INTERNATIONAL STANDARD

ISO 18595

First edition
2007-09-01

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

Reference number
ISO 18595:2007(E)

PDF disclaimer

This PDF file may contain embedded typefaces. In accordance with Adobe's licensing policy, this file may be printed or viewed but shall not be edited unless the typefaces which are embedded are licensed to and installed on the computer performing the editing. In downloading this file, parties accept therein the responsibility of not infringing Adobe's licensing policy. The ISO Central Secretariat accepts no liability in this area.

Adobe is a trademark of Adobe Systems Incorporated.

Details of the software products used to create this PDF file can be found in the General Info relative to the file; the PDF-creation parameters were optimized for printing. Every care has been taken to ensure that the file is suitable for use by ISO member bodies. In the unlikely event that a problem relating to it is found, please inform the Central Secretariat at the address given below.

COPYRIGHT PROTECTED DOCUMENT

© ISO 2007

All rights reserved. Unless otherwise specified, no part of this publication may be reproduced or utilized in any form or by any means, electronic or mechanical, including photocopying and microfilm, without permission in writing from either ISO at the address below or ISO's member body in the country of the requester.

ISO copyright office
Case postale 56 • CH-1211 Geneva 20
Tel. + 41 22 749 01 11
Fax + 41 22 749 09 47
E-mail copyright@iso.org
Web www.iso.org

Published in Switzerland

Contents

Page

Foreword ... iv

1 Scope ... 1

2 Normative references ... 1

3 Terms and definitions ... 2

4 Symbols ... 5

5 Material ... 6
5.1 Form ... 6
5.2 Types of aluminium alloys ... 6

6 Surface conditions ... 6

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

8 Electrodes ... 7
8.1 Materials ... 7
8.2 Dimensions ... 7
8.3 Cooling electrodes ... 9

9 Weld assessment ... 9
9.1 General ... 9
9.2 Weldability test procedure ... 9
9.3 Procedure qualification tests ... 10
9.4 Production tests ... 11
9.5 Frequency of testing ... 11

10 Weld quality requirements ... 11
10.1 Weld diameter ... 11
10.2 Weld dimensions ... 12
10.3 Weld fracture mode ... 12
10.4 Weld strength ... 12
10.5 Weld appearance — Surface condition ... 12

11 Multi-weld arrays ... 13

Annex A (informative) Recommendations for spot welding equipment ... 15

Annex B (informative) Typical spot welding conditions ... 16

Annex C (informative) Non-exhaustive list of aluminium alloys covered by this International Standard ... 17

Annex D (informative) Typical information to appear on a welding procedure sheet for spot welding ... 19

Bibliography ... 21

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 18595 was prepared by Technical Committee ISO/TC 44, *Welding and allied processes*, Subcommittee SC 6, *Resistance welding*.

Requests for official interpretations of any aspect of this International Standard should be directed to the Secretariat of ISO/TC 44/SC 6 via your national standards body, a complete listing of which can be found at www.iso.org.

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

1 Scope

This International Standard 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 International Standard 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 International Standard:

- 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 may 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 anodised material, 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 669:2000, *Resistance welding — Resistance welding equipment — Mechanical and electrical requirements*

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

ISO 5184, *Straight resistance spot welding electrodes*

ISO 5821, *Resistance spot welding electrode caps*

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

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

ISO 14329:2003, *Resistance welding — Destructive tests of welds — Failure types and geometric measurements for resistance spot, seam, and projection welds*

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 669:2000 and ISO 14329:2003 and the following apply.

3.1
corona bond zone
zone outside the weld nugget in which solid phase bonding has occurred

NOTE 1 See Figure 1.

NOTE 2 This zone can contribute towards the strength of the joints but may not be considered for design purposes.

3.2
corona bond diameter
d_c
outer diameter of the corona bond zone

NOTE See Figure 1.

3.3
cross-tension test
test to determine the load-carrying behaviour of a spot-welded joint subjected to cross-tension loading

3.4
interface failure
fracture through the weld nugget between the sheets in the plane of the interface

NOTE See Figure 1.

3.5
nugget diameter
d_n
mean of the maximum and minimum diameters of the fused nugget in the plane of the interface between the pieces joined, measured on a metallographic section taken transversely through the centre of the nugget

NOTE See Figure 1. The nugget diameter is the parameter on which the mechanical behaviour of a structure is based. Other parameters such as the plug or weld diameter can be influenced by the type of destructive test.

3.6
plug failure
slug/button failure
fracture in the base metal, the heat-affected zone, or the nugget leaving attached metal pulled through thickness from the opposing sheet

NOTE See Figure 2.

