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Resistance welding — Procedure for spot welding of uncoated and coated low carbon steels

Soudage par résistance — Mode opératoire pour le soudage par points des aciers à bas carbone revêtus et non revêtus

Reference number
ISO 14373:2006(E)

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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.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. 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.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 14373 was prepared by the International Institute of Welding, recognized as an international standardizing body in the field of welding in accordance with Council Resolution 42/1999.

Requests for official interpretations of any aspect of this International Standard should be directed to the ISO Central Secretariat, who will forward them to the IIW Secretariat for an official response.

Resistance welding — Procedure for spot welding of uncoated and coated low carbon steels

1 Scope

This International Standard specifies requirements for resistance spot welding in the fabrication of assemblies of uncoated and metallic coated low carbon steel, comprising two or three sheets of metal, where the maximum single sheet thickness of components to be welded is within the range 0,4 mm to 3 mm, for the following materials:

— uncoated steels;

— hot-dip zinc or iron-zinc alloy (galvannealed) coated steel;

— electrolytic zinc, zinc-iron, or zinc-nickel coated steel;

— aluminium coated steel;

— zinc-aluminium coated steel.

This International Standard is applicable to the welding of sheets of the same or dissimilar thickness, where the thickness ratio is less than or equal to 3:1. It applies to the welding of three thicknesses, where the total thickness is less than or equal to 9 mm.

Welding with the following types of equipment is within the scope of this International Standard:

a) pedestal welding equipment;

b) gun welders;

c) automatic welding equipment where the components are fed by robots or automatic feeding equipment;

d) multi welders;

e) robotic welders.

Information on appropriate welding equipment is given in Annex A, and information on spot welding conditions is given in Annex B. This information is provided for guidance only. Depending on the service conditions of the fabrication, the type of welding equipment, the characteristics of the secondary circuit, the electrode material, and the shape, it is possible that certain modifications are necessary. In such cases, further information may be obtained from the relevant application standard, where one exists.

The welding of organic coated or primer coated steels is not within the scope of this International Standard.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 669, *Resistance welding — Resistance welding equipment — Mechanical and electrical requirements*

ISO 5182, *Welding — Materials for resistance welding electrodes and ancillary equipment*

ISO 10447, *Welding — Peel and chisel testing of resistance spot, projection and seam welds*

ISO 14270, *Specimen dimensions and procedure for mechanized peel testing resistance spot, seam and embossed projection welds*

ISO 14329, *Resistance welding — Destructive tests of welds — Failure types and geometric measurements for resistance spot, seam and projection welds*

ISO 15609-5, *Specification and qualification of welding procedures for metallic materials — Welding procedure specification — Part 5: Resistance welding*

ISO 15614-12, *Specification and qualification of welding procedures for metallic materials — Welding procedure test — Part 12: Spot, seam and projection welding*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 669, ISO 14329, and the following apply.

3.1
corona bond zone
area of the weld at the faying surfaces in which solid phase bonding has occurred

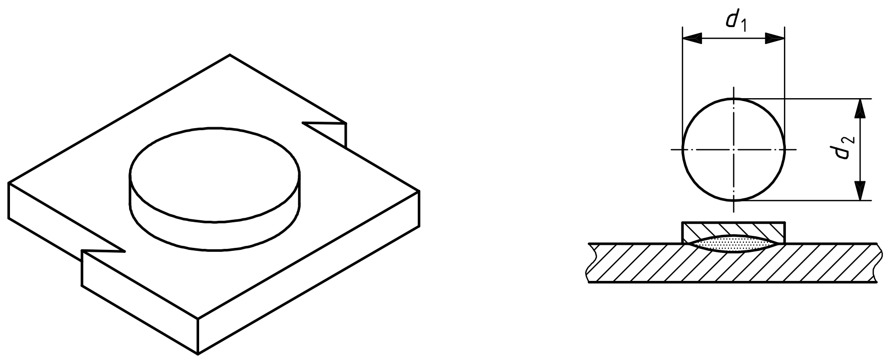
See Figure 2.

