of hot-dip galvanized coating on pull-out resistance with standard coating thickness t_c	Hot dip galvanized coating or duplex coating ^{(5) (10)}
5 (optional)	Minimum ⁽⁶⁾⁽⁷⁾	c_{min}	Pull-out resistance at minimum base material thickness with minimum edge distance c_{min} on one edge	Black, mill scale or coated
6 (optional)	Minimum ⁽⁸⁾		Pull-out resistance at minimum base material thickness with minimum edge distance c_{min} on both edges	Black, mill scale or coated
7 (optional)	Minimum ⁽⁹⁾	c	Pull-out resistance with maximum coating thickness $t_{c,max}$	Coated with maximum coating thickness

- (1) Test covers unlimited base material steel thickness, provided the thickness of component II exceeds double the embedment of the blunt-tip threaded fastener.
- (2) Use of coated base material is also acceptable.
- (3) Test 4a addresses configuration without through penetration: Thickness with the least resistance from Test 1 or 2 be used.
- (4) Test 4b addresses configuration with through penetration: Minimum thickness from Test 3 be used.
- (5) Duplex coating is a hot-dip galvanized coating plus paint layers as top coat.
- (6) Test 5a addresses configuration without through penetration: Thickness and coating with the least resistance resulting from tests 1, 2 and 4 be used.
- (7) Test 5b addresses configuration with through penetration: Thickness and coating with the least resistance from Test 2 or 4b be used.
- (8) coating with the least resistance from Test 1, 2 or 4 be used.
- (9) Selection of thickness (without or with through penetration) and edge distance determine the covered parameters.
- (10) Example of coating specification see Annex A.3.3.

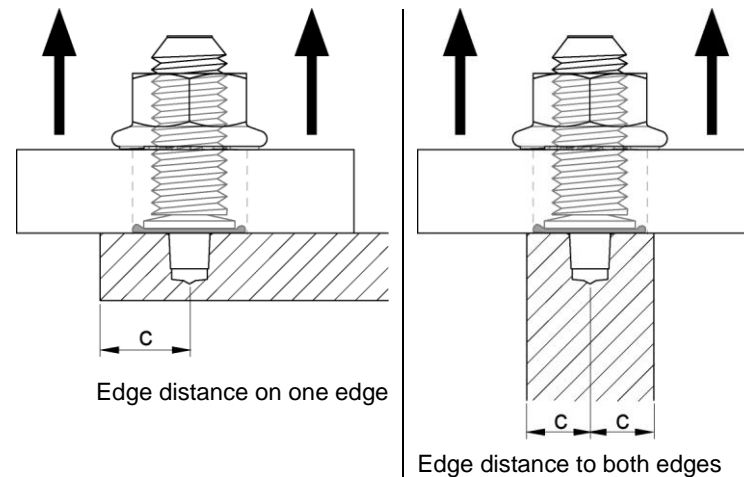


Figure 2.2.2.2.1: Definition of edge distance

Screw-in threaded studs

Table shows the pull-out tests to be performed for blunt-tip screw-in threaded studs. The steel grade of the base material (component II) is S235 according to EN 10025-2. The tensile strength of the base material with the thickness t_{II} shall be at the lower limit according to the relevant product standard (e.g., appropriate part of EN 10025-2 for steel base material and EN 485-2 (for sheets, strips and plates) or EN 755-2 (for extruded rods/bars, tubes or profiles) for aluminium base material). For qualification of minimum edge distances less than 15 mm tension test number 2 and 4 shall be performed.

Table 2.2.2.2.3: Pull-out tests for screw-in threaded studs

Test number	Base material		Objective	Steel surface
	thickness t_{II}	Edge distance c		
1	Minimum	≥ 15 mm	Pull-out resistance ⁽¹⁾	Black, mill scale
2 (optional)	Minimum	c_{min}	Pull-out resistance at minimum edge distance ⁽¹⁾	Black, mill scale
3	Minimum	≥ 15 mm	Pull-out resistance at minimum base material thickness with through-penetration of base material	Black, mill scale
4 (optional)	Minimum	c_{min}	Pull-out resistance at minimum base material thickness with through-penetration of base material, with minimum edge distance	Black, mill scale
5	Minimum	optional	Influence of hot-dip galvanized coating on pull-out resistance with standard coating thickness t_c	Hot dip galvanized coating or paint coating
6 (optional)	Minimum	optional	Pull-out resistance with maximum coating thickness $t_{c,max}$	Coated with maximum coating thickness ⁽²⁾

(1) Minimum base material thickness without through penetration.

(2) The coating thickness $t_{c,max}$ may be simulated by a correspondingly thick intermediate layer of sheet metal or by a corresponding reduction of the screw-in depth.

2.2.2.3 Fastener failure

Threaded studs

No specific tests are required to determine the tension fracture resistance of the threaded studs as the resistance will be implicitly checked in the pull-out tests (clause 2.2.2.2).

Grating fastener or checker plate fastener

These tests are necessary to determine the tension resistance of the grating or checker plate fastener. Test parameters are the mesh width of gratings or the clearance hole and thickness of checker plates. In case of gratings it is distinguished between square grating (with load introduction by 4 grating bars) and rectangular gratings (with a load transfer by 2 grating bars only), see Annex A.3.4.

At least 5 tensile tests shall be carried out for each relevant mesh width of grating or clearance hole of checker plates. The test load shall be increased until failure (fracture of the screw, fracture or excessive deformation of the disc, pull-over of the disc). The respective failure modes as well as the material properties of the grating and checker plate components used for the tests shall be documented. Furthermore, the load-displacement curve shall be recorded. The measurement of the piston or cross-head displacement of the test engine is in general sufficient.

An example of a tension test setup is shown in Annex A.3.4.

2.2.2.4 Pull-through resistance

The characteristic pull-through resistance can be calculated according to EN 1993-1-3, Table 8.3 (for steel fixed material thickness $t_f \leq 3$ mm), or EN 1993-1-8, Table 3.4 (for steel fixed material thickness $t_f > 3$ mm), or EN 1999-1-1, clause 8.5.5, for aluminium fixed material. Alternatively, the pull-through resistance may also be determined by tension pull-through tests to determine the failure of the fixed material (component I).

At least 10 pull-through tests shall be carried out for each relevant material thickness t_f .

The tensile strength f_u of the material of the component with the thickness t_f (sheet metal) shall be at the lower limit according to the relevant product standard (e.g., EN 10346 for steel and EN 485-2 for aluminium). The material properties as well as the thickness of the supporting substructure are optional as long as failure of the substructure is excluded.

2.2.2.5 General handling of the test results

In the absence of more accurate information of the effect of base material thickness and strength on the tension resistance, the test results shall be conservatively multiplied by the following correction factor α_R which depends on the failure mode:

Pull-out tests according to 2.2.2.2 for power-actuated threaded studs and screw-in threaded studs without through-penetration:

$$\text{- Pull-out failure: } \alpha_R = (R_{mII,min} / R_{mII}) \leq 1,0$$

with:

$R_{mII,min}$ = minimum tensile strength of the base material (component II) according to the relevant product standard
 R_{mII} = tensile strength of the base material (component II) used for the tests

Pull-out tests according to 2.2.2.2 for screw-in threaded studs with through-penetration:

$$\text{- Pull-out failure: } \alpha_R = (R_{mII,min} / R_{mII}) \cdot (t_{II,min} / t_{II}) \leq 1,0$$

$$\text{and } (R_{mII,min} / R_{mII} \leq 1,0) \text{ and } (t_{II,min} / t_{II} \leq 1,0)$$

with:

- $R_{mII,min}$ = minimum tensile strength of the base material (component II) according to the relevant product standard
 R_{mII} = tensile strength of the base material (component II) used for the tests
 $t_{II,min}$ = minimum thickness of the base material (components II) according to the relevant product standard
 t_{II} = actual thickness of the base material (component II) used for the tests (if the component is coated or galvanised the steel core thickness shall be taken)

Fastener failure according to 2.2.2.3:

- Tension failure of stud: $\alpha_R = (R_{mST,min} / R_{mST}) \leq 1,0$
- Tension failure of grating fastener: $\alpha_R = (R_{mGR,min} / R_{m,GR}) \leq 1,0$

with:

- $R_{mST,min}$ = minimum tensile strength of the threaded stud according to product specification. If the minimum specification is given as core hardness (e.g., HRC Rockwell hardness) the minimum strength can be converted from the hardness according to EN ISO 18265.
 R_{mST} = tensile strength of the threaded stud used for the tests. The actual strength can be converted from the measured core hardness values according to EN ISO 18265. The average hardness value of the 10 tested specimens can be used for the conversion.
 $R_{mGR,min}$ = minimum tensile strength of the grating fastener
 R_{mST} = tensile strength of the grating fastener used for the tests

Static pull-through tests according to 2.2.2.4:

- Failure of fixed steel or aluminium: $\alpha_R = (R_{mI,min} / R_{mI}) \cdot (t_{I,min} / t_I) \leq 1,0$
 and $(R_{mI,min} / R_{mI} \leq 1,0)$ and $(t_{I,min} / t_I \leq 1,0)$

with:

- $R_{mI,min}$ = minimum tensile strength of the fixed material (component I) according to the relevant product standard
 R_{mI} = tensile strength of the fixed material (component I) used for the tests
 $t_{I,min}$ = minimum thickness of the fixed material (component I) according to the relevant product standard
 t_I = thickness of the fixed material (component I) used for the tests. If the component is coated or galvanised the core thickness shall be taken.

The corrected test results shall be evaluated statistically according to EN 1990, Annex D.7.2 (determination of 5% fractile, confidence level 75%) per test series.

2.2.2.6 Determination of characteristic tension resistance N_{Rk} of the threaded stud and grating fastener

Threaded studs:

The characteristic tension resistance $N_{Rk,II}$ of the threaded stud corresponds with the minimum 5%-fractile value $N_{5\%,t}$ of the pull-out or the tension resistance series (in case of steel failure).

Grating fastener:

The characteristic tension resistance $N_{Rk,g}$ shall be assessed as follows:

$$N_{Rk,g} = N_{5\%,g} \cdot \alpha_g \quad \text{and} \quad \alpha_g = (N_{S,g} / N_{S5\%,g}) \leq 1,0$$

with

- $N_{5\%,g}$ = 5%-fractile value of the grating or checker plate fastener tension resistance depending on the type of grating and mesh width
 α_g = reduction factor limiting deformations of the grating or checker plate fastener
 $N_{S,g}$ = mean value of test results at grating or checker plate fastener deformation of 2 mm (depending on type of grating and mesh width)
 $N_{S5\%,g}$ = calculated tension service force ($N_{S5\%,g} = N_{5\%,g} / \gamma_M \cdot \gamma_F$) of test series, with $\gamma_M = 1,25$ per clause 2.2.2.6

2.2.3 Shear Resistance of individual threaded studs

2.2.3.1 Test procedure and shear failure modes

The possible failure modes of a threaded stud connection under shear load are (see Figure 2.2.1.1):

- Failure of component II (tilting and subsequent pull-out of the threaded stud due to local plastic deformation of the base material in the contact area with the threaded stud)
- Failure of fastener (shear fracture of threaded stud)

The test programme addresses the different possible failure modes. All relevant options of shear load introduction according to Table 1.2.1.2 shall be considered in the test programme.

The test load shall be increased until failure (component II, fracture of the stud, component I) occurs. The respective failure modes as well as the material properties of the base material, the threaded fastener and the fixed component used for the tests shall be documented. Furthermore, the load-displacement curves shall be documented. The material properties shall be documented by means of inspection documents 3.1 according to EN 10204.

Examples of shear test setups are shown in Annex A.4.

2.2.3.2 Base material shear tests (component II)

The results of the shear tests given in Table to Table cover all types of fastening and installation tools to be assessed for setting the power-actuated or screw-in threaded studs, provided the studs can be driven or screwed-in within the specified stand-off tolerance.

At least 10 shear tests shall be carried out per test series.

The material properties of the fixed material are optional as long as failure of the fixed material is excluded. For shear load introduction via the stud (Table), the maximum fixed thickness $t_{l,max,V}$ shall be used in the shear tests. For shear load introduction via the sealing washer (Table), the minimum thickness t_l used in the tests amounts to 3 mm (thickness needs to exceed the thickness of the compressed washer) as long as failure of the fixed material is excluded. These shear tests with load introduction via the sealing washer cover maximum fixed thickness $t_{l,max,V} = 15$ mm.