3.7
partial plug failure
fracture partly in the base material or the heat-affected zone and partly in the nugget leaving attached metal pulled through thickness from the opposing sheet

NOTE See Figure 2.

3.8
shear test
tensile shear test
test to determine the load-carrying behaviour of a spot-welded joint subjected to shear tension loading

3.9
weld diameter
d
⟨in an interface failure⟩ mean diameter of the fused zone measured at the interface omitting the corona bond

3.10
weld diameter
d
⟨in a plug failure⟩ mean diameter of the plug

NOTE See Figure 2 a) and b).

3.11
weld diameter
d
⟨in a partial plug failure⟩ mean diameter of the fused zone measured at the interface, omitting the corona bond area and the maximum diameter of the plug component of the failure

NOTE 1 See Figure 2 c).

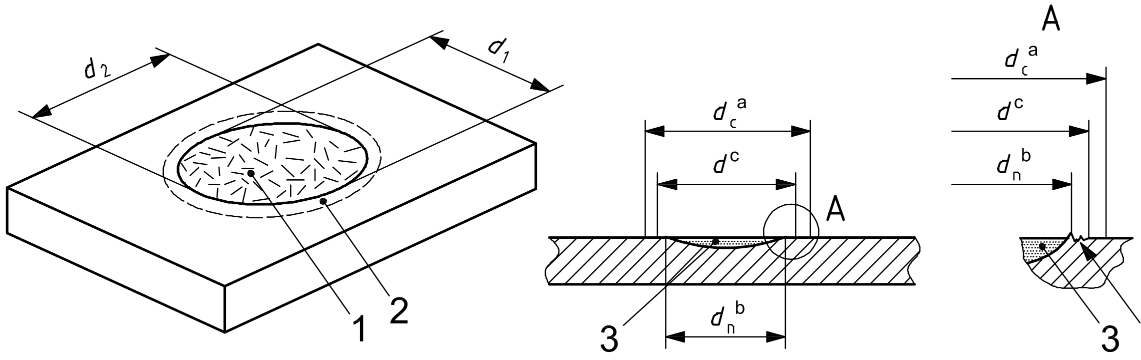
NOTE 2 The minimum diameter of the plug component of the fracture is reported separately (see Figures 1 and 2).

NOTE 3 The plug diameter in aluminium spot welds is generally less than or equal to the diameter of the (weld) nugget.

3.12
weld nugget
lenticular zone in a resistance weld where metal from both (all) sheets has melted and resolidified

3.13
plug diameter
d_p
mean diameter of the plug in both plug and partial plug failure modes

NOTE See Figure 2.



Key

1 weld with interfacial fracture ($d \approx d_n$)

2 corona bond zone

3 molten material of the nugget

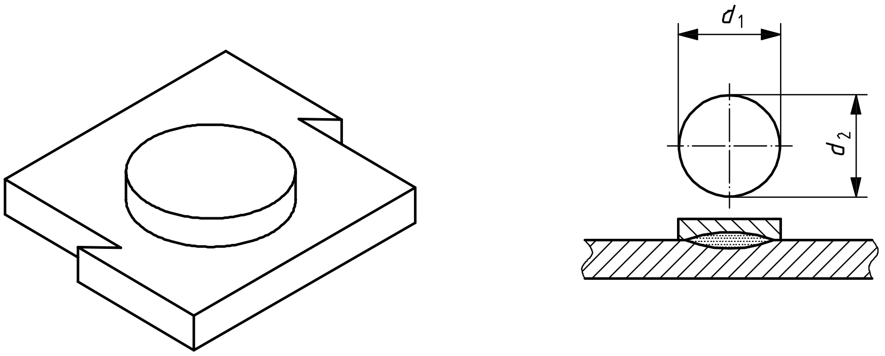
4 rough fracture zone

[a] Corona bond diameter.

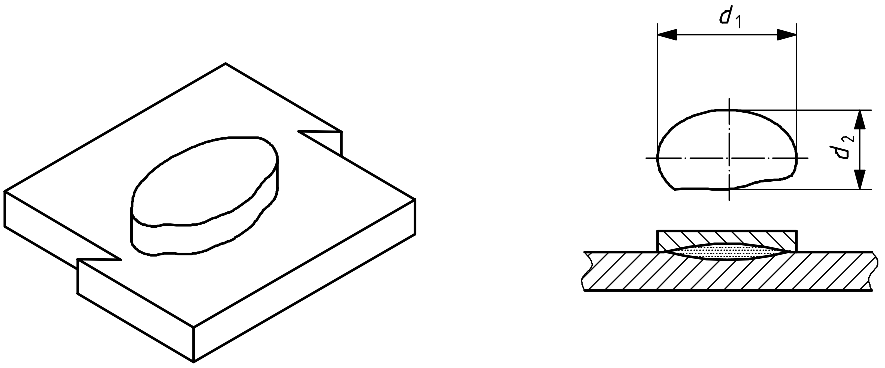
[b] Nugget diameter.