3.2
cross-tension test
test to determine the load-carrying capability of a spot welded joint subjected to cross tension loading

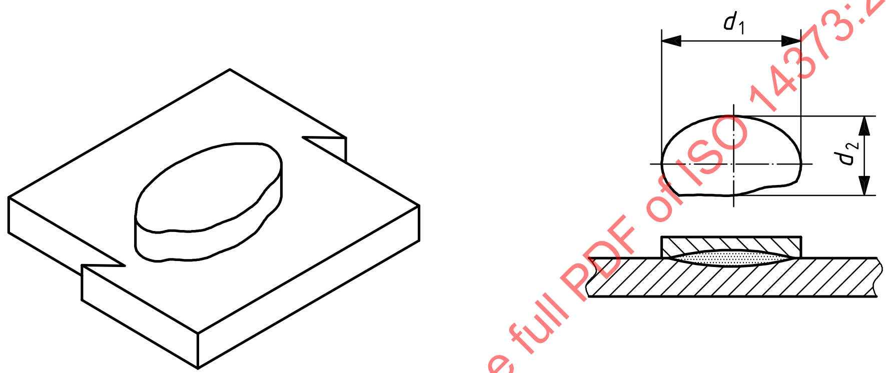
3.3
shear test
tensile shear test
test to determine the load-carrying capability of a spot welded joint subjected to shear tension loading

3.4
weld nugget
lenticular zone in a resistance weld, where metal from both (all) sheets has melted and re-solidified

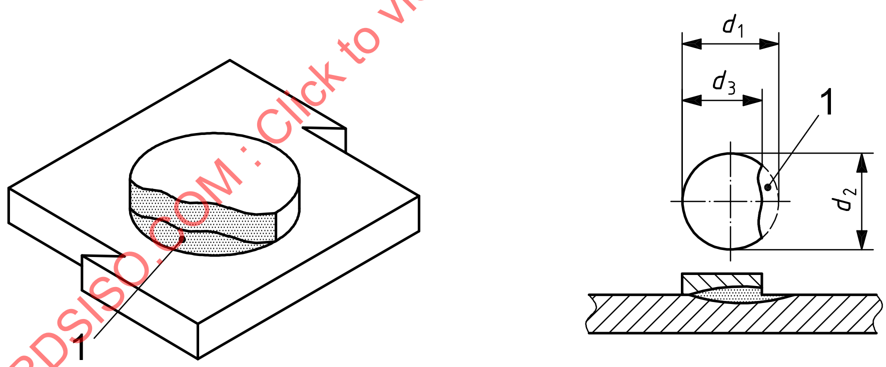
3.5
weld pitch
centre-to-centre distance between adjacent spot welds



a) **Symmetrical** [a]



b) **Asymmetrical** [a]



c) **Partial** [b]

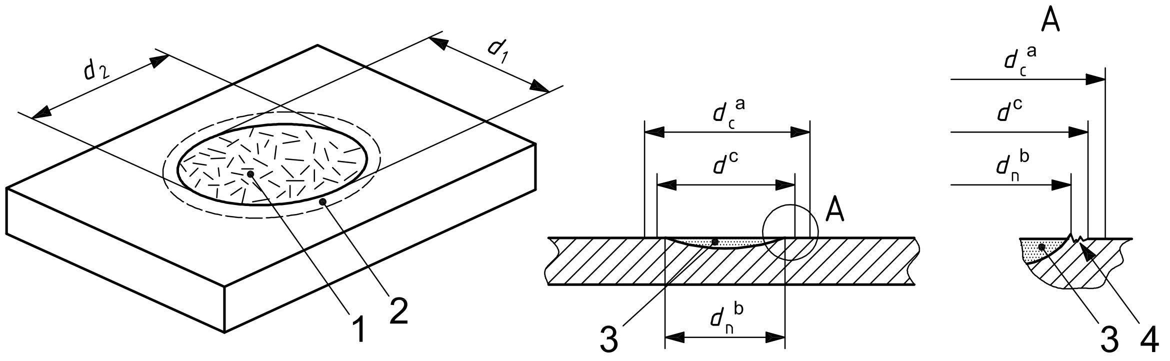
Key

1 interfacial fracture

[a] $d = d_p = (d_1 + d_2)/2$.

[b] $d = (d_1 + d_2)/2$ and $d_p = (d_2 + d_3)/2$.

Figure 1 — Measuring of weld size for weld with plug (slug) failure



Key

1 sheared nugget

2 corona bond zone

3 nugget

4 rough fracture zone

a Diameter of the corona.

b Diameter of the nugget.

c d_1 or d_2.