The nut of the threaded stud shall be only hand-tightened to avoid friction between component I and component II. The edge distance in force direction and perpendicular to the force direction shall be at a selected edge distance c .

The deformation capacity up to maximum load shall be documented.

Sharp-tip powder-actuated threaded studs

Table shows the shear tests to be performed with sharp-tip threaded studs. The steel grade of the base material (component II) is S235 according to EN 10025-2. The tensile strength f_u of the base material with the thickness t_{II} shall be at the lower limit according to EN 10025-2. Test 1 and 2 apply for the edge distance c used in those tests. For qualification of minimum edge distance $c_{min} < c$ Test 3 shall be performed.

Table 2.2.3.2.1: Shear test with sharp-tip studs

Test number	Base material		Objective	Steel surface
	Thickness t_{II}	Edge distance		
1	Minimum ⁽²⁾	c	Shear resistance at minimum base material thickness	Black, mill scale
2	$> t_{II,min}$	c	Shear resistance for different base material thickness $> t_{II,min}$ ⁽¹⁾	Black, mill scale
3	Minimum	c_{min}	Shear resistance at minimum base material thickness with minimum edge distance	Black, mill scale
4 ⁽³⁾ (optional)	Minimum	c	Shear resistance at minimum base material thickness with maximum coating thickness $t_{c,max}$	Coated with coating thickness $\geq t_{c,max}$
5 ⁽³⁾ (optional)	$> t_{II,min}$	c	Shear resistance with maximum coating thickness $t_{c,max}$ for different base material thickness $> t_{II,min}$ ⁽¹⁾	Coated with coating thickness $\geq t_{c,max}$

- (1) Those tests are only required, if shear resistances are published depending on different base material thickness. If those tests are omitted, the performance from test 1 applies for all base material thickness $\geq t_{II,min}$.
- (2) The embedment depth h_{ET} (see Figure) of the stud needs to exceed 1.5-times the minimum thickness of the base material.
- (3) Alternatively, the presence of maximum coating can be considered analytically by means of a bending moment assuming the coating thickness as lever arm.

Blunt-tip power-actuated threaded studs

Table shows the shear tests to be performed for blunt-tip threaded studs for each relevant load introduction according to Table . The steel grade of the base material (component II) is S235 according to EN 10025-2. The tensile strength of the base material with the thickness t_{II} shall be at the lower limit according to EN 10025-2. Tests number 1, 2 and 3 apply for the edge distance c used in those tests. For qualification of minimum edge distance $c_{min} < c$ tests number 5 and 6 shall be performed.

Table 2.2.3.2.2 Shear tests for blunt-tip studs

Test number	Base material		Objective	Steel surface
	Thickness t_{II}	Edge distance c		
1	Minimum	c	Shear resistance at minimum base material thickness without through penetration	Black, mill scale ⁽²⁾
2	Maximum		Shear resistance at maximum base material thickness without through penetration ⁽¹⁾	Black, mill scale ⁽²⁾
3	Minimum		Shear resistance at minimum base material thickness with through penetration	Black, mill scale ⁽²⁾
4	Minimum ⁽³⁾⁽⁴⁾		Influence of hot-dip galvanized coating on shear resistance with standard coating thickness t_c	Hot dip galvanized coating or duplex coating ⁽⁵⁾
5 (optional)	Minimum ⁽⁶⁾⁽⁷⁾	c_{min}	Shear resistance at minimum base material thickness with minimum edge distance c_{min} on one edge	Black, mill scale or coated
6 (optional)	Minimum ⁽⁸⁾		Shear resistance at minimum base material thickness with minimum edge distance c_{min} on both edges	Black, mill scale or coated
7 (optional)	Minimum ⁽⁹⁾	c	Shear resistance with maximum coating thickness $t_{c,max}$	Coated with maximum coating thickness

- (1) Test covers unlimited base material steel thickness, provided the thickness of component II exceeds double the embedment of the blunt-tip threaded fastener.
- (2) Use of coated base material is also acceptable.
- (3) Test 4a addresses configuration without through penetration: Thickness with the least resistance from Test 1 or 2 be used.
- (4) Test 4b addresses configuration with through penetration: Minimum thickness from Test 3 be used.
- (5) Duplex coating is a hot-dip galvanized coating plus paint layers as top coating.
- (6) Test 5a addresses configuration without through penetration: Thickness and coating with the least resistance from Test 1, 2 or 4 be used.
- (7) Test 5b addresses configuration with through penetration: Thickness and coating with the least resistance from Test 2 or 4b be used.
- (8) Coating with the least resistance from Test 1, 2 or 4 be used.
- (9) Selection of thickness (without or with through penetration) and edge distance determine the covered parameters.

Screw-in threaded studs

Table shows the shear tests to be performed for blunt-tip screw-in threaded studs for each relevant load introduction according to Table .

The steel grade of the base material (component II) is S235 according to EN 10025-2. The tensile strength f_u of the base material with the thickness t_{II} shall be at the lower limit according to EN 10025-2 for steel base material and EN 485-2 (for sheets, strips and plates) or EN 755-2 (for extruded rods/bars, tubes or profiles) for aluminium base material.

Table 2.2.3.2.3 Shear tests for screw-in threaded studs

Test number	Base material		Objective	Steel surface
	thickness t_{II}	Edge distance		
1	Minimum	c	Shear resistance at minimum base material thickness ⁽¹⁾	Black, mill scale
2 (optional)	Minimum	c_{min}	Shear resistance at minimum base material thickness with minimum edge distance on one edge ⁽¹⁾	Black, mill scale
3 (optional)	Minimum	c_{min}	Shear resistance at minimum base material thickness with minimum edge distance on both edges ⁽¹⁾	Black, mill scale
4	Minimum	c	Shear resistance at minimum base material thickness with standard coating thickness t_c	Hot dip galvanized coating or paint coating
5 (optional)	Minimum	c_{min}	Shear resistance at minimum base material thickness with minimum edge distance on one edge and standard coating thickness t_c	Hot dip galvanized coating or paint coating
6 (optional)	Minimum	c_{min}	Shear resistance at minimum base material thickness with minimum edge distance on both edges and standard coating thickness t_c	Hot dip galvanized coating or paint coating
7 (optional)	Minimum	c	Shear resistance at minimum base material thickness with maximum coating thickness $t_{c,max}$	Coated with maximum coating thickness ⁽²⁾
8 (optional)	Minimum	c_{min}	Shear resistance at minimum base material thickness with minimum edge distance on one edge and maximum coating thickness $t_{c,max}$	Coated with maximum coating thickness ⁽²⁾
9 (optional)	Minimum	c_{min}	Shear resistance at minimum base material thickness with minimum edge distance on both edges and maximum coating thickness $t_{c,max}$	Coated with maximum coating thickness ⁽²⁾

(1) With 2 different minimum base material thicknesses dependent if through penetration is additionally considered or not.

(2) The coating thickness $t_{c,max}$ may be simulated by a correspondingly thick intermediate layer of sheet metal.

2.2.3.3 Fastener failure

Provided the group shear resistance is not tested (clause 2.2.4), no specific tests are required to determine the shear fracture resistance of the threaded studs as the resistance will be implicitly checked in the base material tests according to clause 2.2.3.2.

In case the group shear resistance will be tested the fastener failure shear test as shown in Table are to be performed with all types of threaded studs. The steel grade of the base material (component II) needs to be at the upper application limit of the respective stud. The minimum thickness of the base material (component II) needs to be 10 mm and the tensile strength R_m of the base material (component II) needs to be at the upper application limit.

The material properties of the fixed material are optional as long as failure of the fixed material is excluded. For shear load introduction via the stud (Table 1.2.1.2) the maximum fixed thickness $t_{l,max,V}$ shall be used in the shear tests. For shear load introduction via the sealing washer (Table), the minimum thickness t_l used in the tests amounts to 3 mm (thickness needs to exceed the thickness of the compressed washer) as long as failure of the fixed material is excluded. These shear tests with load introduction via the sealing washer cover maximum fixed thickness $t_{l,max,V} = 15$ mm.

Shear tests need to be performed for each relevant shear load introduction according to Table .

Table 2.2.3.3.1 Fastener failure shear tests

Test number	Base material Thickness t_{II}	Objective	Steel surface
1	≥ 10	Fastener and base material shear resistance at the upper application limit. Check of minimum ductility	Black, mill scale

2.2.3.4 Fixed material shear tests (component I)

The characteristic shear resistance can be calculated according to EN 1993-1-3, Table 8.4 or EN 1999-1-1, clause 8.5.5. As an equivalent method for determining performance, the shear resistance may also be determined by single layer shear tests to determine the failure of the fixed material (component I).

At least 10 shear tests shall be carried out for each relevant material thickness t_l with the maximum specified clearance hole diameter. In case of a clearance slot, the shape of the clearance slot and the respective load direction shall be considered.

The tensile strength R_m of the fixed material (component I) shall be at the lower limit according to the relevant product standard (e.g., EN 10346 for steel and EN 485-2 for aluminium). The material properties as well as the thickness of the supporting substructure are optional as long as failure of the substructure is excluded. The nut of the threaded stud shall be only hand-tightened to avoid friction between component I and component II.

The deformation capacity up to maximum load shall be documented.

2.2.3.5 General handling of the test results

In the absence of more accurate information of the effect of base material thickness and strength on the shear resistance, the test results shall be conservatively multiplied by the following correction factor α_R which depends on the failure mode:

Fixed material shear tests according to 2.2.3.4:

- Bearing failure (slotted hole): $\alpha_R = (R_{mI,min} / R_{mI}) \cdot (t_{l,min} / t_l) \leq 1,0$
and $(R_{mI,min} / R_{mI} \leq 1,0)$ and $(t_{l,min} / t_l \leq 1,0)$

with:

- $R_{mI,min}$ = minimum tensile strength of the fixed material (component I) according to the relevant product standard
 R_{mI} = tensile strength of the fixed material (component I) used for the tests
 $t_{I,min}$ = minimum thickness of the fixed material (component I) according to the relevant product standard
 t_I = thickness of the fixed material (component I) used for the tests. If the component is coated or galvanised the core thickness shall be taken.

Base material shear tests according to 2.2.3.2 for power-actuated threaded studs and screw-in threaded studs without through-penetration:

- Base material failure: $\alpha_R = (R_{mII,min} / R_{mII}) \leq 1,0$

with:

- $R_{mII,min}$ = minimum tensile strength of the base material (component II) according to the relevant product standard
 R_{mII} = tensile strength of the base material (component II) used for the tests

Base material shear tests according to 2.2.3.2 screw-in threaded studs with through-penetration:

- Base material failure: $\alpha_R = (R_{mII,min} / R_{mII}) \cdot (t_{II,min} / t_{II}) \leq 1,0$
 and $(R_{mII,min} / R_{mII} \leq 1,0)$ and $(t_{II,min} / t_{II} \leq 1,0)$

with:

- $R_{mII,min}$ = minimum tensile strength of the base material (component II) according to the relevant product standard
 R_{mII} = tensile strength of the base material (component II) used for the tests
 $t_{II,min}$ = minimum thickness of the base material (components II) according to the relevant product standard
 t_{II} = actual thickness of the base material (component II) used for the tests (if the component is coated or galvanised the steel core thickness shall be taken)

Fastener failure according 2.2.3.3:

- Shear failure of stud: $\alpha_R = (R_{mST,min} / R_{mST}) \leq 1,0$

with:

- $R_{mST,min}$ = minimum tensile strength of the threaded stud. If the minimum specification is given as core hardness (e.g., HRC Rockwell hardness) the minimum strength can be converted from the hardness according to EN ISO 18265.
 R_{mST} = tensile strength of the threaded stud used for the tests. The actual strength can be converted from the measured core hardness values according to EN ISO 18265. The average hardness value of the 10 tested specimens can be used for the conversion.

The corrected test results shall be evaluated statistically according to EN 1990, Annex D.7.2 (determination of 5% fractile, confidence level 75%) per test series.

2.2.3.6 Determination of characteristic shear resistance V_{Rk} of an individual threaded stud

The characteristic shear resistance $V_{Rk,II}$ of the threaded stud corresponds with the minimum 5%-fractile value $V_{5\%,t}$ of the shear resistance series, covering base material failures with stud tilting (with or without subsequent pull-out) and shear failure of the stud shank.