[c] Weld diameter (d_1 or d_2).

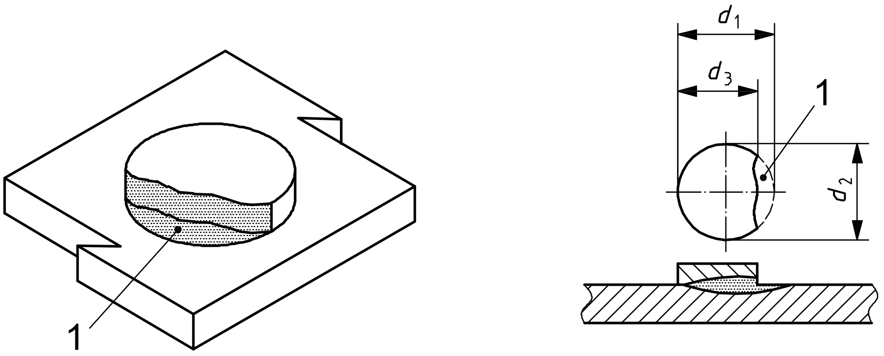
Figure 1 — Measurement of weld size — Weld with interface failure



a) Symmetrical plug failure[a]



b) Asymmetrical plug failure[a]



c) **Partial plug failure**[b]

[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 2 — Measurement of weld size — Weld with plug (slug) failure

4 Symbols

Symbol	Term	Unit
d	weld diameter	mm
d_c	corona bond diameter	mm
d_i	initial or set-up weld diameter	mm
d_n	nugget diameter	mm
d_p	plug diameter	mm
d_t	initial electrode tip diameter	mm
t	sheet thickness	mm
P_s	shear strength of weld	kN
R_m	ultimate strength of aluminium being welded	MPa

5 Material

5.1 Form

The material shall be flat rolled, extruded or cast and shall be free from harmful imperfections.

5.2 Types of aluminium alloys

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

6 Surface conditions

Prior to welding, all surfaces shall be checked for their suitability for spot welding. The surfaces should 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. Mill-finish surfaces are generally not suitable for spot welding; however, aluminium manufacturers can supply surface-treated material suitable for spot welding, e.g. with TiZr conversion coating. Extrusions shall also be in the mill-finish condition and will generally require 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. Excessive quantities of dissolved gases in die-cast material shall be avoided. In addition, coated material can be supplied with chromate or phosphate passivation. Phosphated aluminium may be used in certain applications. These materials can be spot welded, although adjustment to the welding parameters will generally be necessary as outlined in Annex B.

NOTE In most countries, chromate passivation treatment will be prohibited in the near future to avoid health risks.

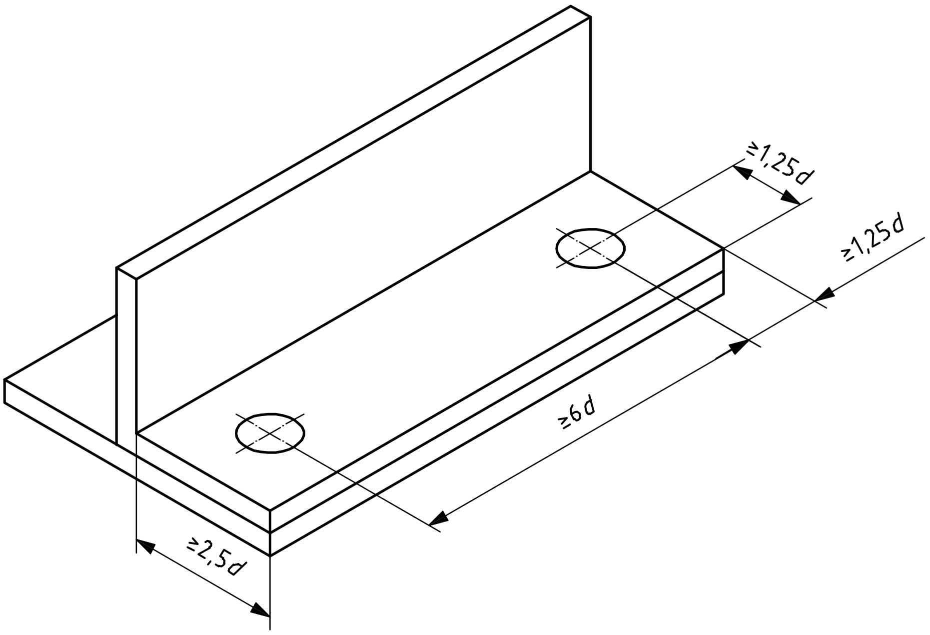
7 Edge distance, edge conditions, form of component and weld spacing