Figure 2 — Measuring of weld size for weld with interface failure, $d < d_c$

4 Symbols and abbreviated terms

Symbol	Term	Dimension
d	weld diameter (see Figures 1 and 2)	mm
d_c	corona diameter	mm
d_e	electrode tip diameter	mm
d_n	nugget diameter	mm
t	sheet thickness	mm
P_s	weld shear strength	kN
R_m	ultimate tensile strength of steel being welded	MPa

5 Material

5.1 Form

The steel shall be flat rolled, in coil or cut to length, and shall be free from harmful imperfections.

5.2 Steel grades

A partial list of steel grades to which this International Standard is applicable is given in Annex C.

6 Surface conditions

Prior to welding, all surfaces of components to be spot-welded shall be free from grease, scale, rust, paint, dirt, or excessive pitting. Uncoated hot rolled steel shall be in the pickled condition [1]. Coated steels can be supplied with a chromate or phosphate passivation treatment. Phosphated mild steel may be used in certain applications. These materials can be spot welded, although adjustment may be required to the welding parameters outlined in Annex B. Generally speaking, only thin phosphate pre-treatment of steel is acceptable prior to spot welding.

7 Edge conditions, form of component, and weld spacing

The components to be welded shall be free from any burrs or other defects which may interfere with interface contact in some way, or which may necessitate excessive force in fitting the parts together.

The shape of the component should be such that there is satisfactory interfacial contact in the area where the welds are to be made. The distance from the edge of the component to the centre of the weld (edge distance) should not be less than 1,25 d (see Figure 3), where d is the weld diameter as defined in 8.2. The use of edge distances less than the recommended values influences weld quality adversely. In such cases, the nominal weld size specified may be less than that given in 8.2, and therefore due allowance is needed for a lower weld strength (see 10.4).

The distance between adjacent spot welds (see Figure 3) should not be less than 16 t, and preferably greater. Tolerances for the distance between the centres of two adjacent spot welds should not exceed ± 10 %, provided that it does not fall below the minimum value.

8 Electrodes

8.1 Materials

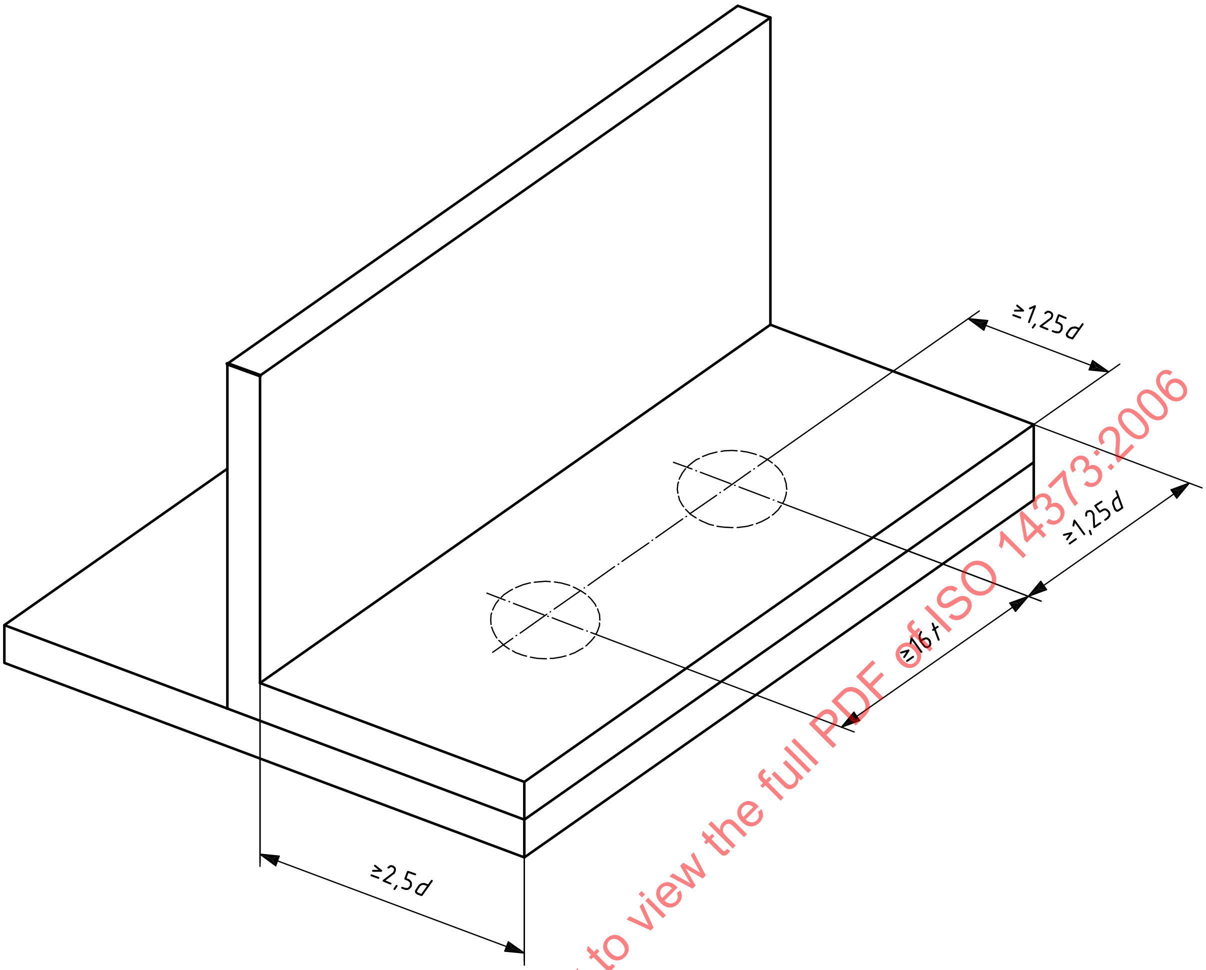
The electrode materials shall be a copper alloy and should possess high thermal and electrical conductivity. They should comply with, and be used in accordance with, ISO 5182.