In case tests are performed, the characteristic shear resistance $V_{Rk,I}$ of the fixed component in combination with a specific threaded stud connection corresponds with the 5%-fractile values of the shear test series covering local bearing with hole elongation.

2.2.4 Shear Resistance of groups of threaded stud connections

2.2.4.1 Test procedure

In the case of group fastenings, the influence of the clearance hole diameter d_c shall be taken into account and the ductility of the threaded studs shall be verified so that all threaded studs of a group can be used as load-bearing. All relevant options of shear load introduction according to Table shall be considered in the test programme.

If group tests are omitted, $\alpha(n) = 1/n$ for “Row-Setup” and $\alpha(n) = 1/2$ for “Rectangular-Plate-Setup” according to Figure .

The objective of the group test is to investigate the group behaviour of threaded stud connection depending on the clearance hole diameter d_c , the group patterns and the number of studs n within a group.

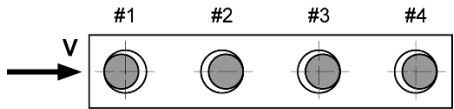
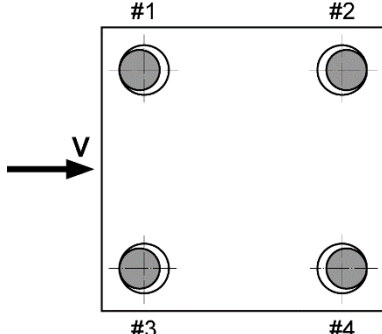
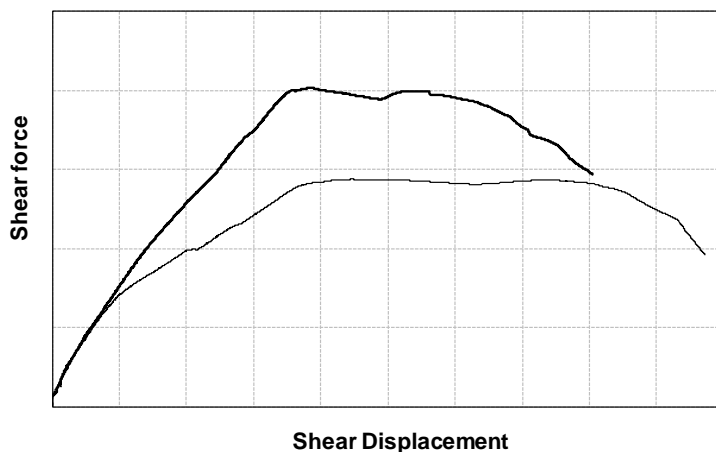
Group pattern	Condition for group test: The test setup shall simulate the following stud position before the test load is applied:
<p>Row-Setup: Row of threaded studs with n studs (example $n = 4$)</p> 	<ul style="list-style-type: none"> • Only one stud of the row is in direct contact with the fixed plate material, when the test load is introduced and increased. • All other studs of the row shall be positioned at the maximum opposite position in the clearance hole.
<p>Rectangular-Plate-Setup Squared or rectangular fixed plate with maximum $n = 4$ studs</p> 	<ul style="list-style-type: none"> • Two studs of the group are in direct contact with the fixed plate material, when the test load is introduced and increased. • The remaining two studs of the group shall be positioned at the maximum opposite position in the clearance hole.

Figure 2.2.4.1.1: Group patterns and geometric test conditions

The general test conditions for the group tests are as follows:

- The group tests are to be performed with the shear test configuration leading to the stiffest behaviour of the individual fastener of the tests according to clause 2.2.3.2 and clause 2.2.3.3, see Figure .



The stiffest behaviour is assessed based on the initial elastic stiffness and the ultimate resistance.

In case of the same initial elastic stiffness (as in the example left), the configuration resulting to the maximum ultimate individual shear resistance shall be used for the group tests.

Figure 2.2.4.1.2: Individual shear test behaviour

- Edge distance in the fixed and the base material are to be sufficiently high in order to avoid any effect on the test results.
- The hole clearance diameter is constant for all studs of the group.
- The nuts of the threaded studs shall be only hand tightened to avoid friction between component I and component II.
- Equivalently to the “Rectangular-Plate-Setup”, the “Row-setup” can be used in the group-tests, if 2 studs of the row of 4 studs are in direct contact with the fixed plate material, when the test load is introduced and increased. The remaining two studs of the group shall be positioned at the maximum opposite position in the clearance hole.

At least 3 shear tests shall be carried out per test series.

Details of group shear test setups as well as test execution are shown Annex A.5.

2.2.4.2 General handling of the test results

A normalization of the test results is only required, if the relevant group setup derives from individual shear tests according to clause 2.2.3.2.

2.2.4.3 Assessment of group behaviour and characteristic shear resistance $V_{Rk,II,g}$

The performance reduction factor $\alpha(n)$ considering the group effect shall be assessed as follows:

$$\alpha(n) = \frac{V_{5\%,t,g}}{n \cdot V_{Rk,II}}$$

with:

$\alpha(n) \leq 1,0$ reduction factor to consider group effect for a specific group pattern.

n total number of studs of the row or group, see Figure

$V_{Rk,II}$ characteristic shear resistance to be published in the ETA for individual threaded studs

$V_{5\%,t,g}$ 5%-fractile value of the group tests without correction of test results

The characteristic shear resistance $V_{Rk,II,g}$ of the group shall be calculated as follows:

$$V_{Rk,II,g} = \alpha(n) \cdot n \cdot V_{Rk,II}$$

2.2.5 Bending moment resistance

2.2.5.1 Test procedure and bending failure modes

The possible failure modes of a threaded stud connection under bending moment are:

- Failure of component II (tilting and subsequent pull-out of the threaded stud due to local plastic deformation of the base material in the contact area with the threaded stud)
- Failure of fastener (shear fracture and plastic deformation of threaded stud, excessive bending deformation)

The test and assessment programme address the different possible failure modes.

The test load shall be increased until failure (fastener, component II) occurs. The respective failure modes as well as the material properties of the base material and the threaded fastener used for the tests shall be documented. Furthermore, the load-displacement curves, the maximum loads and the lever arm ‘e’ shall be recorded. The measurement of the piston or cross-head displacement of the test engine is in general sufficient. The material properties shall be documented by means of inspection documents 3.1 according to EN 10204. The material properties shall correspond to the material specifications supplied by the manufacturer.

An example of a bending test setup is shown in Annex A.6.

2.2.5.2 Bending Tests

At least 10 bending tests shall be carried out for each relevant base material type / base material thickness t_{II} .

The tensile strength of the base material with the thickness t_{II} shall be at the lower limit according to the relevant product standard (e.g., EN 10025-2 for construction steel or EN 485-2 or EN 755-2 for aluminium). For edge distances c less than 15 mm, bending tests shall also be performed at the minimum edge distance in the base material with the thickness t_{II} .

For coverage of the standard coating thickness t_c bending tests can also be performed on black steel provided the following conditions are met:

- For sharp-tip studs: the embedment depth h_{ET} (see Figure) exceeds 1,5-times the minimum thickness of the base material t_{II} .
- For blunt-tip studs: the embedment depth h_{ET} (see Figure) exceeds 4,5 mm.

2.2.5.3 General handling of the test results

For failure of the component II, the provisions for pull-out failure as given in clause 2.2.2.5 apply. For bending failure of the threaded stud, the provisions for tension failure of stud as given in clause 2.2.2.5 apply.

2.2.5.4 Determination of characteristic bending resistance M_{Rk}

The characteristic bending resistance M_{Rk} of the threaded stud corresponds with the minimum 5%-fractile values $M_{Rk,t}$ of the bending resistance taking the different failure modes into account. The characteristic bending resistance M_{Rk} is furthermore limited with the plastic bending resistance $M_{pl,stud}$ of the stud.

$$M_{Rk} = M_{Rk,t} \leq M_{pl,stud}$$

$$\text{with } M_{pl,stud} = \frac{1}{6} R_{m,min} \cdot d_{min}^3$$

with:

$R_{m,min}$ = minimum tensile strength of the threaded stud.

d_{min} = minimum diameter of the stud (in general the diameter at the interface).

2.2.6 Resistance in case of combined loading (interaction)

For experimental evaluation of the shear-tension interaction the tests given in Table shall be performed. For a given base material condition (e.g., Test 1), all tests shall be performed for all load angles α (Figure) with base material from one and the same batch.

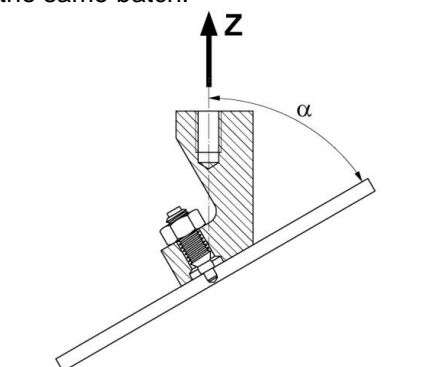


Figure 2.2.6.1 Load angle α

Table 2.2.6.1: Interaction tests for shear-tension interaction

Test number ⁽¹⁾	Base material properties	Load angles α	Number of tests per angle
1	Thickness: minimum t_{II} Strength: Lower range of S235 per EN 10025-2 Surface: Black, mill scale	0, 30, 45, 60, 90	10
2	Thickness and strength combination covering stiff shear behaviour Surface: Black, mill scale	0, 30, 45, 60, 90	10

⁽¹⁾ Every test number 1 and 2 consists of 5 tests series, which differ in the load angle α .

An example of a shear-tension interaction test setup is shown in Annex A.7. The force axis of the test engine shall intersect with the axis of the fastener at the surface of the base material in order to avoid any unintentional bending effects.

For each test number 1 and 2, the mean value $Z_{m,\alpha}$ for every load- angle α shall be determined.

2.2.7 Fatigue classification of base material

Fatigue resistance is usually given in form of a S-N curve and a corresponding fatigue detail category, where the fatigue category is designated by a number which represents in $[N/mm^2]$ the reference fatigue strength $\Delta\sigma_C$ at $2 \cdot 10^6$ cycles, see **Error! Reference source not found.** The S-N curve may have a double slope of m_1 and m_2 . The slope intersection is often at $5 \cdot 10^6$ cycles. The constant amplitude fatigue limit (CAFL) is usually set at $N = 5 \cdot 10^6$ cycles.

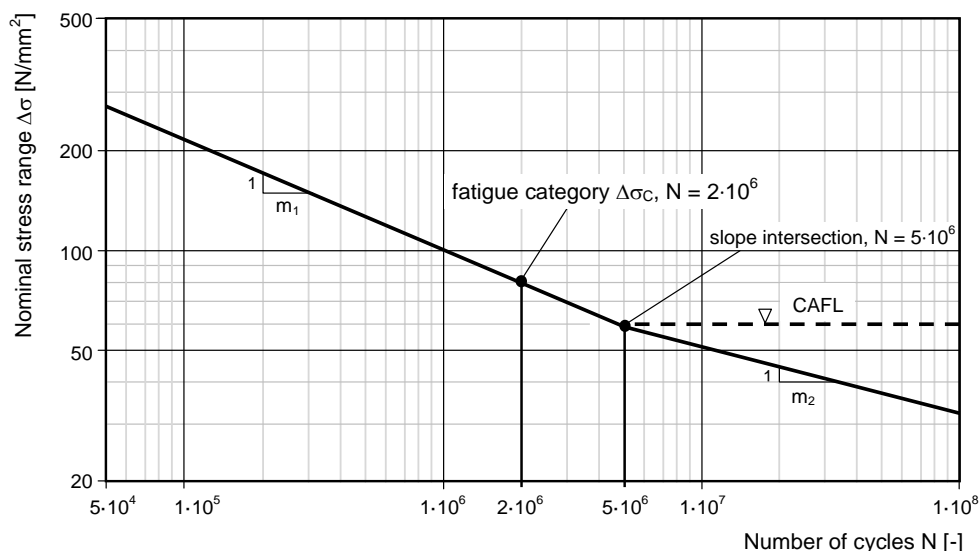


Figure 2.2.7.1 S-N curves for direct stress ranges according to EN 1993-1-9

Fatigue tests

Constant amplitude fatigue tests on a constant stress ratio R shall be performed in order to determine fatigue resistance. Following procedure is recommended to generate a specific S-N curve and corresponding detail class:

- a total of at least 10 single test specimens per S-N curve, see e.g., Annex A.9
- 3 different stress ranges $\Delta\sigma_i$, each comprising 2 - 5 single test specimens allowing for a proper determination of slope m_1 of S-N curve
- constant stress ratio R, preferable $R \geq +0,1$
- fatigue loading until fracture of the specimen
- number of stress cycles in the range of $5 \cdot 10^4$ to $1 \cdot 10^7$
- at least one run-through at a stress range $\Delta\sigma$ of 1,5-times the supposed characteristic value at $5 \cdot 10^6$ cycles (CAFL).