The components to be welded shall be free from burrs or other defects, which may, 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 $1{,}25d$ (see Figure 3), where d is the initial weld diameter as defined in 8.2. The use of edge distances lower than the recommended values will adversely influence weld quality. Edge distances lower than the recommended values should be used only when expressly specified. In this case the nominal weld size specified may be less than that given in 8.2, and therefore due allowance needs to be made for a lower weld strength (see 10.4).

The weld pitch, i.e. the centre-to-centre distance between adjacent spot welds (see Figure 3), shall not be less than $6d$ and preferably larger. Tolerances for distances between the centres of two adjacent spot welds should not exceed ± 10 % provided that the pitch does not fall below the minimum value. Smaller weld pitches may be specified provided that the current is increased after the first weld to compensate for the effect of shunting and the required weld quality can be achieved.

NOTE In the case of aluminium alloys, the shunting effect is much greater due to the higher electrical conductivity as compared to steel.



Key

d weld diameter

Figure 3 — Recommended edge distance and weld pitch

8 Electrodes

8.1 Materials

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

8.2 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, from the point of accessibility, electrodes with a minimum diameter, D, of 20 mm should be used.

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 International Standard are produced.

When welding two sheets of thickness up to 3 mm using truncated cone-type electrodes, the initial electrode tip diameter, d_t, in millimetres, shall be chosen according to the following equation unless otherwise specified:

$$d_t = 6\sqrt{t} + 2 \quad (1)$$

where t is the thickness, in millimetres, of the sheet in contact with the electrode.

When using truncated cone electrodes, the initial or set-up weld diameter, d_i, in millimetres, should be greater than or equal to the diameter of the electrode tip, in accordance with Expression (2):

$$d_i \geqslant d_t = 6\sqrt{t} + 2 \quad (2)$$

where

d_t is the initial tip diameter, in millimetres;

t is the thickness, in millimetres, of the sheet in contact with the electrode.

CAUTION — The use of a smaller weld size than that given by Expression (2) will result in too low a weld strength. This needs to be taken into account for any design calculations (see Table 1).

When using domed electrodes with small tip radii or electrodes with very small working faces, Equation (1) may not apply and the electrode dimensions will depend on accessibility and flange width. In this case, the electrode tip dimensions and welding conditions should be selected to give an initial weld diameter as specified in Expression (2) and 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 thickness of the thinner sheet. In the case of three thicknesses, the thinner sheet of each combination should be used as the reference.

If a smaller or larger initial weld diameter, as determined from Expression (2), is specified, then the initial tip electrode diameter should equal the specified weld diameter. However, these special cases should be specified.

Table 1 — Shear strength of spot welded aluminium specimens

Sheet thickness t mm	**Weld diameter for Class A** d mm	**Mean shear strength of welds in aluminium alloys, (nominal strength for specimen materials of ultimate tensile strength 100 MPa [a])** kN	
		Class A	Class B
0,6	4,5	0,58	0,47
0,8	5,5	0,78	0,63
1,0	6,0	0,96	0,79
1,2	6,5	1,16	0,93
1,5	7,5	1,44	1,17
1,8	8,0	1,74	1,40
2,0	8,5	1,92	1,56
2,5	9,0	2,40	1,95
3,0	9,5	2,89	2,34
3,5	10,0	3,37	2,73
4,0	11,0	3,85	3,12
4,5	11,5	4,34	3,51
5,0	12,0	4,82	3,90
5,5	12,5	5,30	4,30
6,0	13,0	5,80	4,70

[a] These values can be used for design calculations. When the ultimate tensile strength of specimen material is not equal to 100 MPa, the required shear strength of welds can be calculated with the following equation:

Required shear strength = (Minimum ultimate shear strength of the specimen × Strength described in this table)/10

During normal production, electrodes tend to wear, leading to an increase in electrode tip size. The diameter of at least one of the electrodes should not be allowed to increase above a value which results in a reduction in weld size 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 size and contour.

