INTERNATIONAL STANDARD

ISO 14555

First edition
1998-10-15

Welding — Arc stud welding of metallic materials

Soudage — Soudage à l'arc des goujons sur les matériaux métalliques

Reference number
ISO 14555:1998(E)

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

International Standard ISO 14555 was prepared by the European Committee for Standardization (CEN) in collaboration with ISO Technical Committee TC 44, *Welding and allied processes*, Subcommittee SC 10, *Unification requirements in the field of metal welding*, in accordance with the Agreement on technical cooperation between ISO and CEN (Vienna Agreement).

Throughout the text of this standard, read "...this European Standard..." to mean "...this International Standard...".

Annex A forms an integral part of this International Standard. Annexes B to G and ZA are for information only.

For the purposes of this International Standard, the CEN annex regarding fulfilment of European Council Directives has been removed.

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Foreword

The text of EN ISO 14555:1998 has been prepared by Technical Committee CEN/TC 121 "Welding", the secretariat of which is held by DS, in collaboration with Technical Committee ISO/TC 44 "Welding and allied processes".

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by April 1999, and conflicting national standards shall be withdrawn at the latest by April 1999.

This European Standard has been prepared under a mandate given to CEN by the European Commission and the European Free Trade Association, and supports essential requirements of EU Directive(s).

According to the CEN/CENELEC Internal Regulations, the national standards organizations of the following countries are bound to implement this European Standard: Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and the United Kingdom.

Introduction

The purpose of arc stud welding is to weld predominantly pin-shaped metal parts to metal workpieces. In this standard it is only referred as stud welding. Stud welding is used among other things e.g. in bridge building (especially in composite structures), steel structures, shipbuilding, facade-wall fabrication, vehicle manufacture, equipment design, steam-boiler construction, and the manufacture of household appliance.

In stud welding, an arc ist briefly struck between the face of the stud and the workpiece; both parts start to melt and are then joined. Depending on the nature of the welding method, a distinction is made between drawn-arc stud welding and stud welding with tip ignition. Each method needs suitable power supplies, actuating devices, studs and accessories (e.g. ceramic ferrules). A feature of stud welding is the very short arc burn time (approximately 0,5 ms to 3,0 s) and the associated high rate of heating and cooling. Normally the diameter of the stud ranges are up to 8 mm for tip ignition welding and up to 25 mm for drawn-arc welding.

The quality of a stud weld depends not only on strict compliance with the welding procedure specification but also on the correct function of the actuating mechanism (e.g. welding guns), on the condition of the components, of the accessories and of the power supply.

1 Scope

This standard covers arc stud welding of metallic materials subject to static and dynamic loading. It specifies requirements particular to stud welding related to welding knowledge, quality requirements welding, procedure specification, welding procedure approval, approval testing of welders and testing of production welds.

This standard is appropriate where a contract between the parties concerned, an application standard or regulatory requirements (hereafter designated "contract", see EN 729-1) requires the demonstration of a manufacturers capability to produce welded construction of a specified quality.

It has been prepared in a comprehensive manner to be used as a reference in contracts. The requirements given can be adopted in full or some can be deleted, if not relevant to the construction concerned (see Annex A).

2 Normative references

This European Standard incorporates by dated or undated reference, provisions from other publications. These normative references are cited at the appropriate places in the text and the publications are listed hereafter. For dated references, subsequent amendments to or revisions of any of these publications apply to this European Standard only when incorporated in it by amendment or revision. For undated references the latest edition of the publication referred to applies.

EN 287-1
Approval testing of welders – Fusion welding – Part 1: Steels

EN 287-2
Approval testing of welders – Fusion welding – Part 2: Aluminium and aluminium alloys

EN 288-1 : 1992
Specification and approval of welding procedures for metallic materials – Part 1: General rules for fusion welding

EN 288-3
Specification and approval of welding procedures for metallic materials – Part 3: Welding procedure tests for arc welding of steels

EN 288-4
Specification and approval of welding procedures for metallic materials – Part 4: Welding procedure tests for arc welding of aluminium and its alloys

EN 288-6
Specification and approval of welding procedures for metallic materials – Part 6: Approval related to previous experience

EN 288-8
Specification and approval of welding procedures for metallic materials – Part 8: Approval by a pre-production welding test

EN 439
Welding consumables – Shielding gas for arc welding and cutting

EN 573-3
Aluminium and aluminium alloys – Chemical composition and form of wrought products – Part 3: Chemical composition

EN 719
Welding coordination – Tasks and responsibilities

EN 729-1
Quality requirements for welding – Fusion welding of metallic materials – Part 1: Guidelines for selection and use

EN 729-2
Quality requirements for welding – Fusion welding of metallic materials – Part 2: Comprehensive quality requirements

EN 729-3
Quality requirements for welding – Fusion welding of metallic materials – Part 3: Standard quality requirements

EN 729-4
Quality requirements for welding – Fusion welding of metallic materials – Part 4: Elementary quality requirements

EN 1418 : 1997
Welding personnel – Approval testing of welding personel for fully mechanized and automatic welding of metallic materials

EN 1435
Non destructive examination of welds – Radiographic examination of welded joints

EN 10025+A1
Hot rolled products of non-alloy structural steels – Technical delivery conditions (includes amendment A1:1993)

EN 10028-2
Flat products made of steels for pressure purposes – Part 2: Non-alloy and alloy steels with specified elevated temperature properties

EN 10088-1
Stainless steels – Part 1: List of stainless steels

EN 10204
Metallic products – Types of inspection documents

EN 20898-1
Mechanical properties of fasteners – Part 1: Bolts, screws and studs (ISO 898-1:1988)

EN 24063
Welding, brazing, soldering and braze welding of metals – Nomenclature of processes and reference numbers for symbolic representation on drawings (ISO 4063:1990)

EN 60974-1
Safety requirements for arc welding equipment – Part 1: Welding power sources (IEC 974-1:1989, modified)

EN ISO 6947
Welds – Working positions – Definitions of angles of slope and rotation (ISO 6947:1993)

EN ISO 13918
Welding – Studs and ceramic ferrules for arc stud welding

ISO 426-1
Wrought copper-zinc alloys – Chemical composition and forms of wrought products – Part 1: Non-leaded and special copper-zinc alloys

ISO/DIS 857
Welding and allied processes – Welding, brazing and soldering processes – Vocabulary

ISO 5828
Resistance welding equipment – Secondary connecting cables with terminals connected to water-cooled lugs – Dimensions and characteristics

3 Definitions, symbols and abbreviations

3.1 Definitions

For the purposes of this standard, the definitions given in ISO/DIS 857, in accordance with EN 719, EN 729-1, EN 1418 and EN 288-1 and the following definitions are applicable for stud welding:

3.1.1 Welding consumables: In the meaning of this standard studs, pins and other parts to be attached by stud welding are defined as welding consumables.

3.1.2 Auxiliaries: Ceramic ferrules and shielding gases.

3.1.3 Stud welding operator: Operating personnel for stud-welding equipment, who are familiar with the conditions for stud welding. They have the knowledge to operate the equipment, to adjust the equipment properly, to carry out the welding correctly and while doing so to pay attention to good contact, symmetrical connection of the workpiece cables and uniform distribution of ferromagnetic materials. In special cases (e.g. mass production at the manufacturer's factory) the welding can be carried out by suitable auxiliary personnel, appropriately trained and supervised.

3.1.4 Stud diameter: In the drawn arc stud welding with ceramic ferrule or shielding gas, diameter means the diameter at the weld base. In all other stud welding methods, diameter means the diameter above the flange.

3.1.5 Current intensity: Mean value of the welding current in the steady state during the burning time of the arc (not applicable to capacitor discharge).

3.1.6 Welding time: Time difference between the ignition and the final extinction of the main arc.

3.1.7 Lift (L in figure 2): Distance between the stud tip and the workpiece surface with the stud-lifting mechanism in position and activated. For tip ingnition, this definition applies to the ignition gap.

3.1.8 Plunge: Axial movement of the stud towards the surface of the workpiece.

3.1.9 Protrusion (P in figure 2): With unregulated, i.e. spring-loaded, lifting mechanisms, the protrusion is the distance between the tip of the stud and the face of the support device in their initial position where it faces the workpiece.

3.1.10 Arc blow: Magnetic deflection of the arc from the axial direction of the stud.

3.1.11 Flux: Aluminium slug or spray on the weld end of the stud. When melted by the arc, it cleans and de-oxidises the parent metal surface.

3.2 Symbols

For the purposes of this standard, the following symbols apply:

- C (in millifarad) capacitance;
- d (in millimetres) stud diameter;
- I (in ampere) current intensity;
- t_w (in milliseconds or seconds) welding time;
- U (in volt) charging voltage;
- W (in wattseconds) loading power.

3.3 Abbreviations

For the purposes of this standard, the following abbreviations apply:

- CF ceramic ferrule;
- DS drawn-arc stud welding;
- HAZ heat-affected zone;
- L lift;
- NP no protection;
- P protrusion;
- PA flat position;
- PC horizontal position;
- PE overhead position;
- SG shielding gas;
- TS stud welding with tip ignition;
- WPS welding procedure specification;
- WPAR welding procedure approval record;
- pWPS preliminary welding procedure specification.

4 Welding knowledge

4.1 General

This chapter gives general guidance for the satisfactory production and control of stud welding.

4.2 Processes

4.2.1 Drawn arc stud welding (DS)

4.2.1.1 General

This can be done mechanically or automatically, using welding guns or welding heads. The work phases of drawn arc stud welding are illustrated in figure 1. The stud is inserted into the stud holder and - fitted with a ceramic ferrule, if necessary - applied to the workpiece (see figure 1a)). At the beginning of the welding process the stud is lifted by the mechanism and generally first a pilot arc, then the main arc, are struck between the tip of the stud and the workpiece (see figure 1b)). This causes the face of the stud and the parent metal to melt. When the welding time has elapsed, the stud is plunged with limited force (< 100 N) into the molten pool, and the current source is switched off (see figure 1c)). The ceramic ferrule is then removed (see figure 1d)). Figure 2 shows the sequence of events using a ceramic ferrule.