8.2 Dimensions

The welding electrodes should be of sufficient cross sectional area and strength to carry the welding current and electrode force without overheating, excessive deformation, or excessive deflection.

The electrode dimensions should conform to ISO 5184 for straight electrodes, ISO 5830 for male electrode caps, and ISO 5821 for female electrode caps, as applicable.

1) Certain surface treatments, such as the application of paint primers, rust preventatives, and oils, can be applied before welding, provided that the coating is uniform in thickness and it has been shown that consistent welds conforming to this International Standard can be obtained. Excessive use of surface pre-treatment reduces the length of electrode life.



Key

d weld diameter

t sheet thickness

Figure 3 — Recommended edge conditions and weld pitch

When welding two sheets of thickness of maximum 3 mm using truncated cone type electrodes, the electrode tip diameter should be chosen from standard sizes according to the following equation.

$$d_e = 5\sqrt{t} \tag{1}$$

where

d_e is the initial tip diameter, in mm

t is the thickness of the sheet in contact with the electrode, in mm

When using truncated cone electrodes, the initial (or set-up) weld diameter should be equal to the diameter of the electrode tip; i.e.

$$d = d_e = 5\sqrt{t} \tag{2}$$

where

d is the weld diameter, in mm

CAUTION — The use of a smaller weld size than that given by Equation (2) may result in lower weld strength. This needs to be taken into account in all design calculations (see Table 1).

NOTE 1 When using domed electrodes with small tip radii or electrodes with very small working faces, Equation (1) does not always apply, in which case the electrode dimensions depend on accessibility and flange width. In such cases, the electrode tip dimensions and welding conditions are selected to give a weld diameter as specified in Equation (2), and they meet the minimum requirements outlined in Clause 10.

When welding two sheets of dissimilar thickness, the electrode dimensions and the required weld size should be specified with reference to the thinner sheet thickness. In the case of three thicknesses, the thinner sheet of each combination should be used as the reference.

Where a pad or mandrel is used as the second electrode, its surface shall be maintained to match the profile of the work piece.

During normal production, electrodes tend to mushroom, leading to an increase in electrode tip diameter. The diameter of at least one of the electrodes should not normally be allowed to increase above a value which results in a reduction in weld size to less than the acceptable minimum, e.g. $3.5\sqrt{t}$. When this diameter has been reached (if not before), the electrode should be replaced or redressed to its initial size and contour.