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 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 Expression (2), unless otherwise specified.

If an initial weld size smaller than that given by Expression (2) is specified in the application standard, then the initial electrode tip diameter should be equal to the initial weld size indicated. In this case, the permitted increase in electrode diameter due to wear, and consequently the decrease in weld size, shall be specified.

8.3 Cooling electrodes

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

It is recommended that the rate of water flow should be a minimum of 5 l/min per electrode for welding two thicknesses up to and including 3 mm. Higher flow rates are recommended when welding thicker material. 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 backward 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 should not exceed 20 °C (293 K), while the outlet temperature should not exceed 30 °C (303 K).

9 Weld assessment

9.1 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 D.

9.2 Weldability test procedure

The weldability of a particular material can be assessed by determining a weldability lobe as indicated in Figure 4. This procedure may also be used to assess whether particular welding equipment is suitable for producing a specific component. The weldability lobe depicts the welding range defined in terms of welding current and welding time at a constant electrode force, or weld current and electrode force at a constant time. In addition to determining the welding range, it may be necessary in some cases to determine the consistency of weld quality or the electrode life which can be obtained. These factors may need to be taken into account when selecting the appropriate welding conditions.

In the case of aluminium, it is of great importance that the surface condition of the test material is identical to that of the work pieces.

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

9.3 Procedure qualification tests

The following tests shall be carried out in accordance with ISO 15614-12:

a) shear tests (sometimes called tensile shear);

b) either a peel test or a chisel test (manual or mechanised) in accordance with ISO 10447;

c) visual and metallurgical examination.

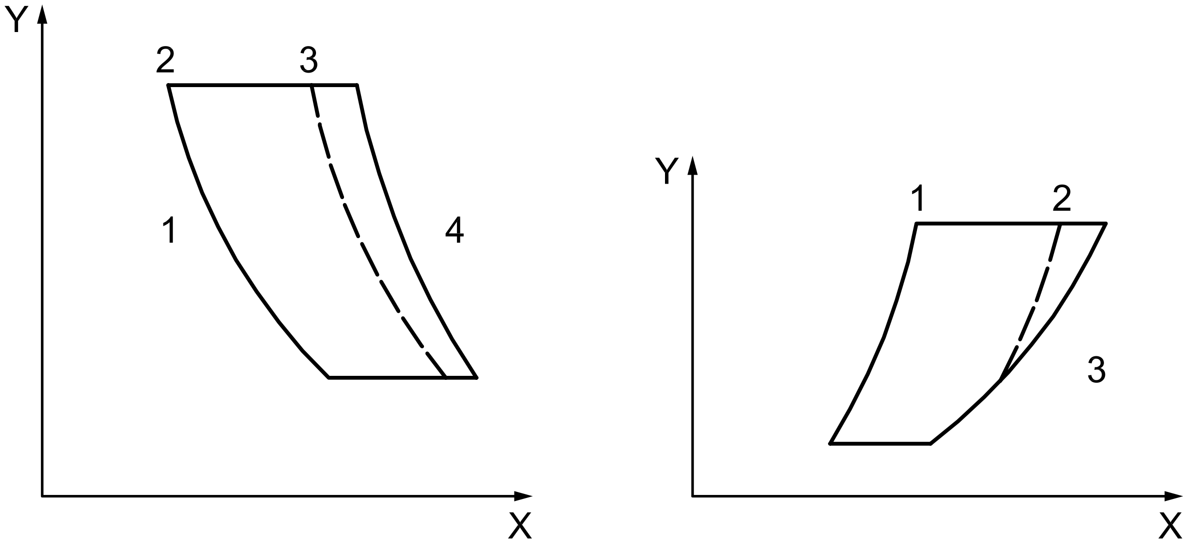
The following tests are optional and can be specified:

d) cross-tension test;

e) hardness test;

f) tests with dynamic loading, e.g. impact or fatigue tests.

All tests shall be carried out in accordance with the appropriate International Standard, where one exists.



a) Spot welding — Constant force

b) Spot welding — Constant weld time

Key

1 less than $4\sqrt{t}$
2 $4\sqrt{t}$
3 $6\sqrt{t}$
4 interfacial splash

X weld current
Y weld time

Key

1 $4\sqrt{t}$
2 $6\sqrt{t}$
3 interfacial splash

X weld current
Y electrode force

Figure 4 — Typical weldability lobes

9.4 Production 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 mechanised) in accordance with ISO 10447.

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

9.5 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. In addition, test pieces shall contain sufficient ferrous material when placed in the throat of the machine to reproduce, as precisely as possible, the magnetic effect of the piece to be welded under production conditions.