The fatigue test programme shall cover following effects:

- type of threaded stud
- base material thickness

The steel grade of the base material (component II) is preferable S235 according to EN 10025-2. Steel surface effects on fatigue resistance can in general be neglected.

Evaluation of test results and determination of fatigue detail category

The test results shall be analysed to produce characteristic fatigue strength values (subscript k). These are values that represent 95% survival probability (i.e. 5% failure probability) calculated from a mean on the basis of a two-sided confidence level of 75% and corresponds to an effective probability of survival of about 97,7%.

When determining the characteristic fatigue resistance using the S-N curve concept it is assumed, that the number of cycles N is considered as a function of the applied stress range S (= $\Delta\sigma$). Consequently, the stress range $\Delta\sigma$ is referred as being the independent variable while the number of cycles N (fatigue life) represents the dependent variable.

Traditionally, in fatigue design it is assumed that there is a linear relationship between $\Delta\sigma$ and N on a double-logarithmic scale as follows, see Figure :

$$\log N = \log a - m \cdot \log \Delta\sigma$$

with

$\log N$ logarithm to base 10 of corresponding number of cycles to failure N

$\log a$ intercept on the $\log N$ axis

m negative slope of S-N curve being linear on a log-log basis

$\log \Delta\sigma$ logarithm to base 10 of stress range

Formulas to derive the characteristic fatigue strength curve and the corresponding fatigue detail category based on test results are given in EN 1990, Annex D.

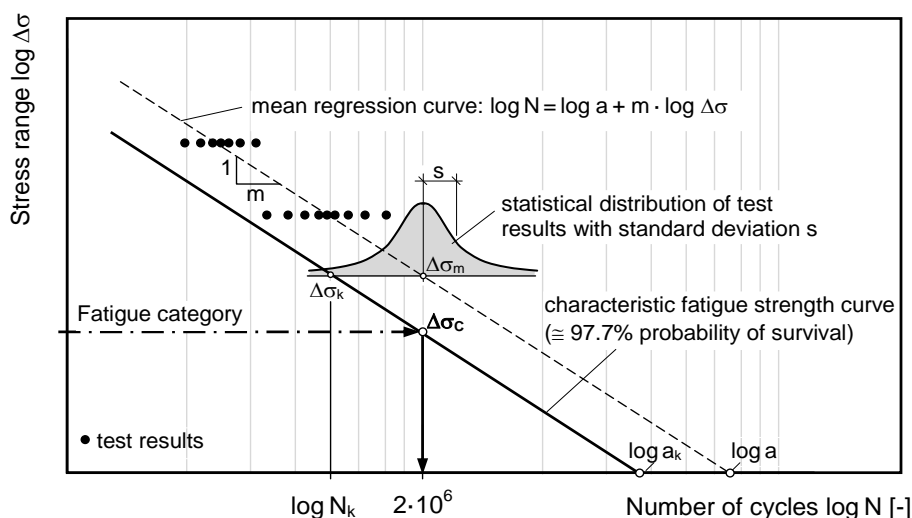


Figure 2.2.7.2 Statistical evaluation of the test results and determination of fatigue category

2.2.8 Reaction to fire

The threaded studs are considered to satisfy the requirements for performance Class A1 of the characteristic reaction to fire in accordance with the Commission Decision 96/603/EC, as amended by Commission Decisions 2000/605/EC and 2003/424/EC, without the need for further testing on the basis of it fulfilling the conditions set out in that Decision and its intended use being covered by that Decision.

Therefore, the performance of the studs made of steel is class A1.

2.2.9 Resistance to fire

The part of the works or assembled system in which the threaded studs are intended to be incorporated, installed or applied shall be tested, using the test method relevant for the corresponding fire resistance class, in order to be classified according to the appropriate part of EN 13501-2.

Additionally, threaded studs can be designed based on temperature dependent resistances, which shall be determined by tests. Corresponding tension pull-out tests shall be performed at elevated temperatures. The steel grade of the base material (component II) is S235 according to EN 10025-2. The tensile strength f_u of the base material shall be at the lower limit according to EN 10025-2.

For sharp-tip threaded studs as well as for blunt-tip threaded studs, the minimum specified base material thickness $t_{II,min}$ shall be used in the tests. For blunt-tip threaded studs without through penetration the maximum thickness of the base material used in the tests amounts to maximum 10 mm.

For all tests at any temperature, base material from one and the same steel batch shall be used. Test specimens are to be prepared with the same driving energy to achieve similar embedment. An example for the test setup is shown in Annex A.8.

Test condition:

- Tests shall be executed at room temperature, subsequently followed with tests at elevated temperature in the following temperature steps: 100 °C, 200 °C, 300 °C, 400 °C, 500 °C, 600 °C etc.
- Minimum 5 tests per temperature level shall be executed.
- The test procedure needs to ensure that the target temperature is achieved in the base material (see Annex A.8) before the threaded stud is loaded to failure.

The temperature dependent reduction factor $k_{u,\Theta,TS}$ is assessed for the threaded stud per each temperature level as follows:

$$k_{u,\theta,TS} = \min \text{ of } (N_{m,t,\theta} / N_{m,t,RT}) \text{ and } (N_{5\%,t,\theta} / N_{5\%,t,RT})$$

with:

$N_{m,t,\theta}$	mean value of tension test result at elevated temperature
$N_{m,t,RT}$	mean value of reference test at room temperature
$N_{5\%,t,\theta}$	5%-fractile of tension test results at elevated temperature
$N_{5\%,t,RT}$	5%-fractile of tension reference test at room temperature

The characteristic tension resistance of the threaded stud at elevated temperature is calculated as follows:

$$N_{fi,II,Rk} = k_{u,\theta,TS} \cdot N_{Rk,II}$$

with:

$N_{fi,II,Rk}$	Characteristic of tension resistance of threaded stud at elevated temperature
$N_{Rk,II}$	Characteristic tension resistance of threaded stud at room temperature
$k_{u,\theta,TS}$	Temperature dependent reduction factor

The temperature dependent reduction factor $k_{u,\theta,TS}$ can also be applied to characteristic shear and bending resistance.

3 ASSESSMENT AND VERIFICATION OF CONSTANCY OF PERFORMANCE

3.1 System(s) of assessment and verification of constancy of performance to be applied

For the products covered by this EAD the applicable European legal act is Commission Decision 98/214/EC, as amended by 2001/596/EC.

The system is 2+.

3.2 Tasks of the manufacturer

The cornerstones of the actions to be undertaken by the manufacturer of the threaded studs in the procedure of assessment and verification of constancy of performance are laid down in Table 3.2.1

Table 3.2.1 Control plan for the manufacturer; cornerstones

No	Subject/type of control	Test or control method	Criteria, if any	Minimum number of samples	Minimum frequency of control
Factory production control (FPC) [including testing of samples taken at the factory in accordance with a prescribed test plan]					
1	Check of raw material specification and properties (tensile and yield strength, fracture elongation, chemical composition)	Inspection certificate 3.1. according to EN 10204	Specific ation	According to control plan	Every manufacturing batch
2	Dimensions and tolerances	Measuring or optical check	Laid down in control plan		
3	Core hardness	Hardness tests as per EN ISO 6508-1 or EN ISO 6507-1 as applicable	Laid down in control plan		
4	Metallurgical properties (only for carbon steel powder actuated studs)	Metallurgical investigations (micro-sections) according . to control plan			
5	Deformation capacity / ductility (only for powder-actuated sharp tip studs)	Bending deformation test according to control plan			
6	Coating (where relevant)	X-ray measurement, microscopic method or magnetic method (zinc-layer) and visual inspection (UV-lamp) for duplex-coating	Laid down in control plan		
7	Manufacturer mark (head mark), Check of packaging: Content and labelling	Visual check			

3.3 Tasks of the notified body

The corner stones of the actions to be undertaken by the notified body in the procedure of assessment and verification of constancy of performance for the threaded studs are laid down in Table 3.2.1

Table 3.2.1 Control plan for the notified body; corner stones

No	Subject/type of control	Test or control method	Criteria, if any	Minimum number of samples	Minimum frequency of control
Initial inspection of the manufacturing plant and of factory production control <i>(for systems 1+, 1 and 2+ only)</i>					
1	Ascertain that the factory production control with the staff and equipment are suitable to ensure a continuous and orderly manufacturing of the threaded studs.	Verification of the complete FPC as described in the control plan agreed between the TAB and the manufacturer	Laid down in control plan	-	When starting the production or a new production line
Continuous surveillance, assessment and evaluation of factory production control <i>(for systems 1+, 1 and 2+ only)</i>					
2	Verifying that the system of factory production control and the specified automated manufacturing process are maintained taking account of the control plan.	Verification of the controls carried out by the manufacturer as described in the control plan agreed between the TAB and the manufacturer with reference to the raw materials, to the process and to the product as indicated in Table 3.2.1	Laid down in control plan	-	Once per year

4 REFERENCE DOCUMENTS

EN 485-2:2016 +A1:2018	Aluminium and aluminium alloys – Sheet, strip and plate – Part 2: Mechanical Properties
EN 755-2:2016	Aluminium and aluminium alloys – Extruded rod/bar, tube and profiles – Part 2: Mechanical Properties
EN 1990:2002+A1:2005/AC:2010	Eurocode – Basis of structural design
EN 1993-1-1:2005+AC:2009	Eurocode 3: Design of steel structures – Part 1-1: General rules and rules for buildings
EN 1993-1-3:2006+AC:2009	Eurocode 3: Design of steel structures – Part 1-3: General rules - Supplementary rules for cold-formed members and sheeting
EN 1993-1-4:2006+A2:2020	Eurocode 3: Design of steel structures – Part 1-4: General rules - Supplementary rules for stainless steels
EN 1993-1-8:2005+AC:2009	Eurocode 3: Design of steel structures – Part 1-8: Design of joints
EN 1993-1-9:2005+AC:2009	Eurocode 3: Design of steel structures – Part 1-9: Fatigue
EN 1993-1-12:2007+AC:2009	Eurocode 3: Design of steel structures – Part 1-12: Additional rules for the extension of EN 1193 up to steel grades S700
EN 1999-1-1:2007+A1:2009-07+A2:2013	Eurocode 9: Design of aluminium structures - Part 1-1: General structural rules
EN 1999-1-4:2007+AC:2009	Eurocode 9: Design of aluminium structures – Part 1-4: Cold-formed structural sheeting
EN 10025-2:2019	Hot rolled products of structural steels - Part 2: Technical delivery conditions for non-alloy structural steels
EN 10025-6:2019	Hot rolled products of structural steels - Part 6: Technical delivery conditions for flat products of high yield strength structural steels in the quenched and tempered condition
EN 10088-2:2014	Stainless steels – Part 2: Technical delivery conditions for sheet/plate and strip of corrosion resisting steels for general purposes
EN 10204:2014	Metallic products – Types of inspection documents
EN 10346:2015	Continuously hot-dip coated steel flat products for cold forming - Technical delivery conditions
EN 13501-2:2016	Fire classification of construction products and building elements - Part 1: Classification using data from reaction to fire tests
EN ISO 6507-1:2018	Metallic materials – Vickers hardness test – Part 1: Test method (ISO 6507-1:2018)
EN ISO 6508-1:2016	Metallic materials – Rockwell hardness test – Part 1: Test method (ISO 6508-1:2016)
EN ISO 8501-1:2007	Preparation of steel substrates before application of paints and related products – Visual assessment of surface cleanliness – Part 1: Rust grades and preparation grades of uncoated steel substrates and of steel substrates after overall removal of previous coatings (ISO 8501-1:2007)
EN ISO 18265:2013	Metallic materials – Conversion of hardness values (ISO 18265:2013)

ANNEX A: DETAILS OF TESTS

A.1 Test procedure – general aspects

The threaded studs, grating fasteners and checker plate fasteners shall be installed according to the installation instructions of the manufacturer. The load shall be increased in such a way that the peak load of a test is reached after at least 30 seconds.

