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Resistance welding — Spot welding of aluminium and aluminium alloys — Weldability, welding and testing

Soudage par résistance — Soudage par points de l'aluminium et des alliages d'aluminium — Soudabilité, soudage et essais

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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.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 44, *Welding and allied processes*, Subcommittee SC 6, *Resistance welding and allied mechanical joining*, in collaboration with the European Committee for Standardization (CEN) Technical Committee CEN/TC 121, *Welding and allied processes*, in accordance with the Agreement on technical cooperation between ISO and CEN (Vienna Agreement).

This second edition cancels and replaces the first edition (ISO 18595:2007), which has been technically revised.

The main changes compared to the previous edition are as follows:

— new Clause 3 Terms and definitions has been added;

— the whole document has been technically revised to the state of the art;

— Annex C has been revised.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Official interpretations of ISO/TC 44 documents, where they exist, are available from this page: https://committee.iso.org/sites/tc44/home/interpretation.html.

Resistance welding — Spot welding of aluminium and aluminium alloys — Weldability, welding and testing

1 Scope

This document specifies requirements for resistance spot welding in the fabrication of assemblies of aluminium sheet, extrusions (both work- and age-hardening alloys) and/or cast material comprising two or three thicknesses of metal, where the maximum single (sheet) thickness of components to be welded is within the range 0,6 mm to 6 mm.

This document is applicable to the welding of sheets or plates of 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 machines is within the scope of this document:

— pedestal welding machines;

— gun welders;

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

— multi-welders;

— robotic welders.

Information on appropriate welding equipment is given in Annex A and on spot welding conditions in Annex B. The latter are for guidance only and can require modification depending on service conditions of the fabrication, type of welding equipment, characteristics of the secondary circuit, electrode material and geometry.

The welding of coated material, e.g. zinc-coated or anodized material, is outside the scope of this document.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements 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 209, *Aluminium and aluminium alloys — Chemical composition*

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

ISO 3522, *Aluminium and aluminium alloys — Castings — Chemical composition and mechanical properties*

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

ISO 5184, *Straight resistance spot welding electrodes*

ISO 5821, *Resistance welding — Spot welding electrode caps*

ISO 5830, *Resistance spot welding — Male electrode caps*

ISO 10447, *Resistance welding — Testing of welds — Peel and chisel testing of resistance spot and projection welds*

ISO 14273, *Resistance welding — Destructive testing of welds — Specimen dimensions and procedure for tensile shear testing resistance spot and embossed projection welds*

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

ISO 17677-1, *Resistance welding — Vocabulary — Part 1: Spot, projection and seam welding*

ISO 18278-2, *Resistance welding — Weldability — Part 2: Evaluation procedures for weldability in spot welding*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 669 and ISO 17677-1 apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

4 Material

4.1 Form

The material shall be according to ISO 209 and ISO 3522.

4.2 Types of aluminium alloys

A partial list of aluminium alloys is given in Annex C.

5 Surface conditions

Prior to welding, all surfaces shall be checked for their suitability for spot welding. The surfaces should preferably be free from oil, grease, lubricant, visible oxidation, paint, dirt or excessive scratches. If necessary, appropriate surface treatment, e.g. chemical etching, shall be carried out. Unless specifically developed for spot welding, mill-finish surfaces are generally not suitable for spot welding and can need pre-treatment. Die-cast material shall be free from excessive surface roughness and imperfections, e.g. as caused by washing out of the die material. Aluminium manufacturers and component suppliers can produce surface-treated material suitable for spot welding, e.g. with TiZr conversion coating. In addition, coated material can be supplied with chromate or phosphate passivation. Phosphated aluminium may be used in certain applications. Excessive quantities of dissolved gases in die-cast material shall be avoided. These materials can be spot welded, although adjustment of the welding parameters is generally necessary as outlined in Annex B.

In all cases, the surface condition and any surface treatment shall be recorded in the testing documentation.

The stability of surface condition can be evaluated by measuring the transition resistance in accordance with ISO 18594.

6 Edge distance, edge conditions, form of component and weld spacing

The components to be welded shall be free from burrs or other defects, which can, in any way, interfere with interface contact or require excessive force to fit the parts together.

The shape of the component shall be such that there is satisfactory interfacial contact in the area where welds are to be made. The distance from the edge of the component to the centre of the weld (edge distance) shall be not less than 1,25 *d* (see Figure 2), where *d* is the target weld diameter as defined in 8.2. The use of edge distances smaller than the recommended values adversely influence weld quality. Edge distances smaller than the recommended values should be used only when expressly specified. In this case, the nominal weld diameter specified may be less than that given in 8.2, and therefore due allowance needs to be made for a lower weld strength (see 9.4).

7 Electrodes

7.1 Materials

The electrode materials shall be copper alloy and should possess high thermal and electrical conductivity. The electrode materials shall comply, and be used in accordance, with ISO 5182. If other electrode materials are used, then these shall be recorded in the testing documentation.