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

a) as soon as is practicable 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 % or 10 pieces, whichever is greater, shall 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 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 weld has been inspected. The surface of the work pieces shall be at least of the same quality as the test pieces that conform to 10.5.

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

10 Weld quality requirements

10.1 Weld diameter

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

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

NOTE 1 The plug diameter in aluminium spot welds is generally less than or equal to the nugget diameter, d_n.

NOTE 2 The available tolerances in welding conditions and machine operation will invariably be lower at these small weld sizes.

10.2 Weld dimensions

When spot welding is carried out for two sheets of equal or dissimilar thickness, the electrode indentation in each sheet should be less than 20 % of the single sheet thickness. 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. Depending on the product requirements, lower indentation values may be specified. In such cases, use of electrodes with larger dome radii may be necessary. Penetration of the weld nugget into each sheet should be between 20 % and 80 % of the sheet thickness. Sheet separation should not exceed 15 % of single sheet thickness unless otherwise specified.

10.3 Weld fracture mode

All welds made on test pieces, test specimens, and components having a single sheet thickness of up to 1 mm shall have a plug for peel or chisel testing.

Interfacial or partial plug failures may be accepted by specification. Such failures are to be regarded as typical of smaller weld sizes, especially in work-hardened aluminium grades or in all weld sizes in thicker material, and are no indication of inferior weld quality. 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 strength

The weld strength depends on weld size, 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 shear are given in Table 1. Values are given for weld sizes equal to a diameter of $5\sqrt{t}$ 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. This value will generally be exceeded when specimens with unequal thicknesses are tested.

Specimens made from age-hardening alloys will 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.

For design calculations for statically loaded components, the values in Table 1 may be used. Higher strengths are generally obtained with high-strength aluminium alloys. Equation (3) can then be applied to give the minimum shear strength, P_s, in kilonewtons, for a given weld size:

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

where

t is the sheet thickness, in millimetres;

d is the weld diameter, in millimetres;

R_m is the ultimate tensile strength, in megapascals, of the aluminium alloy in the as-received condition.

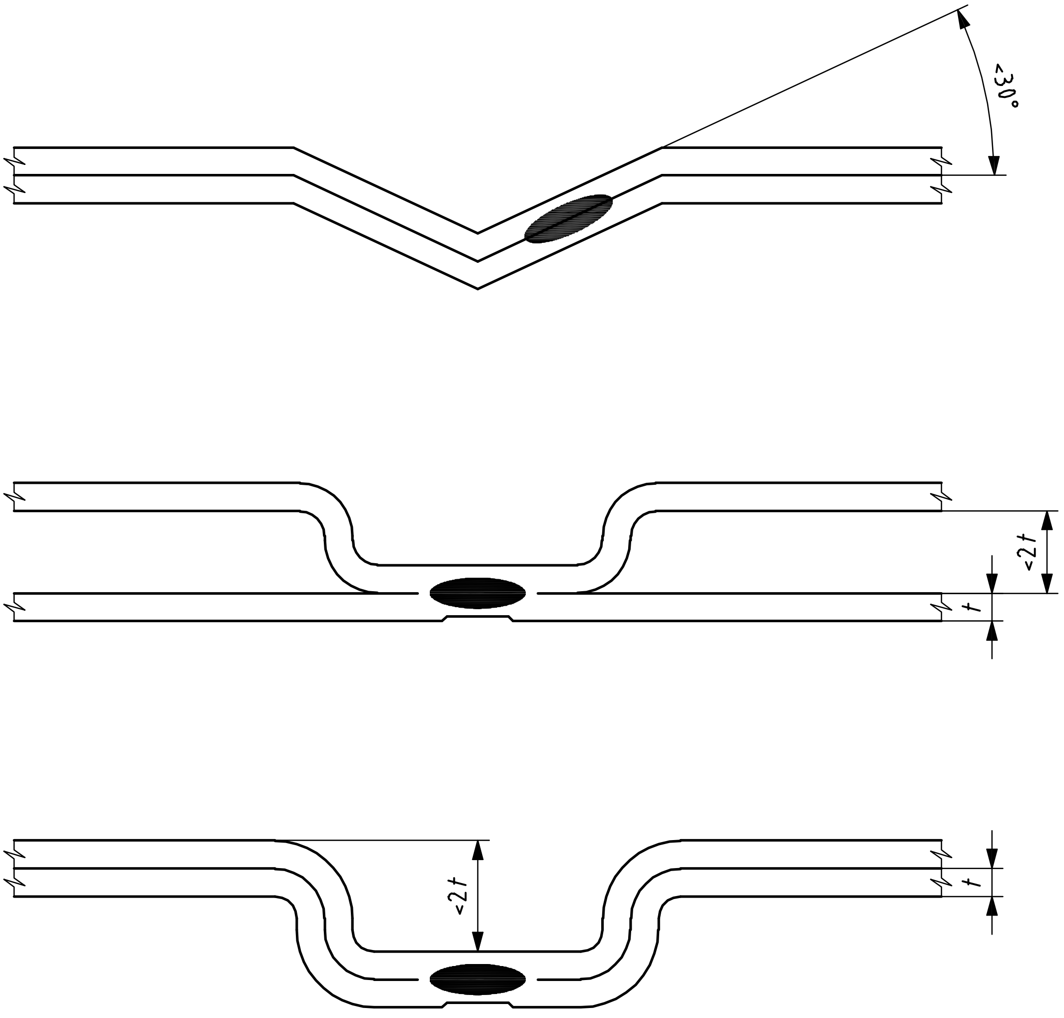
The loss in strength due to the welding process shall be taken into account in the design calculations.