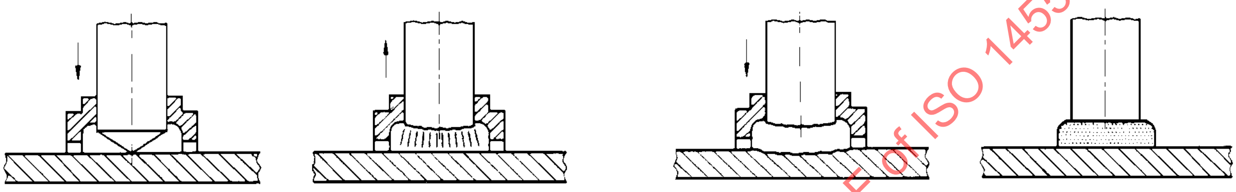


Figure 1a): Application of the stud

Figure 1b): Lift and arc ignition

Figure 1c): Plunge

Figure 1d): Welded stud

Figure 1: Drawn arc stud welding, sequence of operations

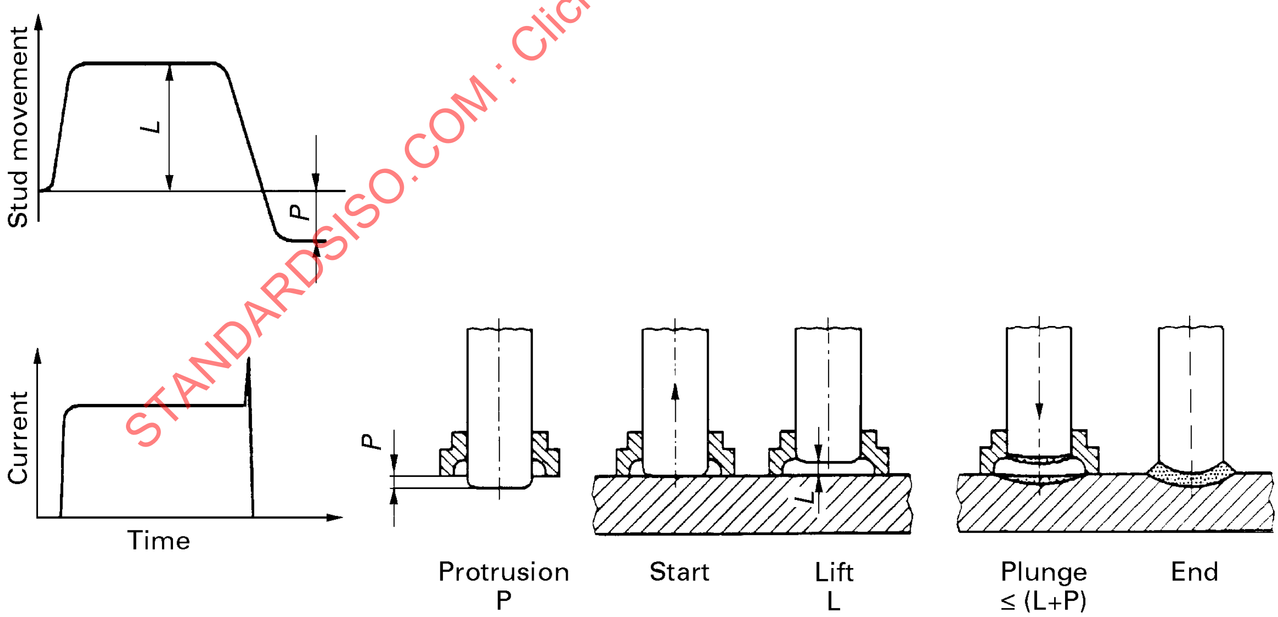


Figure 2: Stud movement in drawn arc stud welding

Stud welding equipment is available for different ranges of work, with different welding times and different forms of shielding of the arc and the weld pool.

4.2.1.2 Methods

A distinction is made between three processes (see table 1):

– drawn arc stud welding with ceramic ferrule or shielding gas (see 4.2.1.2 a));

– short-cycle drawn arc stud welding (see 4.2.1.2 b));

– capacitor discharge drawn arc stud welding (see 4.2.1.2 c)).

Table 1: Working range of the various drawn arc stud welding processes

Processes	Welding time, t_w ms	Stud diameter, d mm	Current intensity, I A	Weld pool protection	Minimum sheet
drawn arc stud welding with ceramic ferrule or shielding gas	> 100	3 to 25	300 to 3000	CF	1/4 d, but not less than 1 mm[1)]
	> 100	3 to 16	300 to 3000	SG	1/8 d, but not less than 1 mm
short-cycle drawn arc stud welding	≤ 100	3 to 12	up to 1500	NP, SG, (CF)	1/8 d, but not less than 0,6 mm
capacitor discharge drawn arc stud welding	< 10	3 to 10	up to 3000 (peak)	NP, (SG)	1/10 d, but not less than 0,5 mm

1) The minimum sheet thickness avoids burn through. Other application requirements can call for bigger thickness.

When the short-cycle process – high-power process (narrow melt zone) – or the capacitor discharge process is used, the stud tips shall be matched to the fusion penetration shape in the workpiece, and be made flatter (e.g. 166° cone angle).

a) Drawn arc stud welding with ceramic ferrule or shielding gas

This process is generally used in the 3 mm to 25 mm diameter range, with welding times of 100 ms to 3000 ms. It is usually carried out with a ceramic ferrule and in special cases only with shielding gas or without pool protection. This method is used for the majority of applications. The minimum sheet thickness is 1/4 for CF and for SG 1/8 of stud diameter, but not less than 1 mm.

b) Short-cycle drawn arc stud welding

With special equipment a short welding time of ≤ 100 ms, can be achieved. This variant is suitable for studs up to 12 mm diameter, but for about 8 mm up to 12 mm diameter shielding gas should be used to prevent increased pore formation. The fusion zone is narrow and the thermal input modest, so that studs up to 12 mm diameter can be welded to thin sheets. At 10 mm to 12 mm stud diameter a ceramic ferrule enhances the formation of the weld collar. Up to 8 mm diameter the operation is frequently carried out without protection of the weld pool and calls for studs with an upset flange as these afford a larger weld area than the plain stud-shaft diameter and thus reach a higher tensile force than the stud shaft, despite pores in the weld zone. The minimum sheet thickness is 1/8 d, but not less than 0,6 mm.

c) Capacitor discharge drawn arc stud welding

Very short welding time (< 10 ms) can be achieved by using a capacitor discharge power source. The range of diameter is 3 mm to 10 mm. The minimum sheet thickness is 1/10 d, but not less than 0,5 mm. The process is similar to the short-cycle drawn arc stud welding process, but the peak current can be up to 3000 A.

4.2.1.3 Weld pool protection

A distinction is made between different techniques, on the basis of weld pool protection:

– ceramic ferrule (CF), (see 4.2.1.3 a));
– shielding gas (SG), (see 4.2.1.3 b));
– no protection (NP), (see 4.2.1.3 c)).

a) Ceramic ferrule (CF)

The ceramic ferrule forms a combustion chamber around the weld location, shielding the welder from both arc and spatter. It concentrates the arc in a small region and reduces heat loss and cooling rate. The atmosphere is only slightly held off by the ceramic ferrule. When the stud is plunged into the weld pool, it forces molten metal out sideways to form an annular weld collar around the stud. Welding can thus be carried out in any position. The ceramic ferrule is used for one weld only and is removed once the molten metal has solidified.

b) Shielding gas (SG)

In stud welding with shielding gas the atmosphere is displaced from the arc region by a shielding gas supplied from outside, this greatly reduces the formation of pores. Steels and most other metals a mixture of 82 % argon and 18 % carbon dioxide (EN 439-M21) is used. For aluminium and its alloys pure argon Ar 99,99 (EN 439-I1) is required.

The shielding gas influences the arc and affects the fusion of the stud and workpiece and also, via the surface tension, influences the shaping of the weld collar and the penetration shape. It is fundamental principle that the welding position PA according to EN ISO 6947 should be preferred. An additional ceramic ferrrule can also be used to improve the shape of the collar and restrict the arc to the immediate area of the workpiece.

c) No protection (NP)

Stud welding without protection is possible only for small stud diameters (less than 10 mm) and with short welding times (less than 100 ms). Among the drawbacks of this method are severe oxidation of the weld zone, increased pore formation and an irregular weld bead.

4.2.2 Capacitor discharge stud welding with tip ignition (TS)

There are two techniques for capacitor discharge stud welding with tip ignition:

– with contact;
– with gap.

In welding with contact, the stud is inserted into the stud holder of the machine (see figure 3a)) and positioned with its ignition tip directly on the surface of the component (see figure 3b)). A spring in the welding gun presses the stud against the metal. Once the capacitor power has been switched on, the ignition tip vaporized and the arc struck (see figure 3c)) the stud is advanced still further towards the sheet metal and finally remains in the solidified melt (see figure 3d)). The welding time is ≤ 3 ms.

The difference between welding with gap and the technique described above is that, before welding begins, the stud is held at a defined, adjustable distance from the workpiece (see figure 3a)).

When the capacitor bank is switched on, the stud is speeded up towards the surface of the metal, and the process continues as described above (see figures 3b), 3c), 3d)). A welding time of about 1 ms makes it possible, among other things, to weld aluminium and its alloys without gas shielding.

The recommended sheet thickness should be ≥ 1/10 d but not less than 0,5 mm.

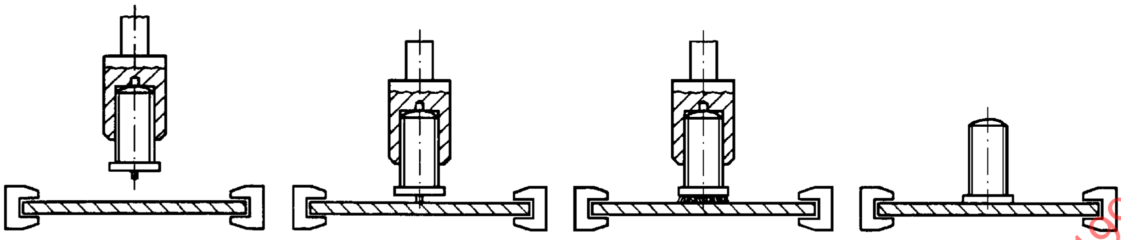


Figure 3a) Figure 3b) Figure 3c) Figure 3d)

Figure 3: Capacitor discharge stud welding with tip ignition - Main phases of the welding process

4.3 Parent metals

4.3.1 General

The brief arc effect initiates melting of both stud and parent metal and the molten pools intermix as the joint is formed, the properties of the heat-affected zone are modified also. This phenomenon differs in the various stud-welding processes. Generally speaking, more stud material melts than parent metal. Usually the weld area on the parent metal is larger than the cross-section of the stud. The strength and deformation properties at the transition from weld to stud shall therefore be investigated with special attention. In the case of steel, particular attention shall be paid to embrittlement due to hardening.

The surface of the parent metal shall be clean. Layers of paint, rust, scale, grease and coatings of non-weldable metals should be removed from the weld location. This can be done mechanically or chemically. Parent metals with scale and rust layers shall be thoroughly ground off. The surface preparation shall be specified in the WPS. Where welding times are short (less than 50 ms), the surface shall be cleaned with particular care.

Table 2: Weldability of typical combinations of stud and parent metals for drawn arc stud welding with ceramical ferrule or shielding gas and short-cycle drawn arc stud welding

Stud material	Parent metal			
	EN 288-3/ groups 1 and 2[3)]	EN 288-3/ groups 4 and 5	EN 288-3/ group 9	EN 288-4/ groups 21 and 22.1
S235 4.8 (weldable) 16Mo3	a	b	b[2)]	–
X10CrAl18 X10CrAl24 X20CrNiSi25-4	c	c	c	–
1.4301 1.4303 1.4401 1.4541 1.4571	b/a[1)]	b	a	–
EN AW-AlMg3 EN AW-AlMg5	–	–	–	b

1) Up to 10 mm in diameter and shielding gas in position PA.
2) Only for short-cycle drawn arc stud welding.
3) Maximum yield strength $R_{eH} \leq 460$ N/mm^2.

Key to weldability numbers:
- –: not weldable
- a: Highly weldable for any application, e.g. for force transfer.
- b: Weldable within limits for force transfer.
- c: Weldable within limits only for heat transfer.

Table 3: Weldability of typical combinations of stud and parent metals for capacitor discharge stud welding with tip ignition and for capacitor discharge drawn arc stud welding

Stud material	Parent metal				
	EN 288-3/ groups 1,2,3,4 and carbon steel up to 0,30 % C-content	EN 288-3/ groups 1,2,3,4 and galvanized and metal coated steel sheet, max. thick-ness 25 µm of coating	EN 288-3/ group 9	Copper and lead free copper alloys, e.g. CuZn37	EN 288-4/ groups 21 and 22.1
S235	a	b	a	b	–
1.4301 1.4303	a	b	a	b	–
CuZn37	b	b	b	a	–
EN AW-Al99,5	–	–	–	–	b
EN AW-AlMg3	–	–	–	–	a
Key to weldability numbers: –: not weldable a: Highly weldable for any application, e.g. for force transfer. b: Weldable within limits for force transfer.					