Table 1 — Typical minimum weld shear strength values for low carbon steel

Sheet thickness	Nominal $3.5\sqrt{t}$		Nominal $4\sqrt{t}$		Nominal $5\sqrt{t}$		Nominal $6\sqrt{t}$	
	Weld diameter	Weld strength	Weld diameter	Weld strength	Weld diameter	Weld strength	Weld diameter	Weld strength
mm	mm	kN	mm	kN	mm	kN	mm	kN
0,6	2,7	1,3	3,1	1,6	3,9	2,0	4,6	2,3
0,8	3,1	2,3	3,6	3,0	4,5	3,6	5,4	4,2
1,0	3,5	3,2	4,0	3,7	5,0	4,3	6,0	5,1
1,2	3,8	4,1	4,4	4,6	5,5	5,4	6,6	6,2
1,6	4,4	5,5	5,1	6,0	6,3	7,4	7,6	8,3
2,0	5,0	7,2	5,7	8,4	7,1	10,8	8,5	13,5
2,5	5,5	10,6	6,3	11,8	7,9	14,5	9,5	17,3
3,0	6,0	12,0	6,9	14,0	8,6	17,8	10,4	22,0

NOTE These values can be used for design calculations. Higher values are generally obtained in practice. Higher strengths are also obtained with higher strength steels.

Where electrode tips of different diameters are in contact with the work, the permissible increase over the initial diameter should apply to the smaller of the two electrode tips.

NOTE 2 A greater increase in electrode tip diameter is permissible only if tests prove that the strength of the weld does not fall below the desired requirements.

NOTE 3 In cases where automatic weld current increase is used (i.e. stepper controls), the increase in electrode tip diameter can be greater. The acceptable increase can be determined by empirical means, provided that the weld size does not fall below that specified in Equation (2).

8.3 Cooling of electrodes

The bore of the cooling water hole and pipe should conform to ISO 5184, ISO 5830, or ISO 5821, whichever is applicable.

It is recommended that the water flow be a minimum of 4 l/min per electrode for welding two uncoated steel sheets of thickness up to and including 3,0 mm. Higher flow rates are recommended when welding coated steels. The internal water-cooling feed tube should be arranged to ensure that the water impinges onto the back working face of the electrode. The distance between the back and the working face of the electrode should not exceed the values given in the relevant International Standard.

9 Weld assessment

9.1 General

A procedure shall be established in accordance with ISO 15609-5 for the welding equipment, sheet thickness, material, or combinations thereof, used in the component being welded. The procedure shall be qualified in accordance with ISO 15614-12.

9.2 Weldability tests

The weldability of a particular steel can be assessed by determining weldability lobes in accordance with ISO 14327. Weldability lobes may also be used to assess whether a particular set of welding equipment is suitable for producing a specific component. In addition to determining the weldability lobes, it may also be necessary to determine the consistency of the weld quality or the electrode life that can be obtained. These factors may need to be taken into account when selecting the appropriate welding conditions.

Guidelines for the welding equipment and welding conditions are given in Annexes A and B.

9.3 Production tests

The following tests shall be carried out to ensure consistent spot weld quality under production conditions:

a) a visual examination, in accordance with Clause 10;

b) either a peel or chisel test (manual or mechanized), in accordance with ISO 10447 or ISO 14270. Alternatively, other equivalent non-destructive tests may be used.

In addition, other tests, such as shear tests, may be carried out.

9.4 Frequency of testing

When practicable, actual components shall be used for testing. When it is not practicable to use actual components, test pieces of the same material with relevant flange widths shall be used, and there shall be sufficient material associated with the test piece in the throat of the machine to approximate the magnetic effect of the work piece under production conditions.

Tests should be carried out on each of the following occasions:

a) at the beginning of each shift or daily work period;

b) immediately before and after new or reconditioned electrodes are fitted to the machine;

c) whenever any of the following occurs: major maintenance, repairs, change in key machine components, or machine settings;

d) immediately following a change of supply sources for materials or components to be welded.

Manufacturing shall not start until a satisfactory test weld has been obtained at the beginning of each period specified above. In the event of the test piece failing at the end of the shift or work period, 2 % or 10 pieces (whichever is greater) shall be selected from the production during the period following the previous test on that machine, and they shall be tested in accordance with Clause 10. In the event of any of the selected components failing, the whole of the production during that period shall be deemed not to have conformed to this International Standard.

