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Welding for aerospace applications — Resistance spot and seam welding

National foreword

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**Welding for aerospace applications —
Resistance spot and seam welding**

*Soudage pour applications aérospatiales — Soudage par résistance
par points et à la molette*



Reference number
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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 on 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 the following URL: www.iso.org/iso/foreword.html.

This document was prepared by ISO/TC 44, *Welding and allied processes*, Subcommittee SC 14, *Welding and brazing in aerospace*.

This second edition cancels and replaces the first edition (ISO 16338:2013), of which it constitutes a minor revision.

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

- a) notes on different determination of clear annulus zone for radiographic and metallographic examination have been added under the keys of [Figures 8](#) and [9](#);
- b) transposed numbering in column *t* in [Table 14](#) has been corrected: row changed for 0,60 mm and 0,65 mm;
- c) [17.5.1.2](#) Span *S* is no longer expressed in %;
- d) to correct a hanging paragraph, a [14.1.3.1](#) "General" subheading has been introduced;
- e) other editorial revisions.

Requests for official interpretations of any aspect of this document should be directed to the Secretariat of ISO/TC 44/SC 14 via your national standards body. A complete listing of these bodies can be found at www.iso.org.

Welding for aerospace applications — Resistance spot and seam welding

1 Scope

This document specifies requirements for resistance spot and seam welding for aerospace applications.

This document does not apply if resistance welding is simply an intermediate operation and does not affect the quality of the end product, for example when tacking basic parts prior to assembly with another process.

Resistance welding of dissimilar material group combinations is not covered by this document.

Safety and health issues and concerns are not covered by 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 6520-2, *Welding and allied processes — Classification of geometric imperfections in metallic materials — Part 2: Welding with pressure*

ISO 14731, *Welding coordination — Tasks and responsibilities*

ISO 17677-1:2009, *Resistance welding — Vocabulary — Part 1: Spot, projection and seam welding*

ISO/TR 25901-1:2016, *Welding and allied processes — Vocabulary — Part 1: General terms*

ISO/TR 25901-3, *Welding and allied processes — Vocabulary — Part 3: Welding processes*

ISO/TR 25901-4, *Welding and allied processes — Vocabulary — Part 4: Arc welding*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 6520-2, ISO 14731, ISO 17677-1, ISO/TR 25901-1, ISO/TR 25901-3, ISO/TR 25901-4 and the following apply.

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

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

— ISO Online browsing platform: available at <http://www.iso.org/obp>

3.1

chisel test

destructive or non-destructive test in which welds are tested by applying a predominantly tensile force that results in stresses primarily normal to the surface of the joint interface

[SOURCE: ISO 10447:2015, 3.1, modified — “or non-destructive test” has been added and the note 1 to entry has been deleted.]

3.2

close spaced welds

spot welds with weld pitch of less than two diameters

3.3
coring
incipient melting

melting and resolidification of material at the grain boundaries of the heat affected zone and/or in the weld nugget

Note 1 to entry: These features appear to be cracks when examined at low magnification, but when examined at high magnification, are seen to be completely filled. This occurs primarily in nickel alloys.

3.4
design authority
engineering authority

organization having the responsibility for the structural integrity or maintenance of airworthiness of the hardware and compliance with all relevant documents

3.5
foil

joint member with a thickness of 0,20 mm or less

3.6
metallographic section

<resistance welding for aerospace applications> transverse cut on the diameter of a spot weld or across a seam weld, or a longitudinal cut down the centre of a seam weld

3.7
nugget

zone in spot, projection or seam weld where the metal has been melted

[SOURCE: ISO 17677-1:2009, 4.10, modified — “See Figure 2.” following the term has been deleted.]

3.8
nugget diameter

diameter of nugget measured at the faying surface

3.9
nugget penetration

extent of the nugget or fusion zone into the thickness of a joined member

3.10
peel test

destructive test in which a resistance-welded lap joint is tested by applying a peel force which results in stresses mainly in the thickness direction of the weld

3.11
preliminary welding procedure specification
pWPS

document containing the required variables of the welding procedure which has to be qualified

[SOURCE: ISO/TR 25901-1:2016, 2.5.6]

3.12
production witness test specimen

weld of test specimen made in production setups and destructively tested to provide data on the qualities of production welds

3.13

resistance seam welding

<resistance welding for aerospace applications> resistance welding process which produces coalescence at the faying surfaces by the heat obtained from resistance to electric current through the work parts held together under pressure by electrodes

Note 1 to entry: The resulting weld is a series of overlapping resistance spot welds made progressively along a joint by turning wheel electrodes or indexing the part under fixed electrodes.