4.3.2 Parent metal for drawn arc stud welding with ceramic ferrule or shielding gas and short-cycle drawn arc stud welding

Parent metal for this type of stud welding are those in table 2. For parent metals according to EN 288-3 group 2 steels with a maximum yield strength of 460 N/mm^2 and according to EN 288-3 group 9 steels excluding those which are sensitive to hot cracking, should be used.

Surfaces to be welded shall be maintained dry and free from condensation. When temperatures are below 5 °C, a suitable preheating can be necessary. For reasons of weldability the carbon content of the steels should be $\leq$ 0,2 %.

Contracts and application standards can also permit the use other steel grades and other metals such as lead free brass for drawn arc stud welding. In such cases additional or other tests as described in clause 7 can be required.

4.3.3 Parent metal for capacitor discharge drawn arc stud welding and capacitor discharge stud welding with tip ignition

Parent metals for this type of stud welding are those in table 3.

Contracts and application standards can also permit the use of other materials. In such cases additional or other tests as described in clause 7 can be required.

4.4 Studs

4.4.1 Stud material for drawn arc stud welding with ceramic ferrule or shielding gas and short-cycle drawn arc stud welding

The stud materials are listed in table 4 shall be weldable.

Non-alloyed steel studs are weldable, if the hardness increase is low. In general this is the case when the C-content is ≤ 0,18 %. Free-cutting steel studs are generally not suitable.

Table 4: Stud materials for drawn arc stud welding with ceramic ferrule or shielding gas and short-cycle drawn arc stud welding

Standard	Grade	Method of deoxidation
EN 10025	S235[1)]	FF
EN 10025	S235 + C450[1)]	FF
EN 10028-2	16Mo3	–
EN 20898-1	4.8 (weldable)	FN at least
	X10CrAl18 X10CrAl24 X20CrNiSi25-4	–
EN 10088-1	1.4301 1.4303 1.4401 1.4541 1.4571	–
ISO 426-1	CuZn37	–
EN 573-3	EN AW-AlMg3 EN AW-AlMg5	–
1) The impact test shall not be carried out on cold formed material.		

4.4.2 Stud materials for capacitor discharge drawn arc stud welding and capacitor discharge stud welding with tip ignition

The stud materials are listed in table 5 shall be weldable.

Table 5: Stud materials for capacitor discharge drawn arc stud welding and capacitor discharge stud welding with tip ignition

Standard	Grade
EN 20898-1	4.8 (weldable)
EN 10088-1	1.4301 1.4303
ISO 426-1	CuZn37 (lead free)
EN 573-3	EN AW-AlMg3 EN AW-Al99,5

4.4.3 Stud shapes

The shape of the stud tip differs for the various processes and materials. Stud shapes, dimensions, materials and ceramic ferrules shall be according to EN ISO 13918.

4.5 Combinations of stud and parent metal

The weldability of the various metals and the recommended combinations of stud and parent metal depends on the method of stud welding. The combinations are shown in table 2 and table 3:

– combinations for drawn arc stud welding with ceramic ferrule or shielding gas and short-cycle drawn arc stud welding (see table 2);

– combinations for capacitor discharge stud welding with tip ignition and for capacitor discharge drawn arc stud welding (see table 3).

Other combinations can be weldable but the weldability shall be assured by extensive procedure testing.

4.6 Auxiliaries

Depending on the process, ceramic ferrules and/or shielding gases are used for protection or to concentrate the arc. The ceramic ferrules shall be correctly chosen for the stud diameter and the type of the stud. Note the following points:

– the ceramic ferrule shall be pressed against the parent metal;

– the ceramic ferrule shall fit centrally with respect to the stud. Tilting or uneven contact of the ceramic ferrule at the stud leads to an uneven collar and can inhibit plunging;

– the ceramic ferrules shall be stored in a dry place;

– in the case of hydrogen influence cracking the ceramic ferrules shall be dried at elevated temperatures (1 h above 900 °C).

In special cases (drawn-arc stud welding of aluminium and its alloys or CrNi steels) it can be necessary to use shielding gases. The gas is fed to a device that shall ensure uniform gas shielding without turbulence. Note also the following points:

– the gas feed should be sealed off on the stud side;

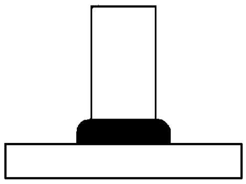
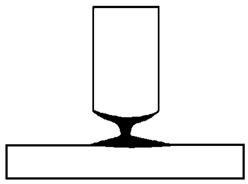
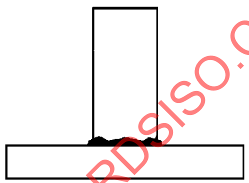
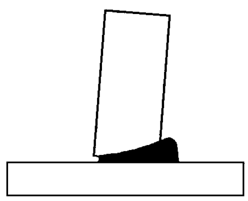
– the gas shall displace the atmosphere before welding starts, so a defined pre-flow time shall therefore be observed;

– in the case of aluminium, exceptionally careful gas shielding is essential.

4.7 Imperfections and corrective actions

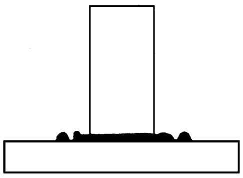
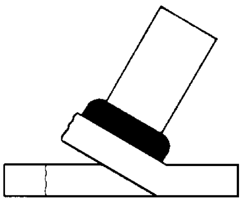
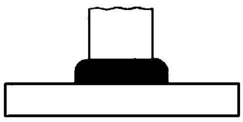
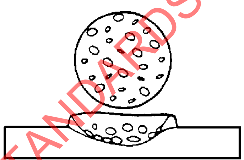
The imperfections and corrective actions are shown in tables 6 to 9.

Table 6: Imperfections and corrective actions for drawn arc stud welding with ceramic ferrule or shielding gas

Visual examination			
No.	**General appearance**	**Probable cause**	**Corrective actions**
1	Collar regular, bright and complete. Lengths after weld within tolerances. 	– Correct parameters.	– none
2	Reduced diameter weld. Length too long. 	– Insufficient plunge or lift. – Welding power too high.	– Increase plunge, check centring of ferrule, check lift. – Reduce current and/or time.
3	Reduced, irregular and greyish collar. Length too long. 	– Weld power too low. – Ceramic ferrule is moist.	– Increase current and/or time. – Dry out ferrules in oven.
4	Collar off centre. Undercut 	– Effect of arc blow. – Ceramic ferrule incorrectly centred.	– See table 9. – Check centring.

(continued)

Table 6 (continued)

No.	General appearance	Probable cause	Corrective actions
5	Collar height reduced, bright, with large lateral projections. Length after weld too short. 	– Weld power too high. – Plunge rate too high.	– Reduce current and/or time. – Adjust plunge and/or gun damper.
	Fracture examination		
No.	**Appearance of fracture**	**Probable cause**	**Corrective actions**
6	Tearing of parent metal. 	– Correct parameters.	– none
7	Fracture above collar after sufficient deformation. 	– Correct parameters.	– none
8	Tearing within the weld. High porosity. 	– Weld power too low. – Metal not suitable for stud welding.	– Increase current and/or time. – Check chemical composition.

(continued)

Table 6 (concluded)

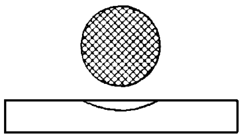
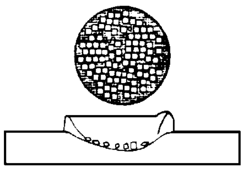
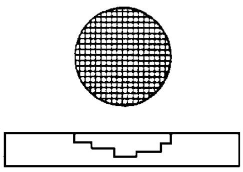
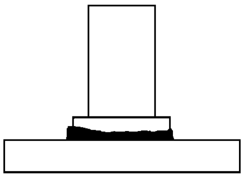
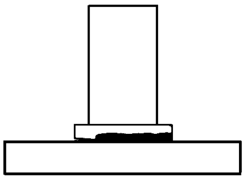
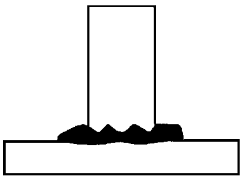
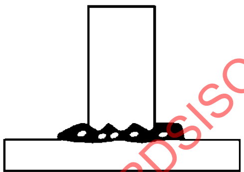
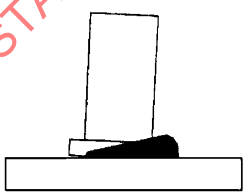
No.	Appearance of fracture	Probable cause	Corrective actions
9	Fracture in HAZ. Greyish fracture surface without sufficient deformation. 	– Carbon content of parent metal too high. – Parent metal not suitable.	– Check parent metal. – Increase weld time. – Preheating can be necessary.
10	Fracture of weld. Bright appearance. 	– Flux content is too high. – Weld time too low.	– Check flux quantity. – Increase weld time.
11	Lamellar tearing of parent metal. 	– Non metallic inclusions in parent metal. – Parent metal not suitable.	

Table 7: Imperfections and corrective actions for short-cycle drawn arc stud welding

Visual examination			
No.	**General appearance**	**Probable cause**	**Corrective actions**
1	Regular collar, no visual defects. 	– Correct parameters.	– none
2	Partial weld. 	– Weld power too low. – Polarity incorrect.	– Increase current and/or time. – Correct polarity.
3	Large irregular collar. 	– Weld time too high.	– Reduce time.
4	Pores in collar. 	– Weld time too long. – Current too low. – Oxidation of weld pool.	– Reduce weld time. – Increase current. – Provide suitable shielding gas.
5	Collar off centre. 	– Effect of arc blow.	– See table 9.

(continued)

Table 7 (concluded)

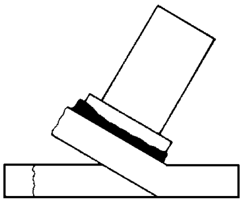
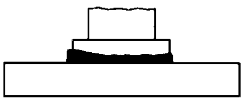
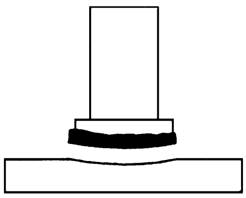
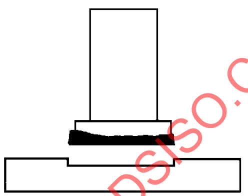
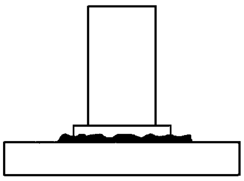
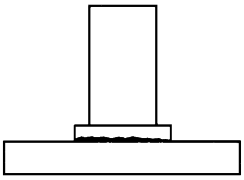
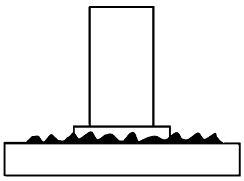
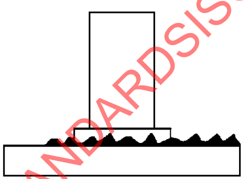
Fracture examination			
No.	**Appearance of fracture**	**Probable cause**	**Corrective actions**
6	Tearing of parent metal. 	– Correct parameters.	– none
7	Fracture above collar after sufficient deformation. 	– Correct parameters.	– none
8	Fracture in HAZ. 	– Carbon content of parent metal too high. – Parent metal not suitable.	– Check parent metal.
9	Lack of penetration. 	– Heat input too low. – Incorrect weld polarity.	– Increase heat input. – Correct weld polarity.