For visual inspection, no dressing, painting, or other operation interfering with the examination of the weld zone shall be carried out on the assemblies until after the welding has been inspected. The surface of the work pieces shall be at least of the same quality as the test pieces in conformance with 10.5.1.

10 Weld quality requirements

10.1 Weld diameter

The weld diameter for full size flange widths should approximate to $5\sqrt{t}$, and shall not fall below $3{,}5\sqrt{t}$, where t is the sheet thickness in mm, unless the application standard permits this.

In cases where a small flange width is specified that fails to satisfy the prescribed relationship between weld size and edge distance (i.e. 1,25 d), a small initial weld size should be specified and reference made to the appropriate application standard. In this case, allowance shall be made in the design calculations for the lower strength obtained with smaller welds (see 10.3).

Experience has shown that weld diameter d is approximately 1,15 times larger than the nugget diameter d_n.

NOTE The available tolerances in welding conditions and machine operation can be lower at these small weld sizes.

10.2 Weld penetration and indentation

When spot welding two sheets of equal thickness, electrode indentation in each sheet shall be less than 20 % of a single sheet thickness. Depending on the product requirements, lower indentation values may be specified. Penetration of the weld nugget into each sheet shall be between 20 % and 80 % of the sheet thickness. When welding two sheets of dissimilar thickness, indentation in the thinner sheet should not exceed 20 %. A larger indentation is permissible on the reverse side of a non-marking weld. Penetration of the weld nugget in these cases will be asymmetric, and will depend on the ratio of the sheet thicknesses being welded.

10.3 Weld fracture mode

All welds made on test pieces, test specimens, and components having a single sheet thickness of up to 1,5 mm usually have plug failures when peel or chisel tested. However, interfacial or partial plug failures may be acceptable if allowed in the application standard. Such failures may be typical of smaller weld sizes in mild steel, or of all weld sizes in some high strength steels. Weld size can be determined by measuring the plug diameter, or in the case of interface failures, the diameter of the fused zone (see Figures 1 and 2).

10.4 Weld shear strength

The weld shear strength depends on weld size, sheet thickness, and steel strength. Typical minimum values for single spot specimens of low carbon steel when tested in shear are given in Table 1. Values are given for weld sizes equating to a diameter of $3{,}5\sqrt{t}$, $4\sqrt{t}$, $5\sqrt{t}$, and $6\sqrt{t}$, produced in shear samples of dimensions specified in the appropriate International Standard. In joints between sheets of unequal thickness, the minimum weld shear strength requirement should be determined by the thickness of the thinner sheet.

For design calculations with total rupture under static loading as the criterion, the values in Table 1 may be used, with a safety factor of up to 20 % for low carbon steels. Higher strengths are generally obtained with high strength steels, and the following formula can be applied to give the minimum shear strength for a given weld size:

$$P_s = 2{,}6 t d R_m \tag{3}$$

where

d is the weld diameter, in mm

P_s is the shear strength of weld, in kN

R_m is the ultimate tensile strength of steel, in MPa

t is the sheet thickness, in mm

10.5 Weld appearance

10.5.1 Surface condition

The weld surface should be free of any surface cracks or surface porosity. Severe brassing of the weld surface should be avoided in the case of zinc-coated steels.

Surface expulsion, sometimes referred to as weld splash (whiskers), should not be acceptable.

10.5.2 Distortion

A weld is considered defective if the parent metal is distorted to the extent that the face of the weld is more than 30° out of the plane of the metal, or if a sheet is pulled more than twice its thickness out of line immediately around the weld (see Figure 4).

11 Multi-weld arrays

In the majority of applications, spot welds exist as a line of welds, or take the form of a weld array. Unless otherwise specified, all the spot welds in a given pattern shall be within ± 10 % of the specified inter-weld spacing. The maximum distance between adjacent welds shall not exceed the specified weld pitch by more than 20 % in the case of welds made using manually-held gun welders. In the case of multi-welders and robotic welding, the distance between adjacent welds shall not exceed the average pitch by more than 10 % and 20 %, respectively, provided that the inter-weld distance does not fall below the minimum specified in Clause 7.