7.2 Dimensions

The welding electrodes shall be of sufficient cross-sectional area and strength to carry the welding current and electrode force without overheating, excessive deformation, or excessive deflection. If possible, electrodes with a minimum shank diameter, *D*, of 20 mm should be used. If other electrode diameters are used, then these shall be recorded in the testing documentation.

The electrode dimensions shall, where practicable, conform to ISO 5184 for straight electrodes, ISO 5821 for female electrode caps, or ISO 5830 for male electrode caps, as applicable. In cases where these standards do not apply, the dimensions of the electrode shall be specified such that welds conforming to this document are produced.

It is recommended to employ either radiused electrodes or electrodes with a tip diameter greater than the target weld diameter *d*.

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

The electrode tip geometry and target weld diameter requirement shall be recorded in the testing documentation.

During normal production, electrodes tend to wear, leading to an increase in electrode tip diameter and damage to the tip surface geometry. The condition of at least one of the electrodes should not be allowed to deteriorate to a level that results in a reduction in weld diameter to less than the acceptable minimum, e.g. $4\sqrt{t}$. When this diameter has been reached (if not earlier), the electrode shall be replaced or restored to its initial diameter and geometry, e.g. by electrode tip dressing.

A common method to control process deterioration is to measure the increase in electrode tip geometry (or contact rea on the sheet surface), where electrode tips of different diameters are in contact with the piece to be welded, the permissible increase over the initial diameter shall apply to the smaller of the two electrode tips.

A greater increase in the diameter of the electrode(s) is permissible only if tests prove that the strength of the weld does not fall below the desired requirements, and only by specification.

In cases where adaptive control or automatic weld current increase (i.e. stepper controls), or other forms of process control are used, a greater deterioration in electrode tip condition can be tolerated. The acceptable increase in tip diameter can be determined by empirical means provided that the weld diameter does not fall below target weld diameter unless otherwise specified.

7.3 Cooling electrodes

The water flow rate should be a minimum of 6 l/min per electrode for welding two thicknesses up to and including 3 mm. Higher flow rates can be beneficial for extending electrode life. The internal water-cooling feed tube should be adjusted to ensure that the water impinges on the backward working face of the electrode. The distance between the back face and the working face of the electrode should not exceed the values given in the relevant International Standard. To achieve satisfactory electrode life, the inlet water temperature of cooling liquid should not exceed 30 °C (303 K).

8 Qualification of welds

8.1 General

A procedure shall be established for each welding machine, sheet thickness and material, or combinations thereof, used in the component being welded. The record of the procedures should be based on the appropriate items from the list given in Annex C.

8.2 Weldability test

The weldability test shall be according ISO 18278-2. The upper current limit, I_{max}, may be optionally defined by the onset of weld splash or by a specific value (or percentage) of electrode indentation. The method selected shall be recorded in the testing documentation.

Guidelines for welding conditions are given in Annex A and Annex B.

8.3 Pre-production tests

Pre-production tests shall be carried out in accordance with ISO 15614-12:

8.4 Routine tests

8.4.1 Type of tests

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

a) visual examination;

b) either a peel or chisel test (manual or mechanized) in accordance with ISO 10447.

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

8.4.2 Frequency of testing

When practicable, actual components shall be used for tests. When it is not practicable to use actual components, test pieces from identical material with relevant flange widths shall be used.

When practicable, tests should be carried out on each of the following occasions:

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

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

c) whenever any changes are made to the equipment or to its settings;

d) immediately upon change of any component of the equipment or material supply source or surface treatment.

Production 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 % may be selected from the production during the period following the previous test on that equipment, 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 conform to this document.

For visual examination, no dressing, painting or other operation interfering with the examination of the weld zone shall be carried out on the assemblies until after the weld has been examined. The surface of the work pieces shall be at least of the same quality as the test pieces that conform to 9.5.

The number and type of tests shall be sufficient to establish the statistical significance of the data in each case and shall be specified.

9 Weld quality requirements

9.1 Weld diameter

The target weld diameter, d, in millimetres, shall be specified between the contracting parties, nominally it should be $5\sqrt{t}$. Weld diameter and plug diameter shall be determined according to the definition in ISO 17677-1.

CAUTION — The use of a smaller weld diameter will result in a lower weld strength. This needs to be taken into account for any design calculations (see Table 1).

In cases where a smaller flange width is specified, which fails to satisfy the prescribed relationship between weld diameter and edge distance (i.e. 1,25d), a smaller target weld diameter 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 9.3).

NOTE The available tolerances in welding conditions and machine operation are invariably lower at these small weld diameters.

9.2 Weld dimensions

When spot welding two sheets of equal or unequal thickness, the electrode indentation in each sheet should be less than 20 % of the individual sheet thickness. A larger indentation is permissible if agreed between contracting parties or on the reverse side of a “non-marking weld”. Penetration of the weld nugget in these cases is asymmetric and depends on the ratio of the sheet thicknesses being welded. Depending on the product requirements, lower indentation values may be specified. In such cases, use of electrodes with larger dome radii can be necessary. Sheet separation should not exceed 15 % of single sheet thickness unless otherwise specified.