Table 8: Imperfections and corrective actions for capacitor discharge drawn arc stud welding and capacitor discharge stud welding with ignition

Visual examination			
No.	**General appearance**	**Probable cause**	**Corrective actions**
1	Small weld spatter around joint no visual defects. 	– Correct parameters.	– none
2	Gap between flange and parent metal. 	– Weld power too low. – Plunging speed too low. – Insufficient support of parent metal.	– Increase weld power. – Correct plunging speed. – Provide support.
3	Considerable spatter around weld. 	– Weld power too high and/or insufficient plunging speed.	– Reduce weld power. – Increase plunging speed.
4	Weld spatter off centre. 	– Effect of arc blow.	– See table 9.

(continued)

Table 8 (concluded)

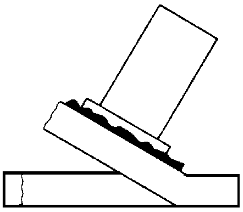
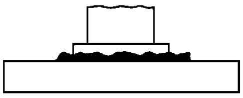
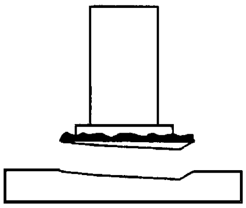
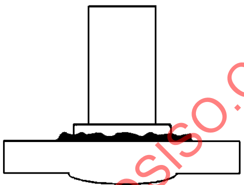
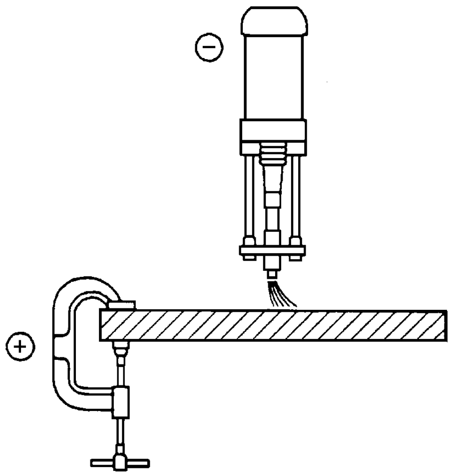
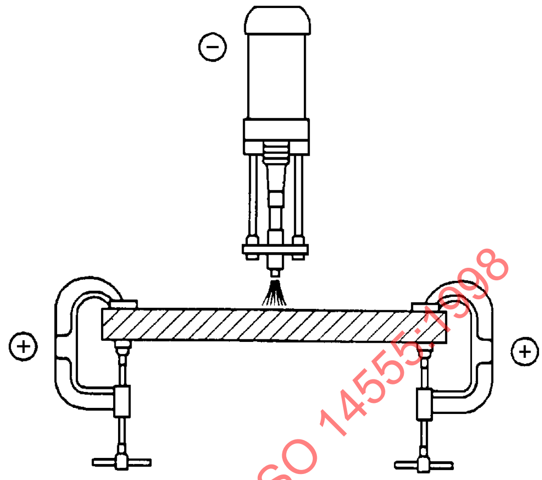
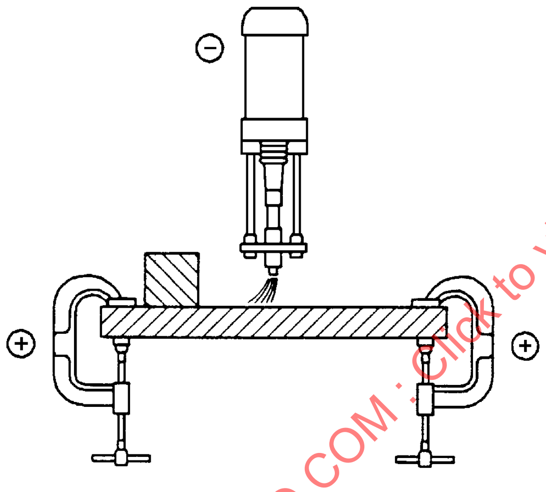
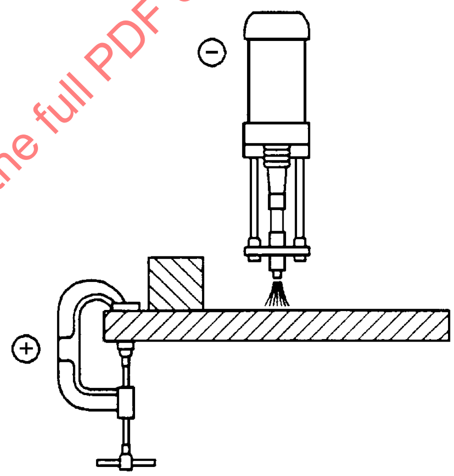
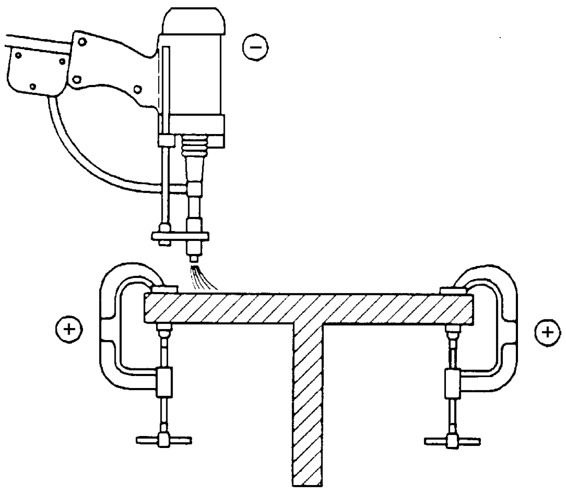
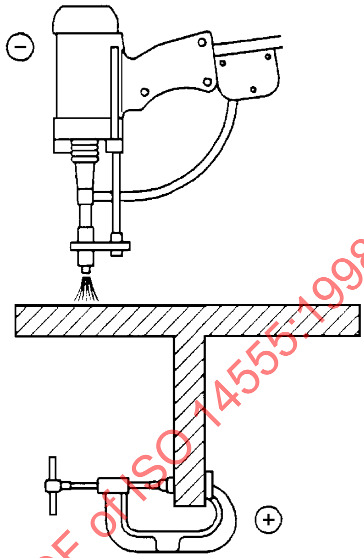
Fracture examination			
No.	**Appearance of fracture**	**Probable cause**	**Corrective actions**
5	Tearing of parent metal. 	– Correct parameters.	– none
6	Fracture of stud above flange. 	– Correct parameters.	– none
7	Fracture in weld. 	– Weld power too low. – Plunging speed too low. – Combination stud/parent metal unsuitable.	– Increase weld power. – Increase plunging speed. – Change stud or parent metal.
8	Deformation on reverse side. 	– Weld power to high. – Pressure too high. – Weld procedure not suitable. – Parent metal too thin.	– Reduce weld power. – Reduce pressure. – Use gap weld procedure and not contact weld procedure. – Increase thickness of parent metal.

Table 9: Effect of arc blow and some possible remedies

No.	Cause	Remedy
A		
B		

(continued)

Table 9 (concluded)

No.	Cause	Remedy
C		
NOTE: Arc blow is proportional to the current intensity and can be influenced by symmetrically attaching the mass clamps and by attaching compensating masses or (in the case of hand guns with an external welding cable) by turning the gun about the vertical axis. It generates one-sided melting and can increase the number of pores in the welded materials.		

4.8 Welding equipment

4.8.1 Welding equipment for drawn arc stud welding with ceramic ferrule or shielding gas and short-cycle drawn arc stud welding

4.8.1.1 General

The welding equipment consists of the power source, control unit, movable fixture and welding cables.

4.8.1.2 Power sources

Power sources are either rectifiers or converters which supply direct current. They should be suitable for brief, high loads. The maximum current intensity in the case of the largest standard studs is approximately 3000 A. The duty cycle is 3 % to 10 %. This means that even for high currents, systems are relatively light and compact. The open circuit voltage is between 70 V and 100 V and should correspond with EN 60974-1.

NOTE:The current intensity should be steplessly adjustable over the entire range. Systems incorporating constant current control are particularly advantageous.

4.8.1.3 Control unit

Control units switch the welding current in accordance with the desired welding time. They also control the movement of the gun. The power source and control unit are combined in most systems (compact systems).

4.8.1.4 Movable fixtures

Movable fixtures are either hand-held guns or welding heads. Welding heads are preferable for automatic stud feed and are securely connected to a frame.

The movable fixture incorporates the following:

- the (in most cases electromagnetic) drive, for lifting the stud for arc starting and for keeping the lift to a constant length during the arc time with respect to the support fixture;
- a spring for plunging the stud into the molten pool after the end of the welding period;
- on some guns (in particular for stud diameters in excess of 14 mm) a hydraulic or pneumatic damper for reducing the plunge speed;
- a clamping fixture for holding the stud in the welding position and for transferring the current to the stud;
- a support fixture for absorbing the reaction force of the press-on force. In the case of hand guns, the support fixture can centre the ceramic ferrule or (e.g. by way of stops or templates) allow the stud to be positioned on the workpiece;
- in the case of welding heads for automatic feed, a feed chamber and a positioning unit (in most cases pneumatic) for the stud; changing clamping fixtures and possibly parts of the support fixture enables a movable fixture to be used for different stud dimensions.

The movable fixture is a power tool, with which hazards from electrical voltage, heating and arc formation can occur. The appropriate safety regulations should therefore be observed.

4.8.1.5 Welding cables

The welding cables shall apply according to ISO 5828 and shall be dimensioned so that impermissible heating is avoided. 50 mm^2 is recommended for studs with a diameter of up to 12 mm and cable length of up to 20 m, cross sections of at least 70 mm^2 are recommended for studs of up to 20 mm diameter and cable lengths of up to approximately 20 m and cross sections of 120 mm^2 are recommended for larger studs or longer cable lengths. The cable and, in particular, all connection points should be checked regularly for damage. Replace damaged system components.

4.8.2 Welding equipment for capacitor discharge drawn arc stud welding and capacitor discharge stud welding tip ignition

4.8.2.1 General

The welding equipment consists of the power source incorporating a charging unit, the movable fixture and the welding cable.

4.8.2.2 Power source

The power source incorporates a capacitor bank with capacitances of between approximately 12 mF and 150 mF. The capacitance is sometimes adjustable in steps. The charging voltages are up to approximately 200 V and require a safety switch-off facility conforming to EN 60974-1. They are adjustable stepless in most cases.

Drawn arc capacitor discharge power source have an additional coil in the welding circuit to provide a welding time of 6 ms to 10 ms.

The capacitor bank shall be charged to the desired voltage following every welding operation. The maximum welding sequence depends on the charging speed. Approximately 500 studs per hour can be welded with manual-operated power sources and up to 3500 studs per hour can be welded in automatic mode.

4.8.2.3 Movable fixture

The movable fixtures are either hand guns or welding heads. Welding heads are preferable for automatic stud feed and are securely connected to a frame. In the drawn arc method the arc is created by lifting the stud. In the tip ignition method the electromagnetic drive creates a gap between stud and parent metal. The arc is ignited by contact of the tip to the workpiece. The design of the movable fixture depends on whether the method used for starting the arc is the drawn arc or capacitor discharge method. The movable fixture incorporates the following:

– the (in most cases electromagnetic) drive for lifting the stud for keeping the lift to a constant length during the arc time with respect to the support fixture;

– a spring for plunging the stud into the molten pool after the end of the welding period;

– a clamping fixture for holding the stud in the welding position and for transferring the current to the stud;

– a support fixture for absorbing the reaction force of the press-on force. In the case of hand guns, the support fixture allows the stud to be positioned on the workpiece, (e.g. by way of stops or templates);

– in the case of welding heads for automatic feed, a feed chamber and a positioning unit (in most cases pneumatic) for the stud.

An electromagnetic drive is not absolutely essential in the case of movable fixtures operating with capacitor discharge drawn arc stud welding. Springs tensioned by hand can also be used to create the necessary arc gap.

Changing clamping fixtures enables a movable fixture to be used for different stud dimensions.