A.2 Test recordings

Following measured values and failure modes:

- Load-displacement-curve
- Any special observations concerning application of the load
- Failure load
- Failure mode
- Particulars of repeated load tests
 - minimum and maximum load
 - frequency of cycles
 - number of cycles to failure
 - displacements as function of the number of cycles

shall be recorded for each test.

A.3 Tension test setup

A.3.1 Pull-out resistance

An example of a test fixture for the pull-out tension test is shown in Figure .

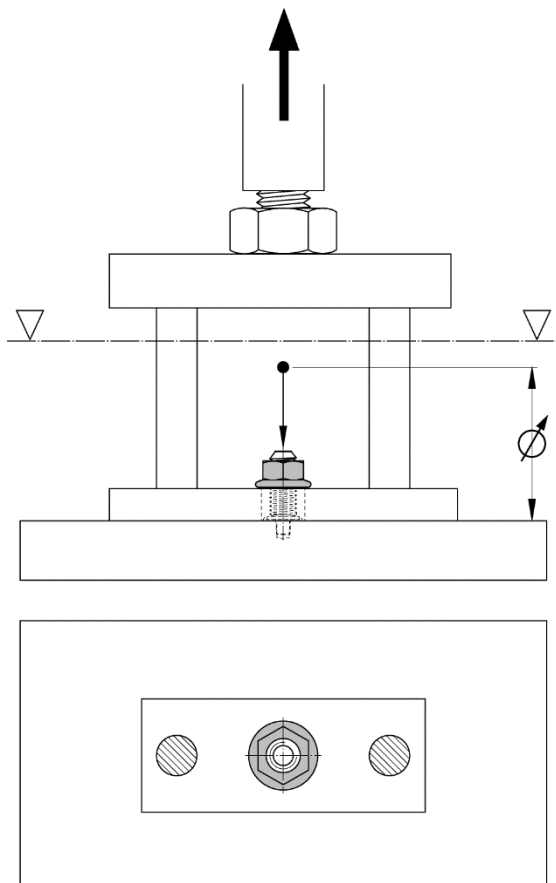


Figure A.3.1.1: Pull-out test fixture

The load application into the installed threaded stud can be achieved by using a cross-head which is connected to the testing machine. The cross-head can either be attached directly to the base material (Figure) or to the sealing washer of the threaded stud (Figure).

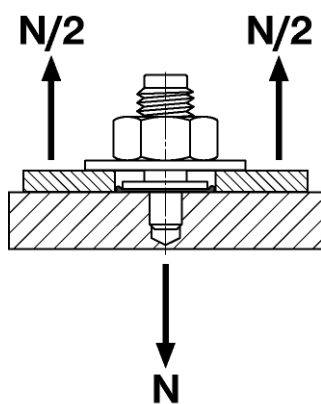


Figure A.3.1.2: Specimen attached directly to the base material

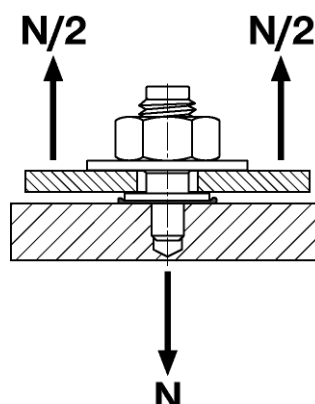


Figure A.3.1.3: Specimen attached to the sealing washer

The applied tightening torque of the nut shall be recorded.

Figure also shows the position and attachment of the extensometer. Provided the fixed steel is sufficiently stiff, the extensometer is also allowed to be positioned on top of the fixed component close to the threaded stud.

Alternatively, the testing machine can also be connected directly to the threaded studs via an internal threaded sleeve with the respective thread diameter.

Deformation of the base material (component II) shall be avoided and may require to choose an appropriate geometry of the base material and/or appropriate brace support.

The test speed shall be adjusted in order to reach the ultimate force after at least 30 seconds. The pull-out tests shall be performed force-controlled with a maximum speed of 20 kN/min. The tests can also be run displacement-controlled. The rate of deformation shall not exceed 5 mm/min. As the minimum duration till failure exceeds 30 seconds, both force-controlled and displacement-controlled tests lead to equivalent results.

A.3.2 Pull-through resistance

The test fixture for the pull-through tension test is shown in Figure in principal.

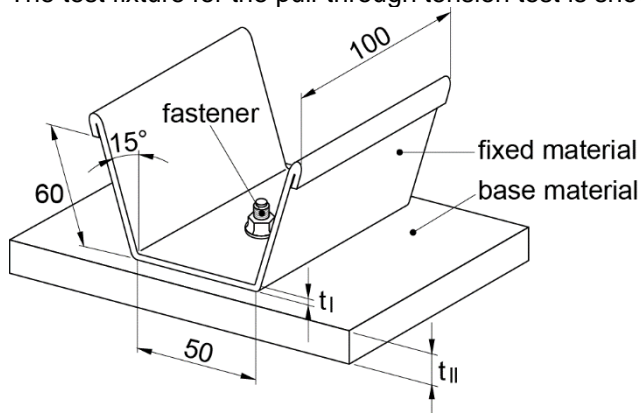


Figure A.3.2.1: Pull-through test fixture

The specimen can either be attached directly to the base material (Figure) or to the sealing washer of the threaded stud (Figure).

For all types of threaded studs, the presence of the base material is a necessary requirement for their proper installation. Therefore, the base material shall be included in the pull-through test according to Figure . The base material (component II) shall be sufficiently thick, to resist pull-out failure of the threaded stud. Deformation of the base material shall be avoided and may require to choose an appropriate geometry of the base material and/or appropriate brace support. The applied tightening torque of the nut shall be recorded.

The test speed shall be adjusted in order to reach the ultimate force after at least 30 seconds. Therefore, the test speed depends on the expected failure load. The pull-through tests shall be performed force-controlled with a maximum speed of 20 kN/min. The tests can also be run displacement-controlled. The rate of deformation shall not exceed 5 mm/min.

A.3.3 Coating specifications

As given in the respective test tables of clauses 2.2.2 and 2.2.3, coated base material shall be used in the test programmes.

Following coatings are considered:

- Paint coatings
- Hot dipped galvanized or duplex coating (duplex = paint applied over zinc coating)

Paint coatings require a surface preparation (Blast-cleaning “Sa” according to EN ISO 8501-1) with the following composition: Primer coat(s) + intermediate coat(s) + finish coat(s).

The composition of the paint system shall be recorded.

An example of a C5 paint system is given below:

- Blast-cleaning Sa 2½
- Primer: Epoxy resin, zinc powder (min 55 µm)
- Layers of intermediate coats: Epoxy resin (min 250 µm)
- Finish coat: Polyurethane (min 65 µm)

An example of a C5 duplex system is given below:

- Appropriate surface preparation for hot dip galvanizing
- Hot dip galvanization (min 60 µm zinc layer)
- Appropriate surface preparation before further application of paints
- Intermediate coat: Epoxy resin, iron mica (min 60 µm)
- Layers of intermediate coats: Epoxy resin (min 200 µm)
- Finish coat: Polyurethane (min 65 µm)

A.3.4 Grating fastener or checker plate fastener

The grating or checker plate fastener is connected with a threaded stud which itself is installed into a test plate. The plate is then attached to the base plate of the test machine. Alternatively, the grating or checker plate can be connected to a threaded rod with the respective thread diameter.

For the test either a piece of grating or checker plate can be used. Alternatively, the tension force is transferred into the disc of the grating or checker plate fastener via a metal device simulating the mesh width of gratings (Figure) or the clearance hole in checker plates. In case of gratings it is distinguished between square grating with load introduction by 4 grating bars) and rectangular gratings (with a load transfer by 2 grating bars only).

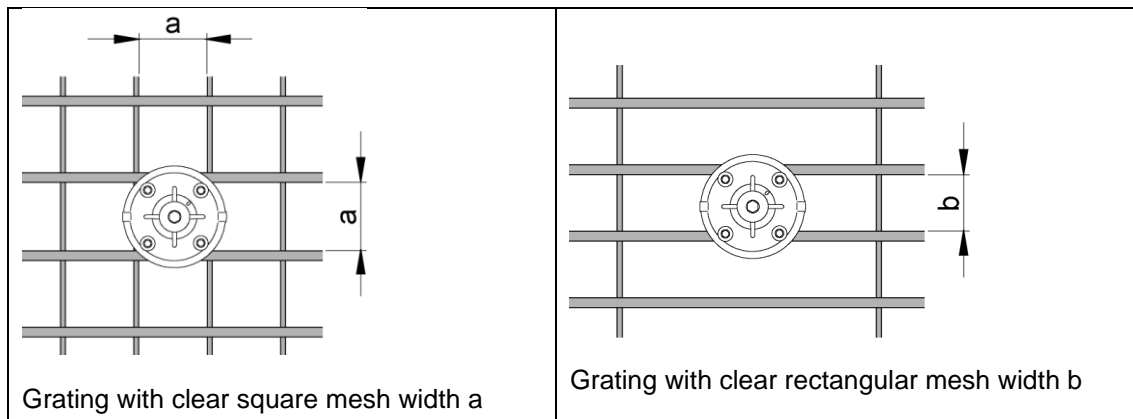


Figure A.3.4.1: Types of grating and clear mesh width a and b

The test speed shall be adjusted in order to reach the ultimate force after at least 30 seconds. The load-displacement curve shall be recorded. The measurement of the piston or cross-head displacement of the test engine is in general sufficient.

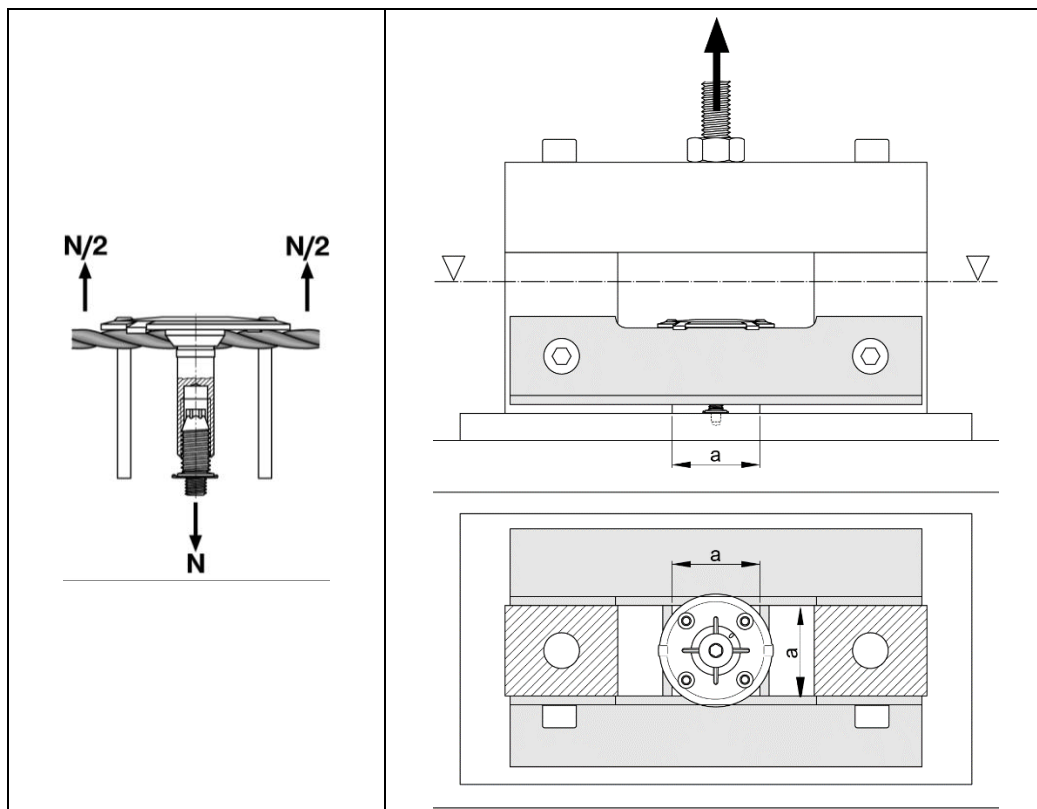


Figure A.3.4.2: Pull-through test fixture for grating fastener tension test

A.4 Shear test setup

The test to determine the shear resistance shall be carried out with specimens according to Figure and Figure .