10.5 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 and/or incorrect weld settings, e.g. insufficient hold 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 a sheet is pulled more than twice its thickness out of line immediately around the weld (see Figure 5).



Key

t sheet thickness

Figure 5 — Maximum permissible distortion of sheet

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 or robotic welding, the distance between adjacent welds shall not exceed the average pitch by more than 10 %, 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:

a) critical welds — all structural or load-bearing welds fall into this classification and shall comply with all the requirements of this International Standard;

b) non-critical welds — i.e. non-structural or non-load-bearing welds fall within this classification. Tack welds also fall within this category. Quality requirements of such welds can be specified but deviations from this International Standard are permissible only with regard to location or surface appearance.

Where non-conformances are specified, sub-standard welds shall be separated by at least three welds which conform to the requirements summarised in Clause 10. All end welds in any array should be located between 10 mm minimum and 17 mm maximum 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.

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 will result in elliptical weld nuggets with smaller fused zones and the electrode life decreases as the angle of approach increases.

Annex A
(informative)

Recommendations for spot welding equipment

The welding machine should be equipped with an automatic control which performs at least the following cycle of operations in the sequence given:

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

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

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

d) interrupts or stops the welding current at the end of the preset time;

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

f) releases the force at the end of this 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

Table B.1 gives guidance on spot welding conditions for aluminium alloys in the most commonly used thicknesses covered by this International Standard for a nugget size of $5\sqrt{t}$. These may require modification depending on the specified nugget diameter, the type of welding equipment/machine, the mechanical properties and the dynamic characteristics of the welding equipment, the electrodes and the material.

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

Sufficient squeeze time should be set 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 thickness greater than 1,6 mm. The welding current and/or weld time may need to be adjusted accordingly.

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

When welding three sheets, welding conditions may be based on the second thinnest sheet. In the case of high-strength alloys, higher electrode force may be necessary. Welding currents may be reduced depending on the type of high-strength aluminium being welded.

Table B.1 — Guidelines for single spot welding of aluminium alloys

Single sheet thickness	**Nugget diameter**	**Electrode**		**Welding parameters**		
t	d_n	D	R	Force	Weld time	Current
mm	mm	mm	mm	kN	ms	kA
0,50	3,6	16	75	1,8	40	26
0,75	4,5	16	75	2,2	60	31
1,00	5,0	16	75	3,0	60	34
1,25	5,5	20	100	3,5	80	36
1,50	6,0	20	100	4,0	100	39
2,00	7,0	20	100	5,0	120	44
2,50	8,0	20	100	6,5	140	50
3,00	8,5	25	100	8,0	160	52

Annex C
(informative)

Non-exhaustive list of aluminium alloys covered by this International Standard

Table C.1 — Aluminium alloys grouped according to their average thermal and electrical conductivity