The movable fixture is a power tool, with which hazards from electrical voltage, heating and arc formation can occur. The appropriate safety regulations should therefore be observed.

4.8.2.4 Welding cables

Welding cables shall be used in accordance with ISO 5828.

The cross sections of the welding cables are generally 25 mm^2 to 70 mm^2. They should be as short as possible due to the high peak currents and the associated voltage drop. Winding the welding cable into coils increases the inductive resistance, which in turn reduces the welding current, but the welding time is increased.

4.9 Welding parameters

4.9.1 Welding parameters for drawn arc stud welding with ceramic ferrule or shielding gas and short-cycle drawn arc stud welding

4.9.1.1 Polarity

When welding steel, the stud is connected to the negative pole and the workpiece is connected to the positive pole. Opposite polarity has proven successful for special metals, e.g. aluminium and its alloys and brass.

4.9.1.2 Welding current

Depending on the stud dimensions, the welding current is between approximately 300 A and 3000 A. For drawn arc stud welding with ceramic ferrule or shielding gas of unalloyed steel, the correct current can be estimated on the basis of the two formulas (formula 1 and formula 2):

I (A) = 80 x d (mm) - for studs up to approximately 16 mm diameter; (1)

I (A) = 90 x d (mm) - for studs of over 16 mm diameter. (2)

Normally, a current approx. 10 % less is selected for alloyed steel.

A current as high as possible (600 A to 1500 A, depending on the size of the power source) is set for short-cycle drawn arc stud welding. In general, the welding energy is varied by the welding time alone.

4.9.1.3 Arc voltage

The arc voltage is mainly determined by the lifting height and the welding current. Values of between 20 V and 40 V are the norm. Surface impurities such as oil or grease increase and inert gases reduce the arc voltage compared with the normal state.

4.9.1.4 Welding time

For drawn arc stud welding with ceramic ferrule or shielding gas, the welding time can be estimated on the basis of the two formulas (formula 3 and formula 4):

t_w (s) = 0,02 x d (mm) - for studs of up to approximately 12 mm diameter; (3)

t_w (s) = 0,04 x d (mm) - for studs over 12 mm diameter. (4)

The given values apply to weldings in the position PA. The welding time shall be reduced for welding in the position PC according to EN ISO 6947. In the case of short cycle stud welding, the welding time is less than 100 ms. It depends not only on the stud diameter, but also on the available current intensity.

4.9.1.5 Lift

The lift is between approximately 1,5 mm and 7 mm and is proportional to the stud diameter. In the case of coated surfaces (e.g. through-deck-welding technique), the lift shall be greater than it is normally. Greater lift increase the arc length and therefore the arc voltage. The magnetic deflection of the arc also increases (arc blow).

4.9.1.6 Protrusion

Generally speaking, the protrusion is 1 mm to 8 mm and proportional to the stud diameter. It also depends on the desired shape of the weld collar, the shape of the stud base and (when welding with a ceramic ferrule) the collar area of the ring.

4.9.1.7 Plunging speed

The plunging speed should be approximately 200 mm/s for studs with a diameter of up to 14 mm diameter and 100 mm/s for larger studs, so as to prevent the weld pool splashing. It is proportional to the protrusion in the case of movable fixtures without dampers.

4.9.2 Welding parameters for welding with capacitor discharge drawn arc stud welding and capacitor discharge stud welding with tip ignition

4.9.2.1 Polarity

In general, the stud is connected to the negative pole and the workpiece is connected to the positive pole. Reverse polarity can be advantageous for copper and aluminium alloys.

4.9.2.2 Welding current

The peak current is between 1000 A and 10000 A and depends on the charging voltage, the capacitance and the inductive and ohmic resistance of the welding cable.

4.9.2.3 Welding time

The welding time cannot be selected directly. Depending on the stored energy and the inductance of the welding circuit, it is 1 ms to 3 ms (tip ignition) or 3 ms to 10 ms (drawn arc). A longer welding time simplifies welding on coated surface by virtue of better degassing.

4.9.2.4 Loading power

Together with the capacitance, the charging voltage determines the loading power on the basis of the formula (formula 5):

$$W = 0{,}5 \times C \times U^2. \qquad (5)$$

The power shall be increased with the weld cross section.

4.9.2.5 Plunging speed

Generally speaking, the plunging speed is determined by a spring and the mass of the moving parts. With some movable fixtures, the spring force can be changed by the operator. The plunging speed is approximatley 0,5 m/s to 1,5 m/s (sometimes more). In the case of the tip ignition method, it directly determined the welding time in conjunction with the stud tip length. It is therefore necessary to constantly maintain the plunging speed within limits in order to obtain a constant quality.

5 Quality requirements

5.1 General

If quality requirements according to EN 729-2, EN 729-3 and EN 729-4 are required the following additional requirements shall be taken into consideration.

5.2 Design review

The manufacturer shall check as required the following points:

– Accessibility and welding position of the stud weld.

– Nature of surface and collar shape of the welded joint.

– Materials and combinations of materials (see tables 2 to 5).

– Ratio of stud diameter to sheet metal thickness (avoidance of damage on the reverse side of the sheet).

– Dimensions and details of the weld preparation and of the finished weld, including e.g. nature of stud surface and sheet-metal surface, positional and angular accuracy and length tolerance of the welded stud.

– Use of special techniques to avoid damage to the reverse side of the sheet.

– Techniques to assure the angular position of the welded stud.

NOTE: Consideration of the multi-axial stress state arising from the localized heating/cooling. This stress concentration, reduces the dynamic strength of a component with welded studs.

5.3 Equipment

The manufacturer shall use a suitable stud welding equipment and power supplies of sufficient capacity to weld the stud properly to the parent metal when the equipment is correctly set up. The following equipment shall be available as necessary:

– power sources, control unit and movable fixtures;

– cables with sufficient cross-section, solid connection terminals and sufficient earth connection;

– handling equipment for the technical aspects of welding fabrication (jigs, fixtures);

– weld data monitoring equipment;

– post-drying equipment for ceramic ferrules;

– cleaning facilities for contact points and welding points; surface shall be dry and free from scale, oil, grease or paint;

– the necessary measuring and testing equipment;

– equipment for pre- and post-treatment;

– equipment and welding plant for retouching.

5.4 Description of the equipment

The manufacturer shall maintain a list of the stud welding equipment. The list serves as evidence of the performance and stud welding application field. It includes, for example:

– details of the smallest and largest weldable stud diameter;

– maximum number of studs to be welded per unit of time;

– regulating range of power supply;

– mode of operation and performance of machine or automatic stud-welding equipment;

– details of the available test equipment.

5.5 Maintenance

The manufacturer shall ensure the correct functioning of the equipment. During production he shall, at fixed intervals, perform a function check of the actuation mechanisms. Cables, terminals, stud and ceramic ferrule holders shall be regularly checked and replaced at the correct time. For mass production, and comprehensive quality requirements according to EN 729-2, a maintenance plan for additional essential systems shall be drawn up. Examples of such systems are:

– stud sorting and feeding systems, stud and ceramic ferrules holders;

– mechanical guides and fixtures;

– state of measuring equipment;

– state of cables, hoses, connecting elements;

– state of the monitoring system.

5.6 Production plan

For stud welding, the production plan shall also contain the following details:

– definition of the required stud welding procedures and equipment;

– details of which jigs and fixtures are used;

– surface preparation method.

5.7 Calibration of the measuring and testing equipment

The manufacturer shall be responsible for the appropriate calibration of the equipment involved in acceptance measurement and testing. All equipment used to assess quality shall be suitably controlled and shall be calibrated at specified intervals, this applies particularly to current intensity and welding time measurement.

6 Welding procedure specification (WPS)

6.1 General

The Welding Procedure Specification (WPS) shall give details of how a welding operation is to be performed and shall contain all relevant information about the welding work.

Welding procedure specifications can cover a certain range of thicknesses of the parent metal and can also cover a range of studs. Some manufacturers can prefer additionally to prepare work instructions for each specific job as part of the detailed production planning.

Information listed below is adequate for most welding operations. For some applications it can be necessary to supplement or reduce the list. The relevant information shall be specified in the WPS.

Ranges and tolerances, according to the manufacturer's experience, shall be specified when appropriate. An example of the WPS-format is shown in Annex B.

6.2 Related to the manufacturer

6.2.1 Identification of the manufacturer

– unambiguous identification.

6.2.2 Identification of the WPS

– alphanumeric designation (reference code).

6.2.3 Reference to the Welding Procedure Approval Record (WPAR) or other documents as required

– alphanumeric designation (reference code).

6.3 Related to the parent metal

6.3.1 Parent metal type

– identification of material, preferably by reference to an appropriate standard;

– parent metal(s) delivery condition;

– a WPS can cover a group of metals.

6.3.2 Material dimensions

– the thickness of the parent metal;

– other relevant dimensions.

6.4 Welding process

– welding process shall be designated according to EN 24063.

6.5 Joint

6.5.1 Joint design

– sketch of the joint design showing relative position of studs and tolerances;

– sequence of welding of studs shall be given on the sketch if essential for the application.

6.5.2 Welding position

– applicable welding positions shall be specified according to EN ISO 6947.

6.5.3 Preparation of parent metal surface

– method of surface preparation, if necessary (e.g. cleaning, degreasing, pickling);

– maximum time permitted between preparation and welding (if necessary).

6.5.4 Jigs and fixtures

– the methods to be used (if necessary);

– fixture details, templates etc.

6.5.5 Support

The method of support, specification of supporting material and dimensions of support (when welding thin plates).

6.6 Studs

6.6.1 Designation

Classification according to standard, supplier and trade name. Non-standard studs shall be specified by reference to drawing or some other adequate specification.

6.6.2 Handling

If the studs are to be treated (e.g. by cleaning) before use, this shall be specified.

6.7 Auxiliaries

6.7.1 Ceramic ferrules (if any)

Classification according to standard, supplier and trade name. Non-standard ceramic ferrules shall be specified by reference to drawing or some other adequate specification.

If the ceramic ferrules are to be treated (e.g. drying) before use, this shall be specified.

6.7.2 Protective gas (if any)

– classification according to EN 439.

6.8 Power source

– type, make.

6.9 Movable fixtures

6.9.1 Welding gun/head

– type, make;

– permitted range of diameter and stud length;

– damper.

6.9.2 Shielding gas system (if used)

– gas flow rate;

– description (schematic) showing nozzle dimensions and position of nozzle(s) in relation to stud and workpiece.

6.9.3 Stud feeding system (if any)

– description of stud feeding system including sketch.

6.10 Welding variables for drawn arc stud welding with ceramic ferrule or shielding gas and short-cycle drawn arc stud welding

– polarity;

– arc voltage;

– welding current;

– welding time;

– lift;

– protrusion;

– plunging speed;

– number and position of earth clamps.

6.11 Welding variables for capacitor discharge stud welding with tip ignition

– polarity;

– capacitance;

– charging voltage;

– plunging speed (spring force, gap length);

– number and position of earth clamps;

– welding cable configuration (if used for current control).

6.12 Thermal conditions

– preheat temperature (if required);

– if preheating is not required, the lowest permitted ambient temperature.

6.13 Post-weld heat-treatment

If in special cases any post-weld heat-treatment or ageing is necessary, specification of the procedure or reference to a separate post-weld heat-treatment or ageing specification is required. This should include specification of the entire thermal cycle.

6.14 Non-thermal treatment after welding

– grinding, machining or any other mechanical treatment;

– pickling or any other chemical treatment;

– any special procedure for removal of ferrules.