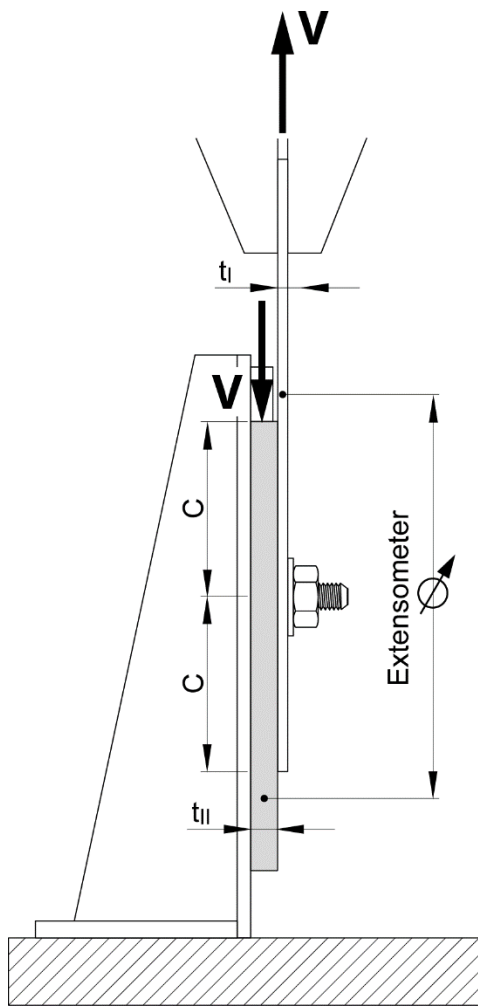


Figure A.4.1: Shear test with edge distance c in force direction

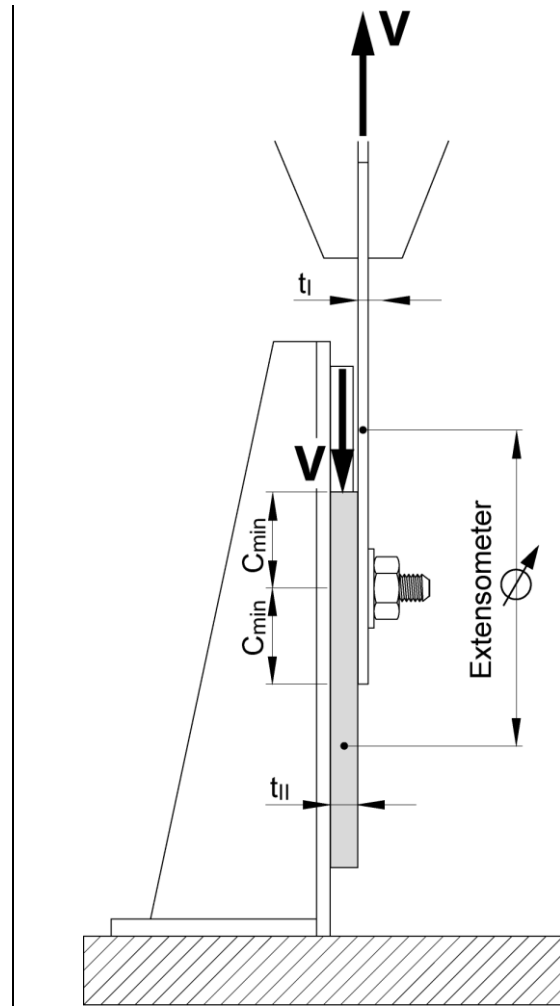


Figure A.4.2: Shear test with edge distance c_{min} in force direction

The fixed material can either be attached directly to the base material (Figure) or to the sealing washer of the threaded stud (Figure). If the specimen is attached directly to the base material, the load application into the threaded stud is via the washer. If the specimen is attached to the sealing washer of the threaded stud, the load application into the threaded stud is via the thread of the stud.

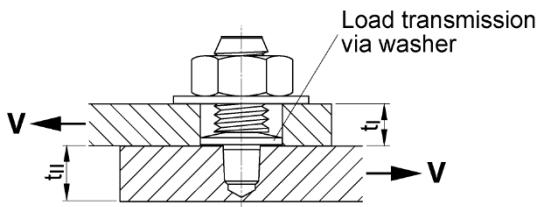


Figure A.4.3: Fixed material attached directly to the base material

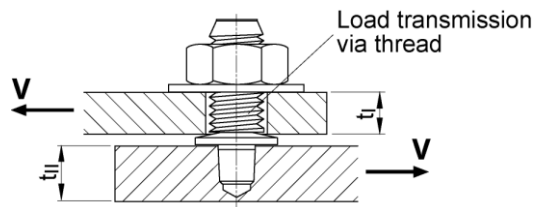


Figure A.4.4: Fixed material attached to the sealing washer

For shear load introduction via the washer (Figure), the minimum thickness t_I of the fixed material used in the tests amounts to 3 mm (thickness needs to exceed the thickness of the compressed washer). The maximum thickness t_I of the fixed material is 15 mm.

For shear load introduction via the thread of the stud (Figure), the fixed material (component I) shall have the maximum intended thickness.

The nut of the threaded stud shall be only hand tightened to avoid friction between component I and component II. Tests for determining the shear resistance values shall be performed with the edge distance c in force direction (Figure).

Tests for determining the shear resistance values at minimum edge distance shall be performed at minimum edge distance in force direction (Figure).

The test speed shall be adjusted in order to reach the ultimate force after at least 30 seconds. The shear tests shall be performed deformation-controlled with a maximum speed of 2 mm/min. The tests can also be run force-controlled.

During the test, the relative displacement between the fixed material (component I) and base material (component II) shall be measured. The recording of the piston displacement of the testing machine is not sufficient.

A.5 Shear resistance of groups of threaded stud connections

The test to determine the shear resistance of groups of threaded stud connections shall be carried out with specimens according to Figure .

Figure shows the example of a row-setup containing 4 threaded studs in a row. With that setup the following group patterns can be addressed per Figure :

- Row-Setup with 4 studs
- Rectangular-Plate-Setup with 4 studs

The purpose of the test is to investigate the effect of unavoidable different clearances of the various studs to the fixed material on the group resistance.

The test device allows to set different hole clearance per individual fastener.

The installation and test process is as follows:

- The studs are driven as accurately as possible in hand-held operation on their target position along the axis of the base material. The spacing between the studs shall be between 80 mm and 120 mm.
- Per stud a square piece (1) of steel plate is attached (side length 40 to 60 mm). The hole clearance shall be as small as possible. Nevertheless, the hole clearance shall be sufficiently high that the piece is in even contact with the base material and that the corresponding assembly is possible without constraints.
- Then the square pieces are moved manually in direction of the later applied test force, till they are in contact with the stud. In the example below, it is seen that all four pieces are in contact with the sealing washer of the respective stud.
- In that state the nuts (2) are applied and torqued with $T = 5 \text{ Nm}$ to avoid slipping of the square piece when the part is subsequently handled. Of special relevance is to ensure that contact at stud S1 remains intact. Therefore, the position of the square piece at stud S1 shall be marked relative to the base material.

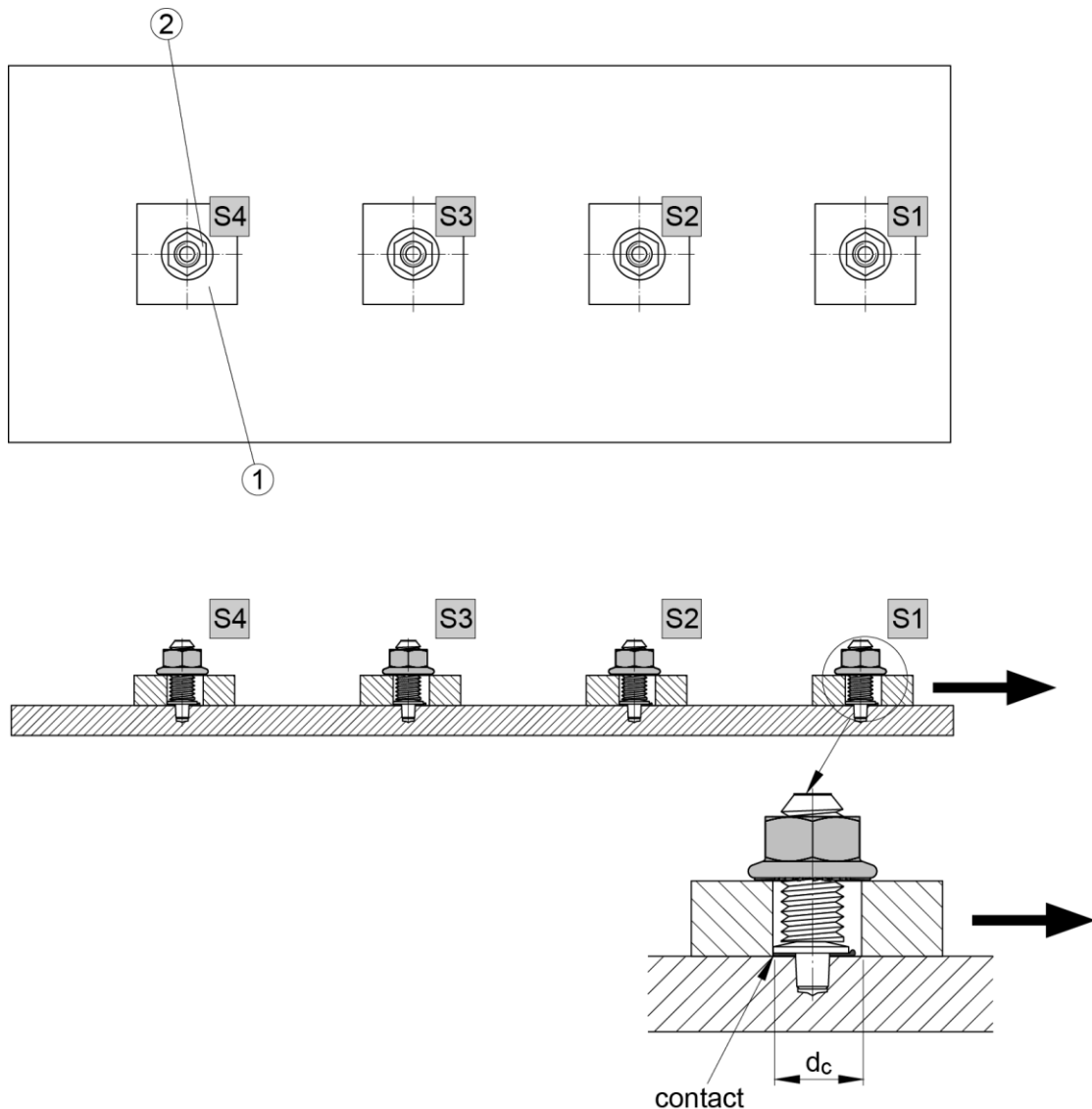


Figure A.5.1: Preparation of test plate: Positioning of square pieces ①

- Then the test plate is attached to the supporting bracket and the “hanger equipment” containing of threaded rods ③ and rectangular steel sections ⑤.
- Then the target hole clearance $h_{c1} = 0$, h_{c2} , h_{c3} and h_{c4} can be accurately set at the stud locations S1, S2, S3 and S4 by means of the double nut fixation ④ of the steel sections ⑤ with the threaded rods ③. First the tight contact at stud S1 is to be ensured.
- Subsequently, the uplift securing device ⑥ is to be attached. Pre-stressing of the hanger equipment shall be excluded, a slight gap between the securing device and the hanger equipment is acceptable.
- Subsequently, attachment of the extensometer allowing the displacement measurement of the hanger equipment relative to the base material.
- The test speed shall be adjusted in order to reach the ultimate force after 60 seconds. The shear tests shall be performed deformation-controlled with a maximum speed of 2 mm/min. The tests can also be run force-controlled.