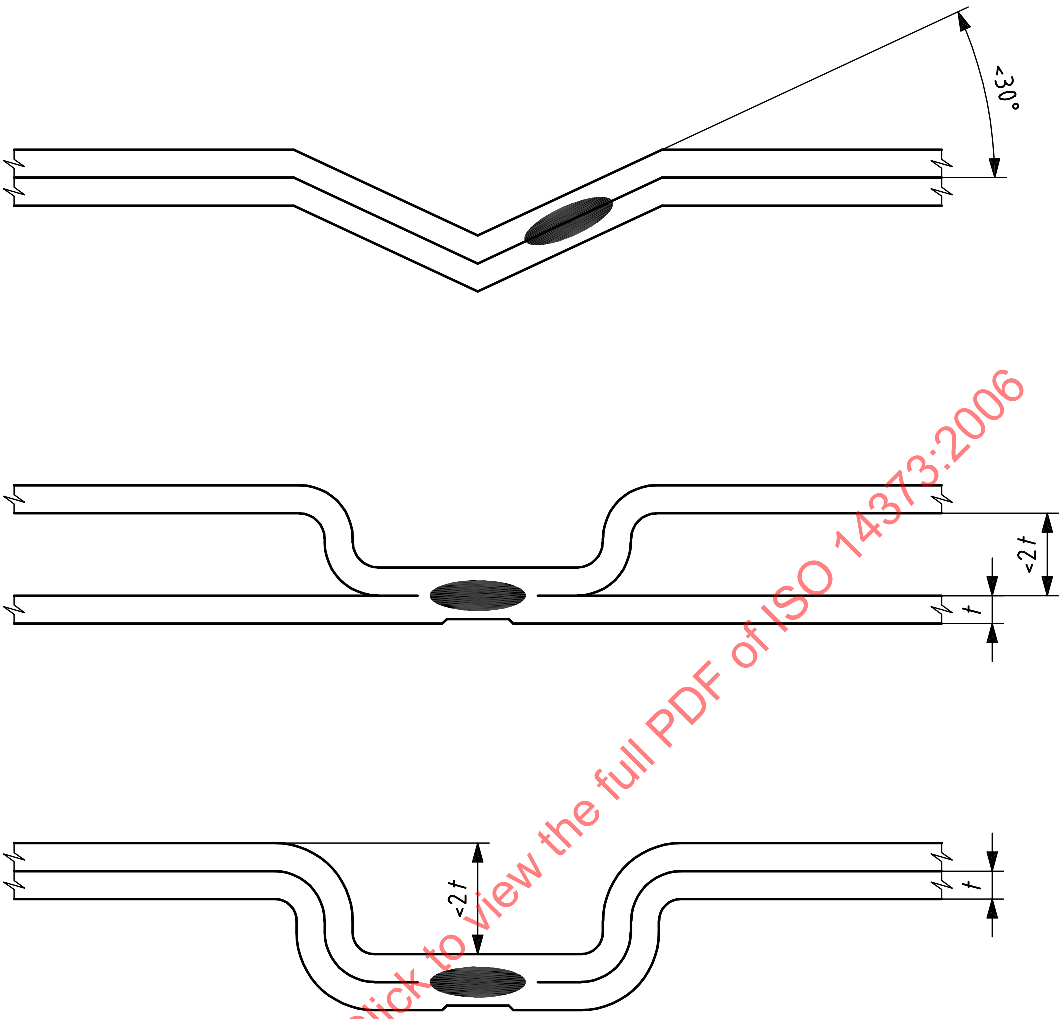
In certain circumstances, individual spot welds in a multi-weld array may be classified as follows.

a) **Critical welds** All structural and load-bearing welds fall within this classification, and shall comply with all the requirements of this International Standard.

b) **Non-critical welds** Non-structural and non load-bearing welds fall within this classification. Tack welds also fall within this category. Quality requirements of such welds can be agreed between supplier and customer, but deviations from this International Standard are permissible only with regard to location or surface appearance.

Sub-standard welds shall be separated by at least three welds conforming to the requirements summarized in Clause 10. All end welds in any array should be located at a distance greater than or equal to 1,25 d from the end of the flange (see Figure 3). Corner welds shall be considered to be end welds, a corner being any change in flange direction greater than 30°. Welds on each side of an interruption of a weld pattern, or at the junction of one panel or flange with any other panel or flange, shall be classified as end welds. All end welds shall meet the requirements of this International Standard.