7 Welding procedure approval

7.1 Principles

Welding procedure specifications for arc stud welding shall be approved prior to production whenever required by the parties concerned or by an application standard. The following methods of approval are, in principle, permitted but contract or application code requirements can restrict the choice of method:

– approval by welding procedure test according to 7.2;

– approval by pre-production tests according to 7.3;

– approval based on previous experience according to 7.4.

All new welding procedure approvals are to be in accordance with this standard from the date of its issue. However, this standard does not invalidate previous welding procedure approvals made to former national standards or specifications providing, the technical requirements are satisfied and the previous procedure approvals are relevant to the application and production work on which they are to be employed. Consideration of previous procedure approvals to former national standards or specifications should be at the time of the enquiry or contract stage and agreed between the contracting parties.

7.2 Welding procedure tests

7.2.1 Application

When procedure tests are required tests shall be carried out in accordance with the provisions in this section unless more severe tests are specified by contract or the relevant application standard when these shall apply.

7.2.2 Preliminary welding procedure specification (pWPS)

The preliminary welding procedure specification shall be prepared in accordance with clause 6 of the standard. It shall specify the range for all the relevant parameters.

7.2.3 Shape and dimensions of test pieces

The dimension of the test piece(s) shall be sufficient to carried out all tests. The thickness of the test pieces shall be chosen so that the plate or flange thickness proposed for production is covered (see 7.2.8.6).

7.2.4 Welding

Preparation, set up and welding of test pieces shall be carry out in accordance with the pWPS, and under the general conditions of production welding which they shall represent. The same welding positions shall be observed as on the actual workpiece. There shall be sufficient distance from the lateral earth clamps.

Welding and testing of the test pieces shall be witnessed by an examining body (see 3.9 of EN 288-1 : 1992).

Procedure tests are to be carried out on the smallest and largest stud diameters used in practice.

At least the following numbers of studs are to be welded in the procedure test:

– drawn arc stud welding with ceramic ferrule or shielding gas (stud diameter ≤ 12 mm) → 12 studs;

– drawn arc stud welding with ceramic ferrule or shielding gas (stud diameter > 12 mm) → 17 studs;

– short-cycle drawn arc stud welding → 12 studs;

– capacitor discharge drawn arc stud welding → 30 studs;

– capacitor discharge stud welding with tip ignition → 30 studs.

NOTE: For setting-up tests and replacement specimens (see clause 10) it is recommended that a sufficient number of additional studs should be provided on the test pieces.

7.2.5 Parent and stud metal inspection documents

The parent and stud metal to be used shall be certified at least with material test reports 3.1.B according to EN 10204.

In the absence of such certificates, the parent and stud materials shall be subjected to additional materials tests before the procedure tests. For this, sufficient amounts of parent and stud material from the same melt as used in the test shall be made available.

7.2.6 Extent for examination and testing

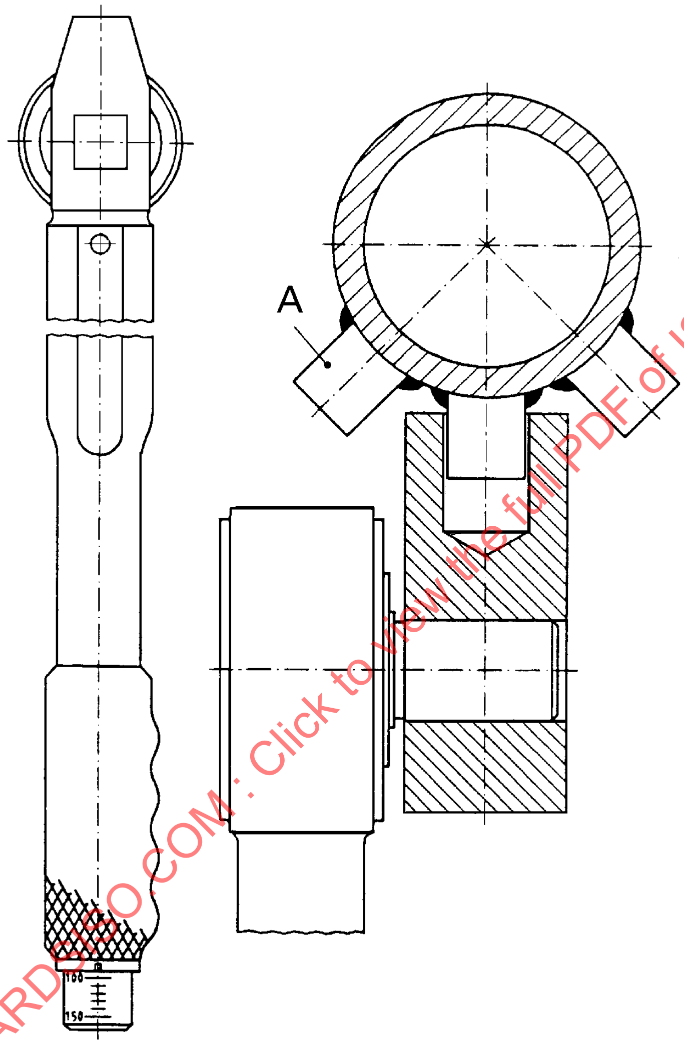
The examination and testing includes non-destructive and destructive tests which shall be in accordance with the requirements of table 10.

All inspection and tests shall be performed in accordance to the procedures specified in clause 8. The number and type of test stated in table 10 shall only be used by approval of a WPS based on the use of stud and parent material, specified in tables 2 and 3.

By use of other type of studs or parent materials, not specified in tables 2 and 3, the same test but with a larger number of test can be used.

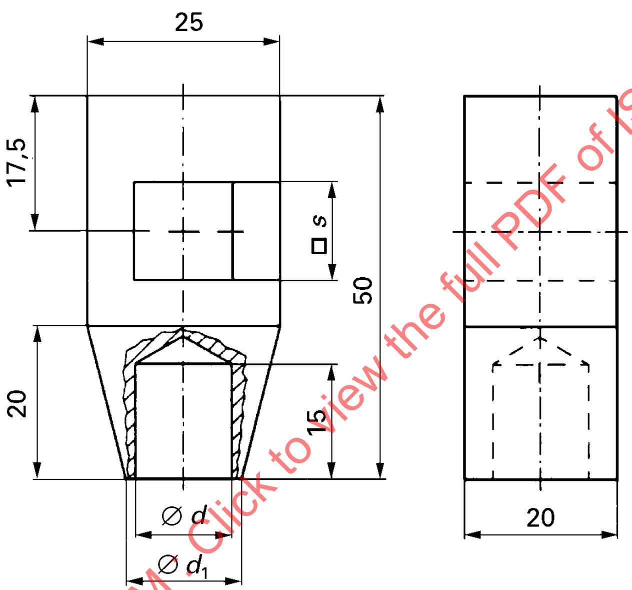
Table 10: Examination and testing of the test pieces

<table>
<tr><th rowspan="3">Process</th><th colspan="3">Type of test</th></tr>
<tr><th colspan="2">Force transfer</th><th>Heat transfer</th></tr>
<tr><td>$d \leq 12$ mm</td><td>$d > 12$ mm</td><td>all diameters (d)</td></tr>
<tr><td rowspan="4">drawn arc stud welding with ceramic ferrule or shielding gas
and
short-cycle drawn arc stud welding</td><td colspan="3">visual examination → all studs</td></tr>
<tr><td colspan="2">bend testing → 60° → 10 studs (see figures 8a), 8b) or 8c))</td><td>bend testing by means of torque wrench → 10 studs (see figures 4a) and 4b))</td></tr>
<tr><td>tensile testing → 1) (see figures 5, 6 or 7)</td><td>tensile testing → 1) (see figures 5, 6 or 7)
or
radiographic examination → 5 studs</td><td>–</td></tr>
<tr><td colspan="3">macro examination → 2 studs (off-set 90° through the center of the stud)</td></tr>
<tr><td rowspan="3">capacitor discharge stud welding with tip ignition
and
capacitor discharge drawn arc stud welding</td><td colspan="3">visual examination → all studs</td></tr>
<tr><td colspan="3">tensile testing → 10 studs (see figures 5, 6 or 7)</td></tr>
<tr><td colspan="3">bend testing → 30° → 20 studs (see figures 8a), 8b) or 8c))</td></tr>
<tr><td colspan="4">1) For welds between stud material of group 9 according to EN 288-3 and parent metal of group 1 or 2 according to EN 288-3 tensile testing of at least 10 studs (pieces) is required.</td></tr>
</table>



A = stud

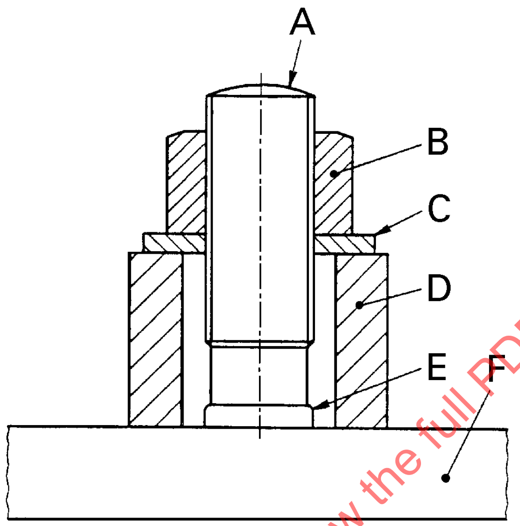
Figure 4a): Torque wrench for bend testing



d = stud diameter + 0,3 mm
d_1 = can be chosen freely by the manufacturer depending on the stud spacing
S = depending on the tool

Figure 4b): Test tool for bend testing

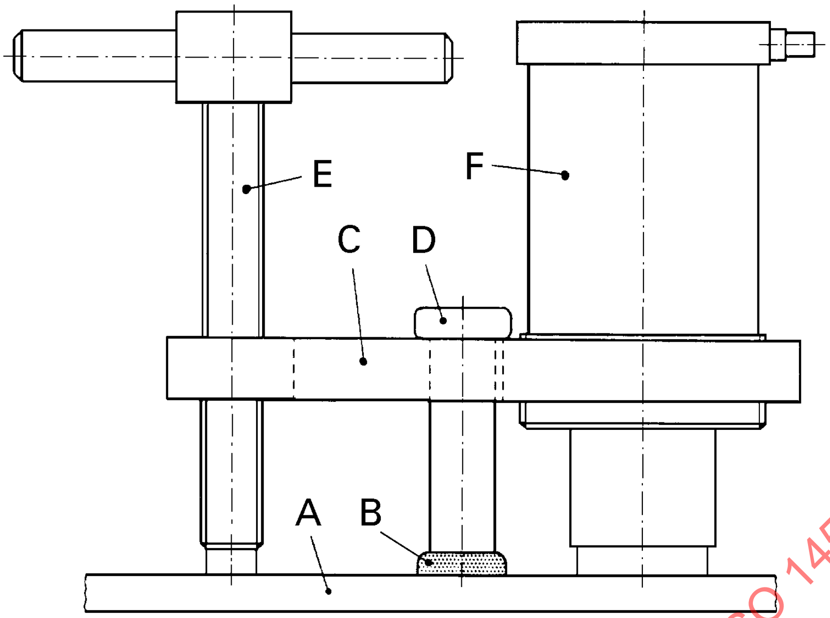
Figure 4: Examples for bend testing by means of torque wrench



A = stud
B = steel nut
C = washer
D = sleeve
E = collar
F = workpiece

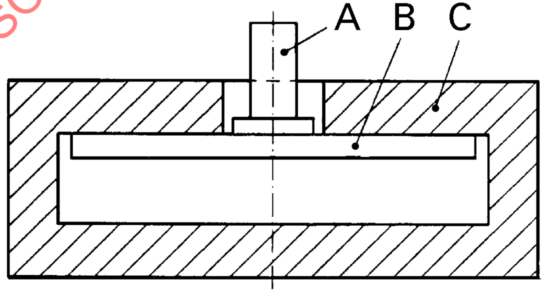
Figure 5: Example for tensile testing of threaded studs

NOTE: Non-threaded studs should be tension tested to destruction using any machine capable of supplying the required force, e.g. figures 6 and 7.