Material short cut	Material group	Average thermal conductivity $\frac{W}{cm \times K}$	Average specific electrical conductivity $\frac{m}{\Omega \times mm^2}$	Average specific electrical resistance $\frac{\Omega \times mm^2}{m}$
Al99,8	I	2,2	36	0,028
Al99,5		2,2	34,5	0,029
Al99,0		2,2	33,5	0,030
AlFeSi		2,2	32,5	0,030
AlMn, AlMnCu	II	1,75	25	0,040
AlMn1Mg/Mg0,5		1,63	24,5	0,041
AlMg0,5		1,95	27,5	0,035
AlMg1		1,85	27,5	0,038
AlMg1,5-1,8		1,75	26,0	0,039
AlMg2Mn0,3		1,5	24,5	0,041
AlMg2,5		1,5	22,0	0,046
AlMg2Mn0,8		1,5	22,0	0,046
AlMgSi0,5 [a c]		2,0	30,0	0,033
AlMgSi0,7 [a c]		1,7	28,0	0,035
AlMgSi1 [a]		1,85	28,0	0,036
AlMg0,4Si1,2 [b d]		1,70	27,0	0,037
AlCuMg1 [b]		1,55	23,5	0,044
AlCuMg2 [b]		1,50	23,0	0,046
AlCuSiMn [a]		1,65	23,5	0,044
AlMg3	III	1,45	21,0	0,048
AlMg5 [e]		1,3	17,0	0,063
AlMg2,7Mn		1,35	20,0	0,051
AlMg4,5Mn		1,2	17,5	0,058
AlZn4,5Mg1 [a]		1,3	20,5	0,050
AlZnMgCu0,5 [a]		1,35	20,0	0,052
AlZnMgCu1,5 [a]		1,35	21,0	0,049

[a] Valid for the condition in which generally used: heat treated (aged).

[b] Valid for the condition in which generally used: aged at ambient temperature.

[c] Can be supplied only as extrusion.

[d] Not a standardised alloy for auto bodies.

[e] Valid for the non-standardised alloy of the same type.

Table C.2 — Weldability of aluminium alloys with the spot and roller-seam[a] welding processes, taking into consideration the surface treatment and the state of the material — work hardened or aged (thickness range 0,35 mm to 3,5 mm)

Material group [b]	**Material condition** [c]		**Brinell hardness**	**Surface treatment**			
	state	intermediate suffix		without	chemical pre-treatment	mechanical pre-treatment	service treatment in aluminium plant [d]
I	soft	.10	20...25	A, C	A, C	A, C	A, C
	semi-hard	.26	30...40	A, C	A, C	A, C	A, C
	hard	.30	40...55	A, C	A, C	A, C	A, C
II	soft	.10	30...50	A, C	A, C	A, C	A, C
	semi-hard	.26	45...70	B, C	B	B	B
	hard	.30	50...85	B, C	B	B	B
	ambient temperature ageing	.51	[e]	B, C	B	B	B
	artificial thermal ageing	.71	[e]	B, C	B	B	B
III	soft	.10	55...70	B, C	B	B	B
	semi-hard	.26	70...100	B	B	B	B
	hard	.30	88..105	B	B	B	B, C
	artificial thermal ageing	.71	[e]	B, C	B	B	B

A	No current/force programme required (only with respect to weld quality)
B	Current/force programmes recommended for higher demands on strength values with sheet thickness ⩾ 1 mm
C	Short electrode life

[a] Welding equipment shall be suitable for welding aluminium alloys: the evaluation criteria are weld quality (no imperfections) and electrode lifetime. Appropriate surface treatment improves electrode lifetime in all cases.

[b] Material groups according to Table C.1.

[c] The evaluation of the intermediate conditions is shown by the lower suffix. The conditions denoted by the suffixes .25, .27, .29, and .31 lead to an unfavourable result.

[d] Weldable as supplied.

[e] Dependent on the alloy group.

Annex D
(informative)

Typical information to appear on a welding procedure sheet for spot welding

Some or all of the following information should be included in the welding procedure sheet (see 9.1):

a) welding test procedure number;

b) related specification and/or drawing number;

c) material to be welded, specification number or composition;

d) metallurgical condition of material;

e) welding equipment/machine;

f) tooling details;

g) top electrode particulars:

  1) type and initial tip size,

  2) permissible increase of tip diameter before replacement/restoration;

h) bottom electrode particulars:

  1) type and initial tip size,

  2) permissible increase of tip diameter before replacement/restoration;

i) method of surface pre-treatment, if applicable;

j) set-up of joints;

k) welding sequence;

l) particulars of welding conditions or machine control settings:

  1) transformer tap setting,

  2) heat control setting (percentage heat),

  3) electrode force,

  4) pressure gauge setting,

  5) squeeze time,

  6) weld time,

  7) hold time,

  8) off time,

   9) throat depth,
   10) distance between arms;

m) routine for making test welds.

Bibliography

[1] ISO 14373, *Resistance welding — Procedure for spot welding of uncoated and coated low carbon steels*

ICS 25.160.10

Price based on 21 pages