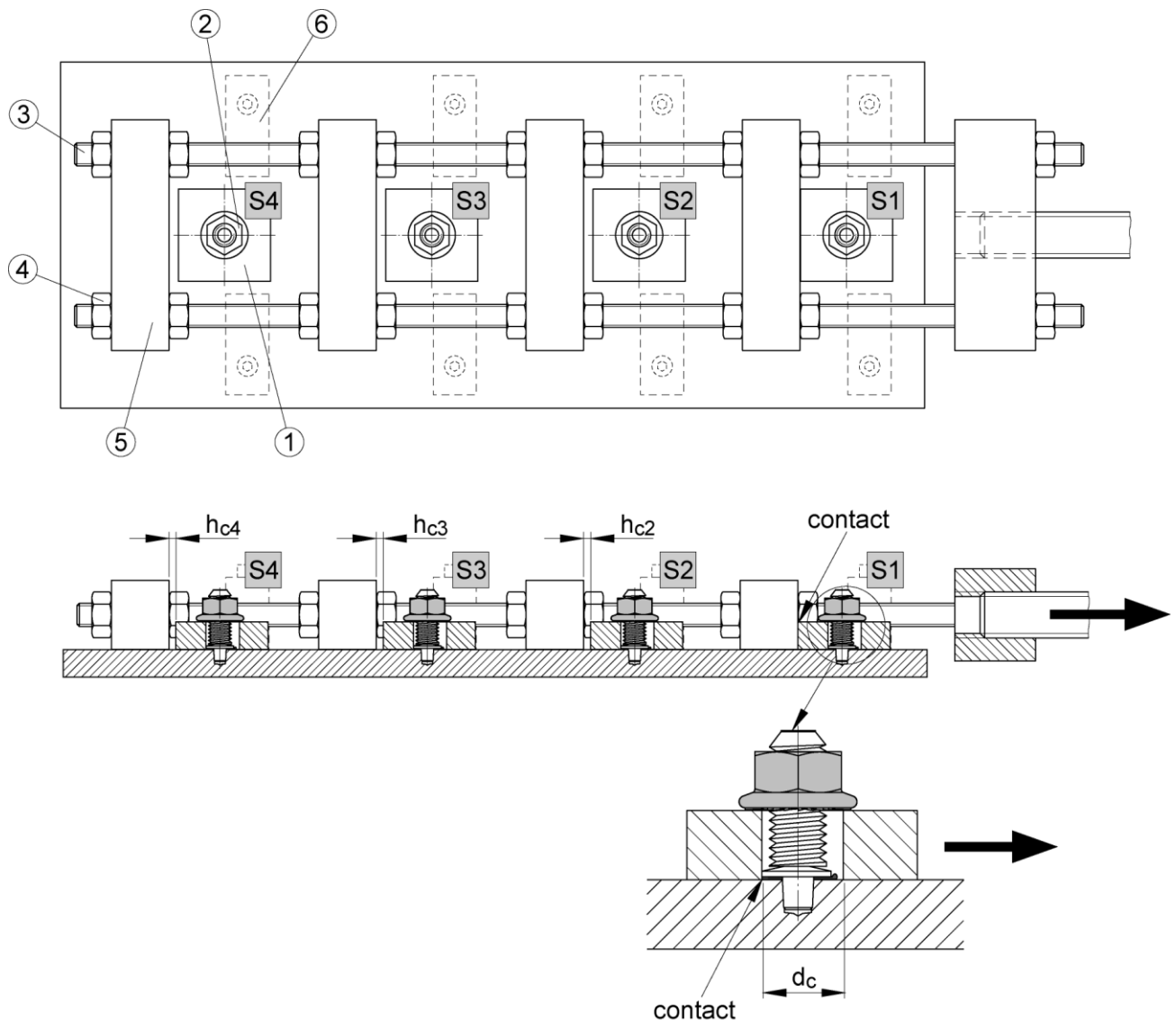


Figure A.5.2: Preparation of group test: Attachment of hanger equipment ③, ④, ⑤ and setting of hole clearances

The following parameters shall be included into the test checklist:

- Record hole clearance d_c of fixed square pieces ①
- Confirm contact of all square pieces with studs S1, S2, S3, S4
- Tighten all studs with a torque $T = 5 \text{ Nm}$
- Mark position of square pieces S1 relative to the base material
- Confirm contact at stud S1 ($h_{c1} = 0$),
- Record all actual clearances at stud S2, S3, S4
- Confirm that square piece at stud S1 remains in the correct position (visual check of mark) before the test starts and confirm contact at stud S1 ($h_{c1} = 0$)
- Confirm attachment of extensometer

The above “Row-Setup” can also be used to simulate a “Rectangular-Plate-Setup”. In that case the same fundamental procedure applies, with the exception that the clearance for 2 studs S1 and S2 equals zero ($h_{c1} = h_{c2} = 0$). The respective topics from the above checklist apply then for stud S1 and stud S2.

A.6 Bending test setup

The test to determine the bending resistance shall be carried out with specimens according to Figure or Figure .

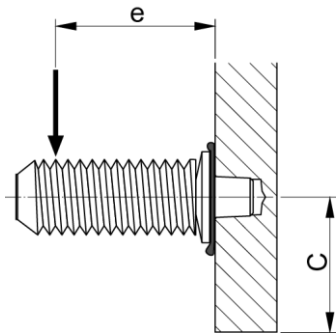


Figure A.6.1: Bending test with edge distance c in force direction

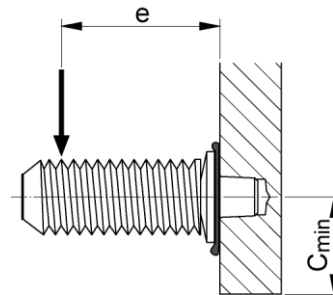


Figure A.6.2: Bending test with edge distance c_{min} in force direction

The lever arm "e" is the distance between base material surface and the push point and shall be defined according to the bolt length. However, it shall not be less than 10 mm.

During load application in compression direction it shall be ensured that the shear force always acts parallel to the base material, so that the lever arm remains constant and does not change during the entire load introduction.

In Figure examples of bending tests are shown. All 10 studs of a test series can be driven into one and the same steel base plate, which is then attached upright to angle brackets, which itself are connected to the base of the testing machine. The load application into the threaded stud can be achieved by using a piston rod, tapered at the tip or a metal plate forming a blade. Those load introductions aim to allow the free rotation of the threaded stud. Additionally, a smooth sleeve can be screwed on the stud (Figure).

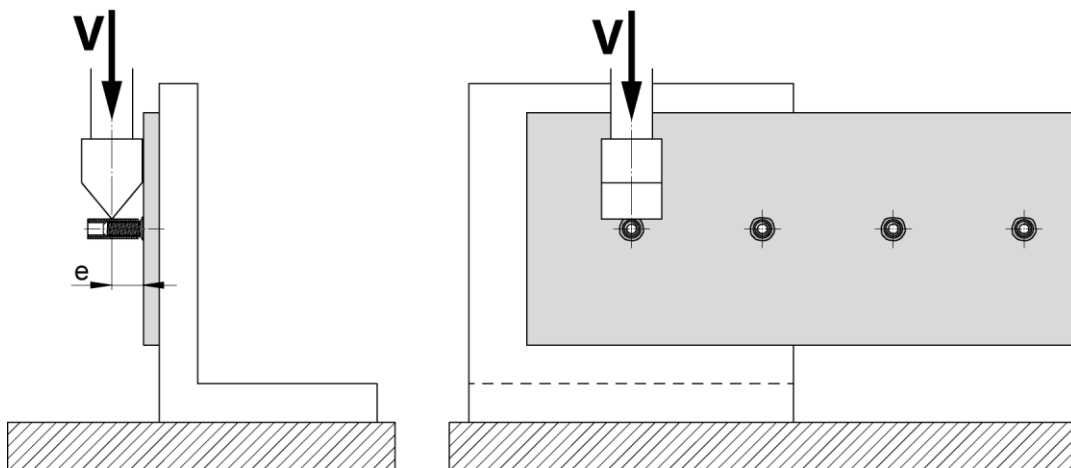


Figure A.6.3: Example of bending test set up

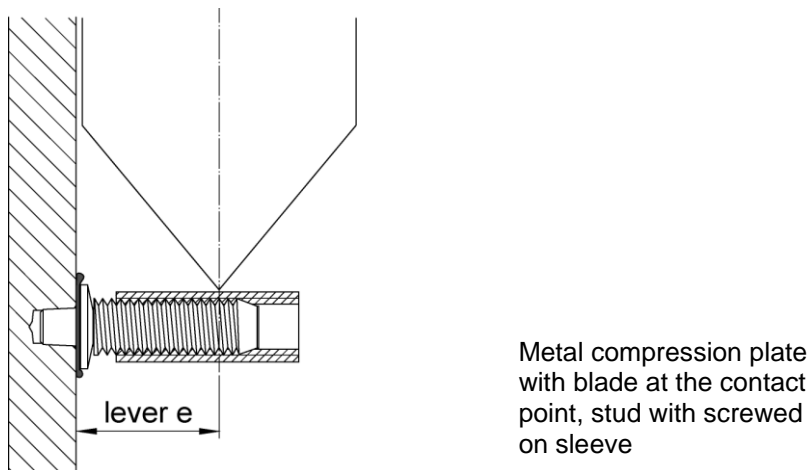


Figure A.6.4: Detail of compression point

The test speed shall be adjusted in order to reach the ultimate bending resistance after at least 30 seconds. The bending tests shall be performed deformation-controlled with a maximum speed of 2 mm/min.

Tests for determining the bending resistance values shall be performed with the edge distance c (Figure). Tests for determining the bending resistance values at minimum edge distance shall be performed at minimum edge distance c_{min} (Figure).

A.7 Resistance in case of combined loading (interaction)

Combined shear and tension tests (interaction tests) are suitable for determining the load-bearing behaviour of the threaded studs more precisely if the connection is subjected to combined shear and tension loading.

The test to determine the resistance of the threaded stud in case of combined loading (interaction) shall be carried out with specimens according to Figure . The nut of the threaded stud shall be only hand tightened to avoid friction between component I and component II. Special steel parts to be fixed by the threaded stud shall be machined for the interaction tests per investigated angle. Those parts need to allow the intended load introduction from the stud into the steel and they need to allow for the connection of the inclined resulting force, if the tests are executed in a universal testing machine. The base material together with the fixed special part are attached to a table, which can be positioned inclined in all investigated angles.

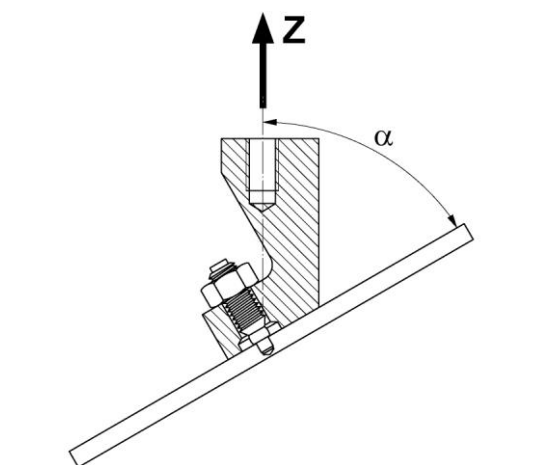


Figure A.7.1: Interaction test setup for shear-tension interaction

The force axis of the testing machine needs to intersect with the axis of the threaded stud at the surface of the base material.

Further execution of tests according to clause A.3.1.

A.8 Resistance to fire test

Figure shows an example of the test setup for the tension tests at elevated temperatures. The test specimen (Figure) is connected to the base support, preferable made of concrete. The specimen is encased within a heating chamber. The head of the stud is further connected with the tension ram by means of a threaded rod passing through the heating chamber. Rods and connecting grip devices shall be made from appropriate high temperature resistant material.

Figure shows an example of the base material test specimen. The stud is to be driven in the centre of the specimen. The width of the specimen is in the range of 50 mm, and the length is in the range of 150 mm. The plate needs to be held close to the stud in order to avoid excessive bending deformation of the plate itself.