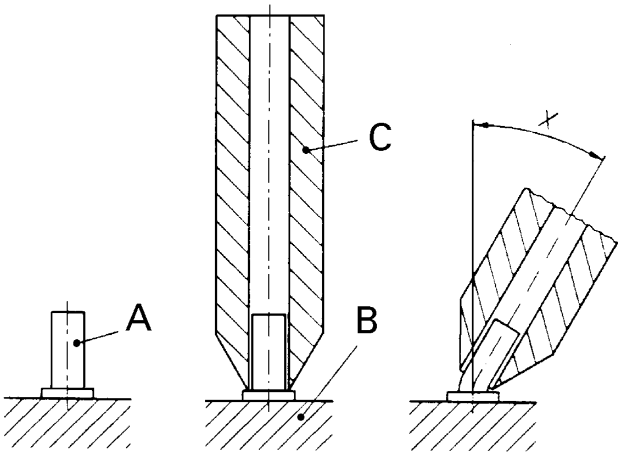
A = workpiece
B = weld
C = bridge
D = shear connector
E = screw for levelling
F = hydraulic cylinder

Figure 6: Example for tensile testing of shear connectors



A = stud
B = workpiece
C = tensile device

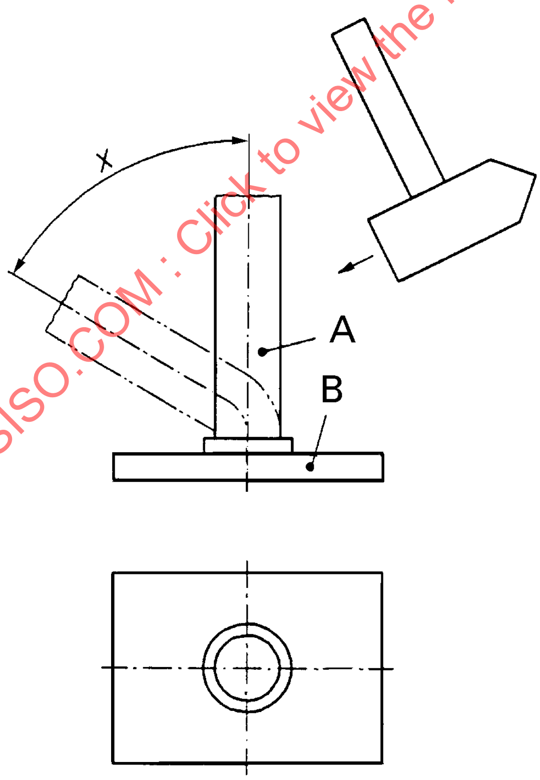
Figure 7: Example for tensile testing of non-threaded studs



X = for capacitor discharge stud welding with tip ignition and drawn arc capacitor discharge stud welding 30° and for drawn arc stud welding with ceramic ferrule or shielding gas or for short cycle drawn arc stud welding 60°

A = stud
B = workpiece
C = tube

Figure 8a)



X = for capacitor discharge stud welding with tip ignition and drawn arc capacitor discharge stud welding 30° and for drawn arc stud welding with ceramic ferrule or shielding gas or for short cycle drawn arc stud welding 60°

A = stud
B = workpiece

Figure 8b)

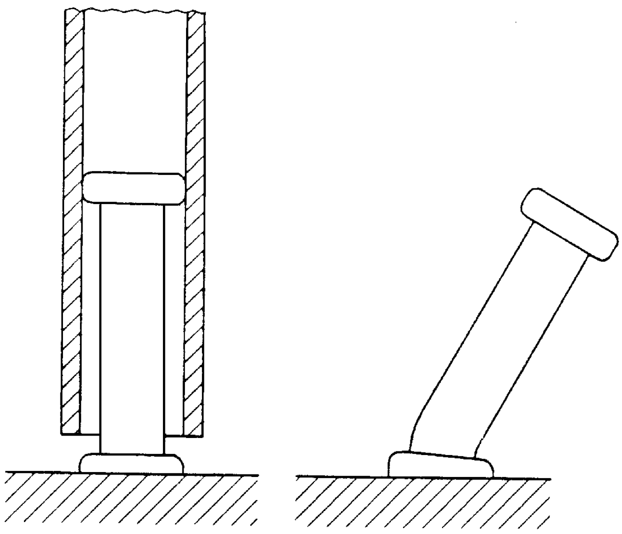


Figure 8c)

Figure 8: Examples for bend testing

7.2.7 Re-testing

If one stud (of all studs) fails to meet the requirements, two similar replacement studs can be taken from the associated test pieces. If this is not possible, equivalent studs shall be welded subsequently. It is therefore recommended that a sufficient number of replacement studs shall be provided for the procedure tests.

If more than one stud, or one of the two replacement studs, does not satisfy the requirements, the test has failed.

7.2.8 Range of approval

7.2.8.1 General

All the conditions of validity stated below shall be met independently of each other.

Changes outside of the ranges specified shall require a new welding procedure test.

There is no limit to the duration of the validity of the welding procedure qualification provided that no quality changes are made and that a production log according to 10.6 is kept.

However since the result of stud welding is dependent not only on compliance with the welding procedure specification, but also, for example, on the fact that the mechanical capability of the welding guns is critical in terms of weld quality, a normal work test as laid down in 10.2 shall be carried out at least once a year.

In the event of production being suspended for more than one year, the validity of the welding procedure qualification shall be confirmed in a normal work test.

7.2.8.2 Related to the manufacturer

An approval of a WPS obtained by a manufacturer is valid for welding in workshops or sites under the same technical and quality control of that manufacturer.

7.2.8.3 Related to the welding process

The approval is valid only for the welding process used in welding procedure test.

The energy which can be calculated from the parameters shall be kept within limits ± 25%.

7.2.8.4 Related to the parent material

A procedure test carried out with one of the steels of a group covers the lower alloyed steels of the same group for the intentional added elements, but not for fortuitous impurities, or the steels with lower specified yield stress of this group, as long as the welding consumables used for the test can also be used for the other steels of this group. Material group 2 according to EN 288-3 covers group 1. Material group 21 according to EN 288-4 covers group 22.1 but not vice versa.

7.2.8.5 Stud material

Procedure test covers only the same grade of material. However for capacitor discharge stud welding with tip ignition studs made by Al99,5 covers studs made by AlMg3 but not vice versa.

7.2.8.6 Parent metal thickness

Following the recommentation given in table 1 the material thickness used for the procedure test covers all thicknesses above the recommended minimum sheet thickness.

For material thickness below the recommended minimum thickness new procedure tests are required.

7.2.8.7 Related to the stud diameter and shape

A single procedure test covers only the diameters used in the test.

Two procedure test on different diameter studs covers the range between the two diameters.

A single procedure test covers studs of all shapes.

7.2.8.8 Related to the welding position

Using capacitor discharge stud welding with tip ignition and capacitor discharge drawn arc stud welding a procedure test carried out in any one position approves for welding in all positions. Using drawn arc stud welding with ceramic ferrule or shielding gas and short-cycle drawn arc stud welding, position PC covers positions PE and PA, but not vice versa. For position PC special ceramic ferrules can be used.

7.2.8.9 Related to the welding equipment

The output limits and timing accuracy of the power sources, control units and welding guns or heads used in production shall at least correspond to those used in the welding procedure tests.

If there is a change in the type of welding gun or head and/or power source or of the welding equipment manufacturer, the welding procedure specification shall be verified by a normal production test.

7.2.8.10 Preheating

Welding procedure specifications that have been approved by a procedure test without preheating are also valid for those for welding with preheating but not vice versa.

7.3 Pre-production tests

The general provisions of EN 288-8 shall be adhered to with the following additions and modifications:

– welding procedure specifications, pWPS and WPS, shall conform to the provisions of clause 6 of the present standard;

– the actual production shall be controlled by a suitable scheme for process control;

– the number of stud (produced items) tested shall meet the requirements of 7.2.4 if possible;

– approval is limited to the same type of equipment, the same type and thickness of the parent metal and the same diameter of studs as used during the pre-production test.

The use of pre-production tests is not permitted for steel welds with standard or comprehensive quality requirements (see Annex A).

7.4 Previous experience

The general provisions of EN 288-6 shall be adhered to with the following additions and modifications:

– welding procedure specifications, pWPS and WPS, shall conform to the provisions of clause 6 of the present standard;

– the former production on which the experience is based shall have been controlled by a suitable scheme for process control, giving a statistical confidence compatible with the future application of the welding procedure to be approved;

– approval is limited to the same type of equipment, the same type and thickness of the parent metal and the same diameter of studs as used during the production on which the experience is based.

The use of previous experience instead of procedure tests is not permitted for steel welds with standard or comprehensive quality requirements (see Annex A).

7.5 Welding procedure approval record (WPAR)

The welding procedure approval record (WPAR) is a statement of the results of assessing each test piece including re-tests. The relevant items listed for the WPS in clause 6 of this standard shall be included, together with details of any features that would be rejectable by the requirements of clause 8. If no rejectable features or unacceptable test results are found, a WPAR detailing the welding procedure test piece results is approved and shall be signed and dated by the examiner or test body.

A WPAR format as shown in Annex C or Annex D shall be used to record details for the welding procedure and the test results, in order to facilitate uniform presentation and assessment of the data.

8 Examination and testing

8.1 General

Normally the welds of the studs shall be free of imperfections except those which are to be accepted by the different tests and examinations.

In the case of force transfer using the processes drawn arc stud welding with ceramic ferrule or shielding gas and short-cycle drawn arc stud welding welds and fractures shall be examined for pores, lack of fusion, cracks, cavities and inclusions.

If comprehensive quality requirements are required in accordance with EN 729-2, the total area of all imperfections (see table 11) shall not exceed 5 % of the stud area. Cracks are not acceptable. No individual imperfection on the fracture surface of weld shall be larger than 20 % of the stud diameter. Even for small imperfections, the number of imperfections shall not exceed the number for the stud diameter. Pores with a diameter of less than 0,5 mm are disregarded.

If standard quality requirements are required in accordance with EN 729-3, the total area of all imperfections shall not exceed 10 % of the stud area.

If elementary quality requirements are required in accordance with EN 729-4, the limit of the imperfections shall be agreed between the contracting parties.

Table 11: Relationship between stud diameter, permissable imperfection size and permissable total imperfection area

Stud diameter mm d	Permissable imperfection size mm $\frac{d}{5}$	Permissable total imperfection area mm^2 $\frac{d^2 * \pi}{80}$
3	0,6	not applicable
4	0,8	not applicable
5	1,0	not applicable
6	1,2	not applicable
8	1,6	not applicable
10	2,0	not applicable
12	2,4	not applicable
14	2,8	7,7
16	3,2	10,0
18	3,6	12,7
20	4,0	15,7
22	4,4	19,0
25	5,0	24,5

8.2 Visual examination

For drawn arc stud welding with ceramic ferrule or shielding gas and short-cycle drawn arc stud welding the examination covers the uniformity of shape and size of the collar. Imperfections shown in table 6, No. 2 to No. 5, and imperfection shown in table 7, No. 2, need corrective actions.

For capacitor discharge drawn arc stud welding and capacitor discharge stud welding with tip ignition the examination covers the uniformity of the spatter ring. Imperfections shown in table 8, No. 2 to No. 4, need corrective actions.