9.3 Weld fracture mode

All welds made on test pieces, test specimens and components having a single sheet thickness of up to 1 mm shall fail through plug failure when subjected to peel or chisel testing.

Interfacial or partial interfacial (partial plug) failures may be accepted by specification. Such failures are to be regarded as typical of smaller weld diameters and can be influenced by aluminium grade and work hardening or heat treatment condition.

9.4 Weld strength

The weld strength depends on weld diameter, sheet thickness and the strength of the aluminium alloy in the annealed condition. Typical minimum values for single spot specimens of different aluminium alloys when tested in tensile shear are given in Table 1. Values are given for weld diameters equal to a diameter of $5\sqrt{t}$ and $4\sqrt{t}$ produced in tensile shear samples of dimensions specified in the appropriate International Standard. In joints between sheets of unequal thickness, the minimum weld tensile shear

strength requirement should be determined by the thickness of the thinner sheet. This value is generally exceeded when specimens with unequal thicknesses are tested.

Specimens made from age-hardening alloys achieve higher strength values and can show different fracture modes when tested after longer periods of storage after welding or after being subjected to heat treatment. The time delay or application of heat treatment between welding and testing should be appropriate to the alloy grade and final application. The time delay and heat treatment conditions shall be recorded in the testing documentation.

The strength shall be measured in accordance with ISO 14273.

Table 1 — Recommended minimum tensile shear strength of spot-welded aluminium specimens

Thickness mm	Required tensile shear strength (TSS_{100}) kN			
	Class A		Class B	
	Minimum	Mean	Minimum	Mean
0,4	0,27	0,38	0,22	0,31
0,5	0,34	0,48	0,27	0,39
0,6	0,41	0,58	0,33	0,47
0,7	0,47	0,68	0,38	0,55
0,8	0,54	0,78	0,44	0,63
0,9	0,61	0,86	0,49	0,71
1,0	0,68	0,96	0,55	0,79
1,2	0,81	1,16	0,66	0,93
1,4	0,95	1,34	0,77	1,10
1,5	1,01	1,44	0,82	1,17
1,6	1,08	1,54	0,88	1,25
1,8	1,22	1,74	0,98	1,40
2,0	1,35	1,92	1,09	1,56
2,3	1,55	2,22	1,26	1,80
2,5	1,69	2,40	1,37	1,95
2,6	1,76	2,50	1,42	2,03
2,8	1,89	2,70	1,53	2,19
3,0	2,03	2,89	1,64	2,34
3,2	2,16	3,08	1,75	2,49
3,6	2,43	3,46	1,97	2,81
3,8	2,57	3,66	2,08	2,96
4,0	2,70	3,85	2,19	3,12

NOTE 1 These values can be used for design calculations. The values are indicated when 100 MPa class materials are used. When the ultimate tensile strength of materials is not equal to 100 MPa, the required tensile strength of welds can be calculated by multiplying the above table values by C_f in accordance with this formula:

$$C_f = \frac{R_m}{100}$$

where

C_f is the correction factor;

R_m is the ultimate tensile strength of materials used.

NOTE 2 Strength of Class A corresponds to $5\sqrt{t}$ weld diameter. In ISO 18595:2007, Table 1, the weld sizes corresponding to Class A welds were between $5{,}5\sqrt{t}$ and $6\sqrt{t}$.

NOTE 3 Strength of Class B corresponds to $4\sqrt{t}$ weld diameter.

Table 1 *(continued)*

Thickness mm	Required tensile shear strength (TSS_{100}) kN			
	Class A		Class B	
	Minimum	Mean	Minimum	Mean
4,5	3,04	4,34	2,46	3,51
5,0	3,38	4,82	2,74	3,90

NOTE 1 These values can be used for design calculations. The values are indicated when 100 MPa class materials are used. When the ultimate tensile strength of materials is not equal to 100 MPa, the required tensile strength of welds can be calculated by multiplying the above table values by C_f in accordance with this formula:

$$C_f = \frac{R_m}{100}$$

where

C_f is the correction factor;

R_m is the ultimate tensile strength of materials used.

NOTE 2 Strength of Class A corresponds to $5\sqrt{t}$ weld diameter. In ISO 18595:2007, Table 1, the weld sizes corresponding to Class A welds were between $5{,}5\sqrt{t}$ and $6\sqrt{t}$.

NOTE 3 Strength of Class B corresponds to $4\sqrt{t}$ weld diameter.

9.5 Weld appearance — Surface condition

The weld surface should be free of any surface cracks or surface porosity. Pick-up of electrode material on the weld surface can cause severe corrosion problems and should be avoided.

Surface expulsion, sometimes referred to as weld splash (whiskers), is an indication of poor surface quality, misalignment, electrode wear and/or incorrect weld settings, e.g. insufficient squeeze time, electrode force too low or weld current too high, and should not be acceptable.

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 the weld area is vertically displaced greater than two times the sheet thickness out of the plane of the sheet (see Figure 1).