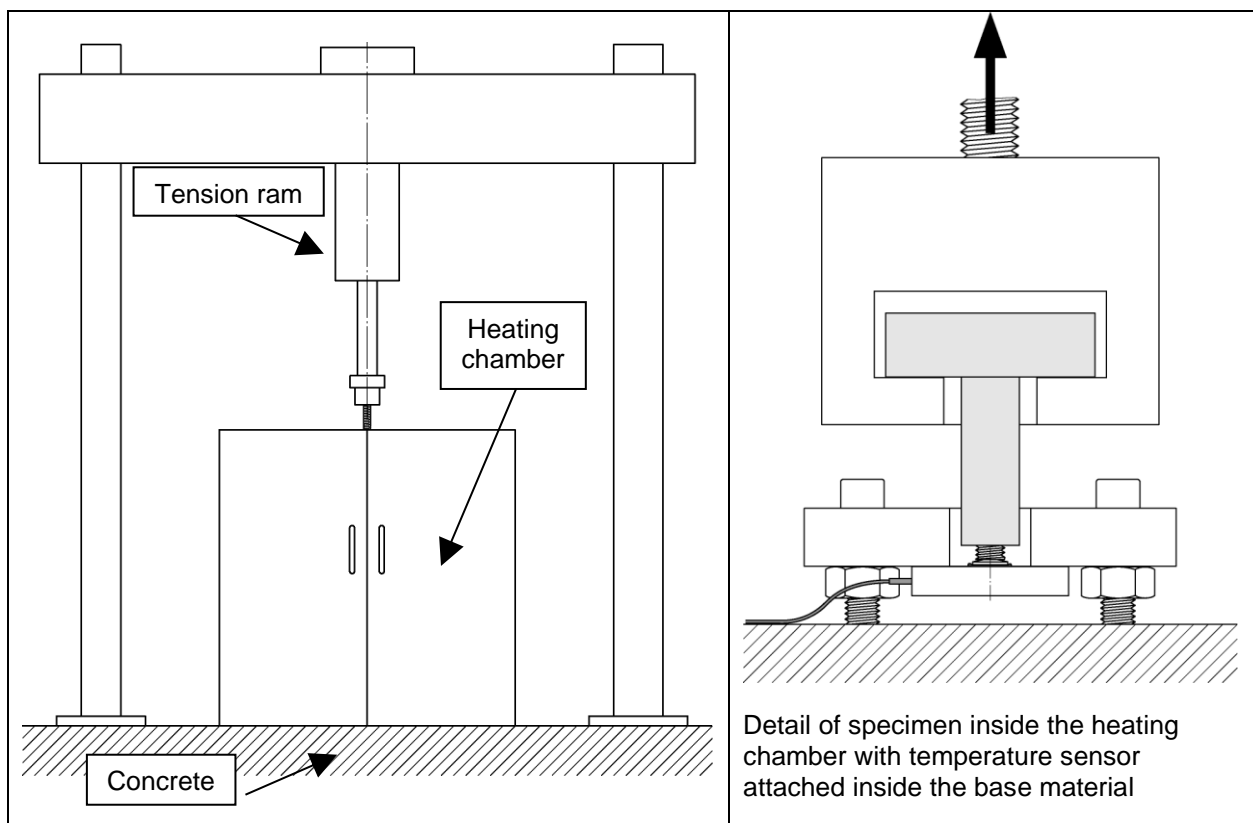


Figure A.8.1: Tension test at elevated temperature: Test setup and detail of specimen connection

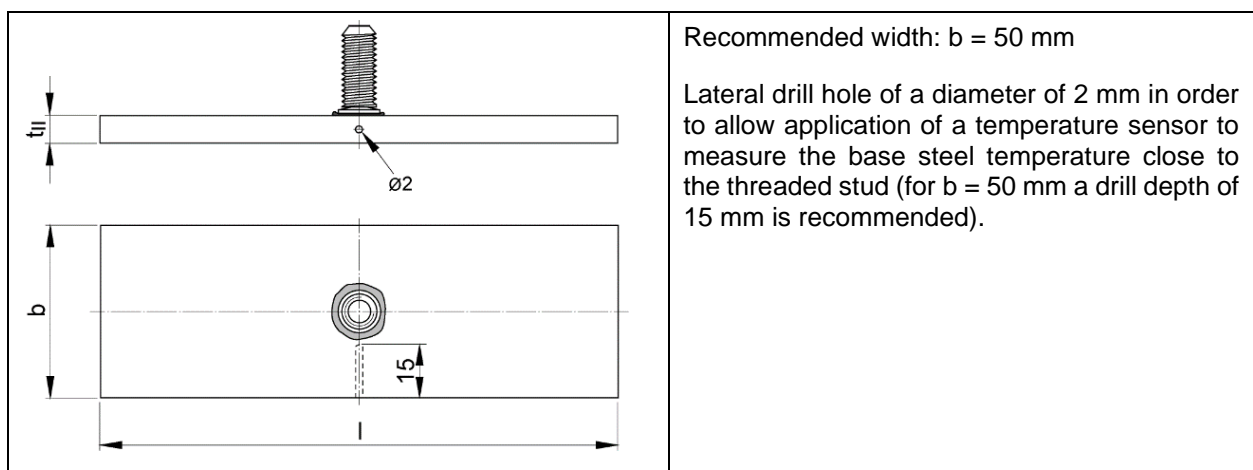


Figure A.8.2: Test specimen for tension tests at elevated temperatures

The heating chamber is heated up to the target temperature after fixation of the test specimen to the concrete and closing of the chamber. The tension test can be started, provided the base material has reached the target temperature. The temperature of the base material close to the stud shall be measured by means of an appropriate temperature sensor. Figure shows the required drill hole in the base material to allow application of a temperature sensor and Figure indicates the temperature sensor (black wire). The development of the temperature shall be recorded for each specimen.

The chamber shall remain closed till the tension test has been performed.

A.9 Base material constant amplitude fatigue tests

The tests to determine the effect of threaded stud fastenings on the fatigue strength of base material structural steel (component II) shall be carried out with coupons according to Figure . Two studs per specimen shall be driven in the centre line of the test specimen. For stress ratios $R < 0$ the spacing of the studs can be reduced from 100 to 50 mm in order to avoid buckling of the coupon.

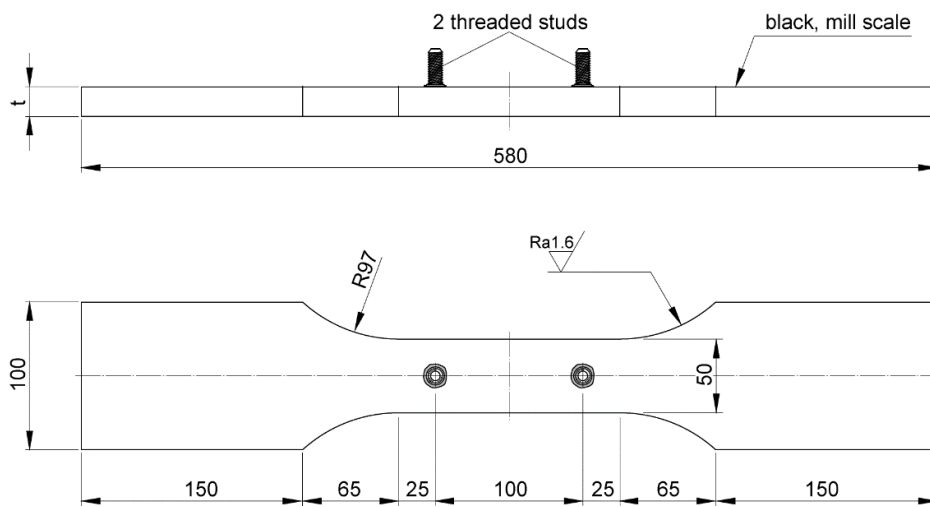


Figure A.9.1: Shape and dimension of flat-sheet test specimen

The fatigue tests are carried out using constant amplitude loading with sinusoidal wave form and a load-controlled simulation method (Figure). The frequency may vary dependent on the forces applied. Uncontrolled warming of the test specimens shall be excluded. Tests are carried out at ambient temperatures. The tests are carried out with a servo hydraulic test facility which is equipped with lateral operating clamping grips for upper and lower load introduction.

For definition of the cross-sectional area the specimen's width and thickness are to be measured at three locations (at the section of each stud as well as in the middle of the specimen). Width and thickness of the smallest section area shall be used for the test load calculation. The actual areas of each specimen shall be recorded.

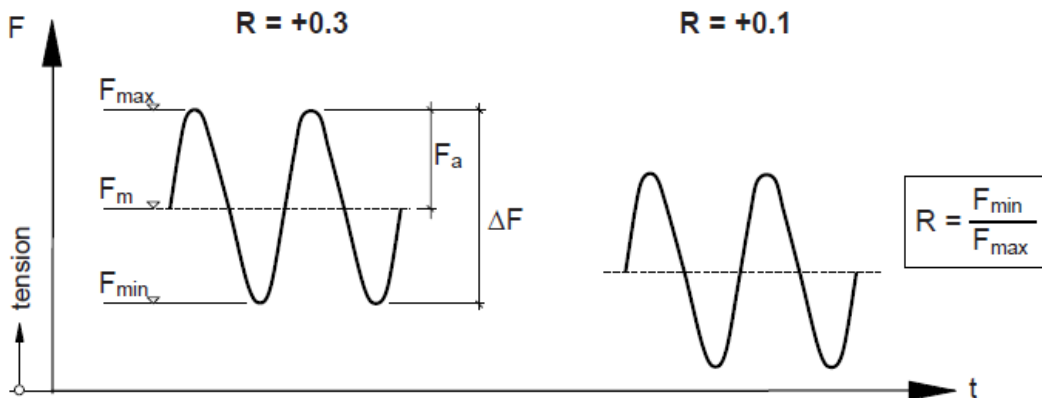


Figure A.9.2: Constant amplitude fatigue loading

The tests are to be run till fracture of the specimen. The respective number of cycles to failure are to be recorded. Furthermore, the fracture origins shall be identified per specimen and be recorded.

An example of a test facility for the fatigue tension tests is shown in Figure .

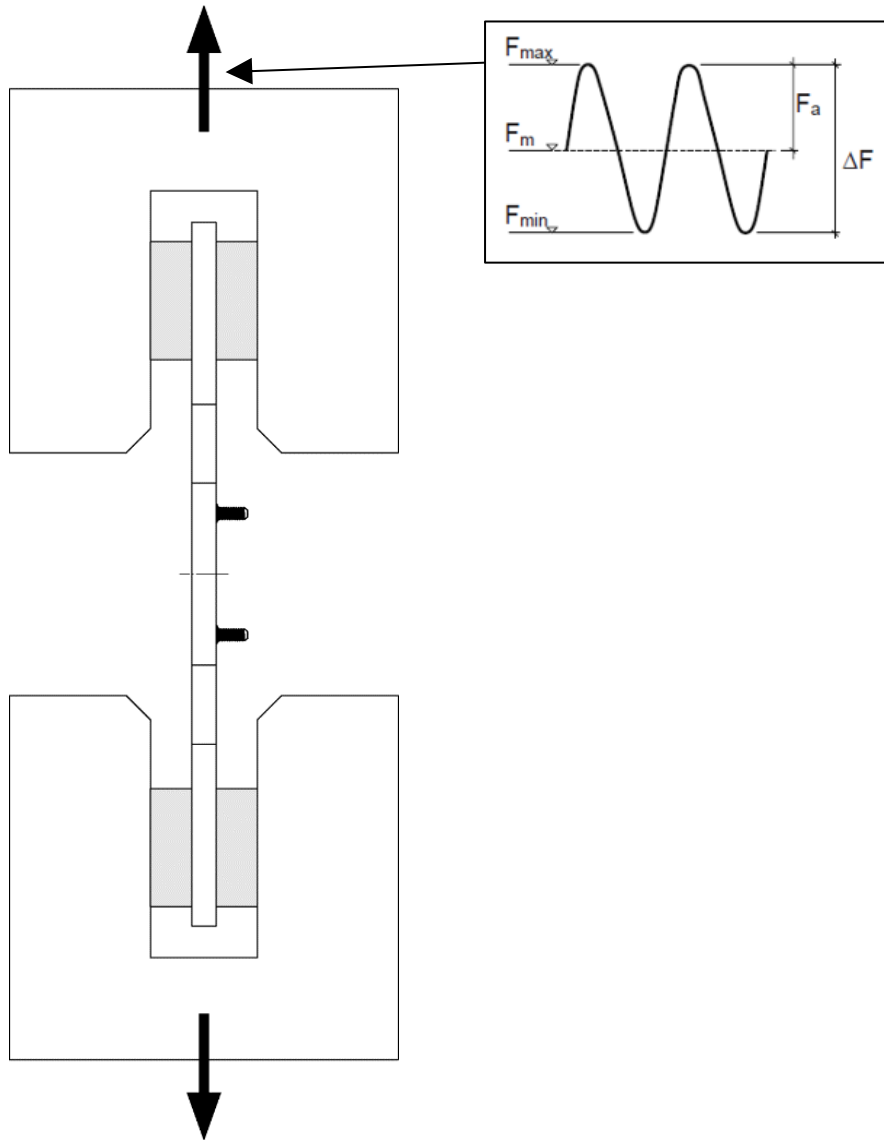


Figure A.9.3: Example of servo-hydraulic test facility, sketch of clamped tension coupon