8.3 Bend testing

The studs are bent through 30° using capacitor discharge stud welding with tip ignition or capacitor discharge drawn arc stud welding, through 60° using drawn arc stud welding with ceramic ferrule or shielding gas or short-cycle drawn arc stud welding (see figure 8).

The test serves as a simple bench test for approximate checking of the chosen welding data. In the test, the weld ist subjected to bending in an undefined manner.

A weld is deemed to have passed the test if no cracks are found in the weld after bending of the stud through 30° or 60°.

If a low-deformation fracture occurs in the heat-affected zone, the weldability of the materials shall be checked (e.g. tendency to hardening).

8.4 Bend testing by means of torque wrench

The bend testing by means of torque wrench is performed only for heat transfer studs welded by the processes drawn arc stud welding with ceramic ferrule or shielding gas or short-cycle drawn arc stud welding (see figure 4).

The bending strain depends on the stud diameter (see table 12).

Table 12: Bending strain depends on the stud diameter

Stud diameter mm	Bending strain Nm
8	40
10	60
12	85

The test serves as a simple bench testing for approximate checking of the chosen welding data.

The weld is deemed to have passed the test if no cracks are found after bending.

If a low-deformation fracture occurs in the heat-affected zone, the weldability of the materials shall be checked (e.g. tendency to hardening).

8.5 Tensile testing

The tensile testing is used for the processes drawn arc stud welding with ceramic ferrule or shielding gas and for short-cycle drawn arc stud welding (only for force transfer) and for the processes capacitor discharge stud welding with tip ignition and capacitor discharge drawn arc stud welding.

Using a suitable tension device (see figures 5, 6 and 7) the welded studs are axially pulled till fracture. If the stud or parent material fractures outsides the weld zone after sufficient deformation the weld passes the test (see table 6, No. 6 or No. 7, and table 7, No. 6 and No. 7, and table 8, No. 5 and No. 6).

A fracture in the weld area is not permitted, if comprehensive quality requirements according to EN 729-2 are required.

If standard quality requirements according to EN 729-3 are required by use of the processes drawn arc stud welding with ceramic ferrule or shielding gas, short-cycle drawn arc stud welding and capacitor discharge stud welding with tip ignition and drawn arc capacitor discharge stud welding fractures within the weld zone are only permitted if the nominal tensile strength of the stud material is reached. Imperfections in the fracture surface shall be in accordance with the limits specified in 8.1.

By use of flanged stud and the processes capacitor discharge drawn arc stud welding or capacitor discharge stud welding with tip ignition fractures within the weld zone are permitted if the non welded area does not exceed 35 % of the flanged area.

8.6 Macro examination

Macro examination is only required for the processes drawn arc stud welding with ceramic ferrule or shielding gas and short-cycle drawn arc stud welding.

In the case of force transfer and comprehensive quality requirements in accordance with EN 729-2 imperfections shall be in accordance with limits specified in table 11.

In the case of heat transfer a sufficient weld between stud and tube material has to be achieved whilst leaving a minimum of 2 mm wall thickness none molten in the tube.

Micro cracks shall be disregarded.

8.7 Radiographic examination

Radiographic examination is only required for the process drawn arc stud welding with ceramic ferrule or shielding gas above $d > 12$ mm for force transfer, when tensile tests are not carried out.

For the performance of the test the studs shall be cut off just over the collars.

When radiography shall be carried out in accordance with EN 1435 using class B technique.

The imperfections shall be in accordance with limits specified in 8.1.

8.8 Additional tests

In certain stud welding applications e.g. steam boilers, shipbuilding or nuclear industry additional tests (e.g. hardness tests or ultrasonic examinations) can be required by the contract or application standards.

9 Welding personnel

9.1 Stud welding operators

Stud welding operators shall be approved by any method according to EN 1418.

Approval based on pre-production welding test or production test according to 4.2.3 of EN 1418:1997 shall include testing to the extent specified in 10.2.

A test of job knowledge is required for all approval methods. This test shall cover at least:

– setting up the welding equipment in accordance with the welding procedure specification;

– knowledge of the significance of variation in the setting parameters (lift, plunge, current intensity, welding time);

– basic knowledge of the requirements for stud welding (selections of materials, symmetrical connection of the workpiece cables, polarity of the stud, avoidance of arc blowing);

– visual assessment of the welded joint (imperfections and corrective actions);

– safe execution of the welding operations (good contact of stud in stud holder, no movement during the welding process, operation checking, correct positioning of the guns).

9.2 Welding coordination

Welding coordination shall be performed in accordance with EN 719.

Welding coordination personell for stud welding shall have experience in stud welding, especially in the process in use.

Only for very simple stud welds without defined force or heat transfer, a welding coordinator is not required (see Annex A).

10 Process control

10.1 General

For quality assurance, various quality requirements shall be met, depending on the stud welding process and the field of application (see Annex A). Before, during and after production, tests shall therefore be performed. The various tests are as follows:

– normal production test;
– simplified production test;
– online production monitoring.

This test can be carried out by using the actual production pieces or by using special test pieces. The pieces shall correspond to the production conditions.

10.2 Normal production test

10.2.1 General

Generally, normal production tests shall be performed by the manufacturer before the beginning of welding operations on a construction or a group of similar constructions and/or after a specified number of welds. This number shall be laid down in the contract or shall be taken from the relevant application standard.

The normal production test is limited to the stud diameter used, the parent metal and the type of equipment.

10.2.2 Normal production test for drawn arc stud welding with ceramic ferrule or shielding gas and short-cycle drawn arc stud welding

Ten studs shall be welded. For setting-up tests and, where appropriate, replacement tests, a sufficient number of additional stud should be provided on the test piece. The following examinations and tests shall be performed:

– visual examination (all studs);

– bend testing (5 studs);

– macro examinations of two different studs (off-set by 90° through the center of the stud).

The examinations and testing are performed and evaluated in accordance with clause 8.

The results of the normal production test shall be documented (see Annex E) and should be included with the quality records.

10.2.3 Normal production test for capacitor discharge stud welding with tip ignition and capacitor discharge drawn arc stud welding

Ten studs shall be welded. For setting-up tests and, where appropriate, replacement tests, a sufficient number of additional studs should be provided on the test piece. The following examinations and tests shall be performed:

- visual examination (all studs);
- tensile testing (3 studs);
- bend testing (5 studs).

The examination and tests are performed and evaluated in accordance with clause 8.

The results of the normal production test shall be documented (see Annex F) and should be included with the quality records.

10.3 Simplified production test

The purpose of the simplified production test is to check that the equipment is correctly set up, and that it is operating correctly. Three studs shall be welded before the start of each shift. They can also be requested after a certain number of welds, under contract or by the application standard rules. The simplified production tests comprise at least the following test and examination:

- visual examination (all studs);
- bend testing (all studs).

The examination and test are performed and evaluated in accordance with clause 8.

The results of the simplified production test shall be documented and should be included with the quality records.

10.4 Re-testing for normal or simplified production test

If, in a normal production test, one of all the studs does not meet the requirements, two replacement stud of the same kind can be taken from the associated test piece. If this is not possible, similar studs shall be additionally welded. It is therefore recommended that a sufficient quantity of replacement specimens should be provided in a normal production test.

If one stud does not satisfy the requirements in the simplified production test, the production test shall be repeated after the cause of the fault has been corrected.

10.5 Online production monitoring

10.5.1 General

If there is an indication of unsatisfactory welding, e.g. porosity, collar not complete or unequal or if the length of one stud is insufficient compared to the others corrective actions according to 10.7 shall be carried out or a bend test (15°) or tensile test (limited to the design strength) shall be performed on that stud. If the stud weld fails to satisfy the requirements in this test, three welds made before and, where appropriate, after the defective weld shall also be subjected to bend or tensile testing.

If one of these studs also fails to satisfy the requirements in the test, corrective actions shall be carried out on all studs on the same work piece.

The results of the online production monitoring shall be recorded in a production log (see 10.6).

10.5.2 Visual examination

Visual examination is generally sufficient for online production monitoring, but shall cover all welds.

10.5.3 Checking the welding data parameters

The relevant welding data parameters can be monitored by suitable equipment.

10.5.4 Other non-destructive examinations and testings

By agreement between of the contracting parties or where specified in the application standard non-destructive testing can be added to continuous production monitoring, if the relevant experience is available. Suitable techniques are:

– checking the length of the studs after welding;

– tensile testing with restricted load;

– bend testing with restricted load (torque wrench);

– bend testing with restricted permissible deformation;

– ultrasonic examination.

10.6 Production log

The manufacturer keeps a record of production monitoring known as the production log which records the results of the normal production test, simplified production test and on-line production monitoring. The manufacturer shall keep a different log for each stud welding process and the log shall be kept to hand at the workplace, with the results of all tests recorded in the log. Annex G is an example form and should be used, where appropriate.

10.7 Non-conformance and corrective actions

Where the production is inadequate, e.g. incorrect dimensions or defective welds, removal of the defective stud and repeat welding can be demanded under the terms of the contract or under the application standard. If the collar of a stud welded by the processes drawn arc stud welding with ceramic ferrule or shielding gas or short-cycle drawn arc stud welding is not closed, it can be closed by processes 111, 135 or other suitable processes in accordance with EN 24063 using a suitable electrode. Depending on stud diameter, a fillet weld shall reach the precalculated throat.

By use of process 111, the welding shall be done with basic or rutile-coated electrodes as appropriate.

If stud welds are repaired by processes 111, 135 or other suitable welding processes, the welded studs shall be re-tested in accordance with the original conditions. In addition, steps shall be taken to ensure that factors adversely affecting the welded product are identified and compensated.

In isolated cases it is also permissible to weld the studs by means of process 111, 135 or other suitable processes. Depending on stud diameter, a fillet weld shall reach the precalculated throat.

Defective studs shall not necessarily be removed unless the parent metal has been damaged. They can be substituted by extra studs for certain applications.

In each cases the alternative welding procedures shall be approved in accordance with EN 288-3 or EN 288-4 and welder carried out the repair shall be approved according to EN 287-1 or EN 287-2.

10.8 Calibration of the measuring and testing equipment

In the case of comprehensive quality requirements in accordance with EN 729-2 the manufacturer shall be responsible for the appropriate calibration of inspection, measuring and testing equipment. All equipment shall be suitably controlled and shall be calibrated at specified intervals.

This applies particulary to current intensity and welding-time measurement.

Annex A (normative)

Quality requirements for stud welding

Table A.1: Quality requirements for stud welding

Quality requirements for stud welding – Parts of EN 729 required	Comprehensive quality requirements in accordance with EN 729-2	Standard quality requirements in accordance with EN 729-3	Elementary quality requirements in accordance with EN 729-4
Typical fields of applications	force transfer by utilization of the permissible tensile stress up to 100 % or shear connectors for composite bridges	force and heat transfer without fully utilization of the permissible stress	very simple welds without defined force or heat transfer
Processes	drawn arc stud welding with ceramic ferrule or shielding gas and short-cycle drawn arc stud welding	all stud welding processes	
Operator	approved in accordance with 9.1		
Technical knowledge of welding coordination personel	basic knowledge in accordance with 9.2		9.2 does not apply
Quality record measured	production log in accordance with 10.6		10.6 does not apply
Method of approval of WPS	procedure test in accordance with 7.2 or preproduction test in accordance with 7.4		previous experience in accordance with 7.5
Calibration of measurement and testing equipment	procedures shall be available in accordance with 10.8	10.8 does not apply	
Examination and testing during production	normal production test in accordance with 10.2; simplified production test in accordance with 10.3; online production monitoring in accordance with 10.5		simplified production test in accordance with 10.3
Non-conformance and corrective actions	in accordance with 10.7		