In general, multi-welding techniques and robotic welding require more generous weld spacing and electrode clearances. Permissible tolerances in the location of individual welds from the specified location on the appropriate engineering design drawing shall not exceed 10 %. For both multi-welding and robotic welding, the angle of approach of the electrode when the welding current is initiated should not exceed 10° to the vertical. It should be emphasised that inclined electrodes result in elliptical weld nuggets, and the electrode life decreases as the angle of approach increases.



Key

t sheet thickness

Figure 4 — Maximum permissible distortion of sheet

Annex A
(informative)

Recommendations for spot welding equipment

The welding equipment should be equipped with an automatic control that performs at least the following cycle of operations, in the sequence specified, i.e.

a) it brings the electrodes into contact with the component and applies the welding force (the force between the electrodes) to the work piece,

b) it causes the welding current to flow after the preset welding force has been attained,

c) it maintains the flow of welding current for a preset time, the welding force being maintained throughout,

d) it interprets or stops the welding current at the end of the preset time,

e) it maintains the welding force for a preset time, the hold time, after the current ceases to flow, and

f) it releases the force at the end of the hold time, and returns the welding equipment to a condition where it is ready to recommence the cycle of operations.

The welding force, welding current, weld time, and, where needed, the squeeze time and hold time, should be variable over a range sufficient to ensure that optimum welding conditions can be obtained.

Effective tooling should be specified and any locating and clamping devices should not interfere with the welding, or cause shunting of current through the fixtures themselves.

Annex B
(informative)

Typical spot welding conditions

Tables B1 to B3 give guidance on spot welding conditions for the uncoated and coated steels in the most commonly-used thicknesses covered by this International Standard. These may require modification, depending on the mechanical properties and electrical characteristics of the welding equipment (see ISO 669).

These welding conditions are applicable for truncated cone electrodes of ISO 5182 Class A2/2 material, and may require modification for other electrode geometries and materials.

Sufficient squeeze time should be chosen to enable the electrode force to build up to its preset value.

For lightweight gun welders with limited force capability, the electrode force values are reduced by up to 30 % for sheet thicknesses greater than 1,6 mm. The welding current or weld time, or both, should be adjusted accordingly.

When welding two sheets of dissimilar thickness, welding conditions should be based on the thinner sheet.

In the case of high strength steels, higher electrode force may be necessary. Welding currents may be reduced depending on the type of high strength steel being welded. Pulse welding schedules may be necessary at the higher carbon equivalent levels, and at sheet thicknesses greater than 2,0 mm.

Table B.1 — Guidelines for spot welding of uncoated low carbon steel sheets of thickness 0,4 mm to 3,0 mm

Single sheet thickness		Electrode tip diameter	Welding parameters					
			Low force, long time conditions			High force, short time conditions		
			Force	Weld time cycles [a]	Current	Force	Weld time cycles [a]	Current
mm	mm	mm	kN		kA	kN		kA
> 0,4	⩽ 0,6	4	0,9 to 1,1	5 to 7	4 to 6	1,3 to 1,8	4 to 5	5 to 8
> 0,6	⩽ 0,8	4	1,2 to 1,3	7 to 10	5 to 7	1,7 to 2,0	6 to 8	6 to 9
> 0,8	⩽ 1,0	5	1,4 to 1,5	9 to 12	6 to 8	1,9 to 2,6	7 to 10	7 to 10
> 1,0	⩽ 1,2	5	1,6 to 1,8	11 to 15	7 to 9	2,5 to 3,2	8 to 12	8 to 12
> 1,2	⩽ 1,6	6	1,9 to 2,1	14 to 18	8 to 11	3,0 to 4,0	9 to 13	10 to 13
> 1,6	⩽ 2,0	7	2,6 to 2,9	18 to 22	9 to 13	3,9 to 5,2	10 to 14	12 to 15
> 2,0	⩽ 2,5	8	3,4 to 3,7	22 to 28	10 to 15	5,0 to 6,2	12 to 16	14 to 18
> 2,5	⩽ 3,0	9	4,4 to 4,7	28 to 35	12 to 17	6,0 to 7,5	15 to 20	17 to 20

[a] 1 cycle = 0,02 s.