3.14

resistance spot welding

resistance welding process that produces a weld at the faying surfaces between overlapping parts by the heat obtained from resistance to the flow of welding current through the workpieces from electrodes that serve to concentrate the welding current and pressure at the weld area

[SOURCE: ISO 17677-1:2009, 1.12]

3.15

roll spot welding

resistance welding process variant that makes intermittent spot welds using one or more rotating circular electrodes

Note 1 to entry: The rotation of the electrodes might or might not be stopped during the making of a weld.

[SOURCE: ISO 17677-1:2009, 3.5]

3.16

seam weld width

width of the weld metal in the plane of the faying surfaces in a direction normal to the longitudinal axis of the linear seam weld

[SOURCE: ISO 17677-1:2009, 4.14]

3.17

sheet

<resistance welding for aerospace applications> joint member with a thickness of more than 0,20 mm

3.18

weld pitch

centre-to-centre distance between adjacent spot welds

[SOURCE: ISO 14373:2015, 3.4]

3.19

welding condition

<resistance welding for aerospace applications> provision for the manufacture of a given weld, including material, configuration, material preparation, cooling, electrode material, electrode geometry, welding machine number, and all weld parameters that have a direct influence on the quality of the weld

3.20

welding parameter

<resistance welding for aerospace applications> machine setting or adjustment

EXAMPLE Examples are electrode force, welding current, welding speed, welding time.

3.21

welding procedure specification

WPS

document that has been qualified and provides the required variables of the welding procedure to ensure repeatability during production welding

[SOURCE: ISO/TR 25901-1:2016, 2.5.4]

4 Symbols and abbreviated terms

D_s	minimum required nugget diameter or seam weld width (see Table 11)
e_l	lower electrode indentation
e_u	upper electrode indentation
F	force
l	length of test specimen
s_M	actual nugget diameter or seam weld width, as determined by metallographic examination
t	thickness of the thinner sheet
t_o	thickness of outer member
w	test specimen width/overlap
Ac	test lot average
NDT	non-destructive testing
pWPS	preliminary welding procedure specification
QA	quality assurance
SPC	statistical process control
WPQR	welding procedure qualification record
WPS	welding procedure specification

5 Specific engineering requirements

In the event of any conflict between the requirements of this document and those requirements specified in the engineering definition, the engineering definition shall take precedence.

The classification of the joint (see [Clause 6](#)) shall be designated on the part specification or drawing.

6 Classification of the joint

Classification of the joint is based on the following.

- Class I: a welded joint whose failure under operating conditions causes the loss of the aircraft/spacecraft or one of its main components, or constitutes a direct hazard to people.
- Class II: a welded joint whose failure causes malfunctions without compromising continued safe flight until the end of the mission.
- Class III: a welded joint whose failure does not affect the safety and the transport function of the aircraft/spacecraft.

7 Production requirements

Prior to production, the following requirements shall be met:

- a) personnel qualification;

- b) welding machine qualification;
- c) welding procedure qualification.

8 Welding personnel requirements

The welding personnel shall be trained and be competent for the process. If requested by the design/engineering authority, ISO 14732 may be invoked.

9 Person responsible for welding procedure qualification and welding machine qualification tests

The welding coordinator (see ISO 14731) shall be designated, in writing, as responsible for welding procedure qualification and welding machine qualification test. The welding coordinator shall have knowledge and experience relevant to the welding process, and be acceptable to the responsible design/engineering authority or recognized examining body.

It is recommended that the welding coordinator be qualified as International Welding Engineer (IWE) according to IIW IAB-252-11.

The welding coordinator may authorize another person to administer the welding procedure qualification or welding machine qualification test.

10 Material groups

Material group A: unalloyed steel, low-alloyed steels, high-alloyed ferritic steels.

Material group B: high-alloyed austenitic and martensitic steels, nickel and nickel alloys, cobalt alloys.

Material group C: titanium and titanium alloys, niobium, zirconium and other reactive metals.

Material group D: aluminium and aluminium alloys, magnesium and magnesium alloys.

Material group E: materials that do not conform to material groups A to D (e.g. molybdenum, tungsten and copper alloys).

11 Preparation of parts to be welded

11.1 General

External and faying surfaces of the parts to be welded shall be free from contaminants, such as heavy oxides, scale, ink, grease, dirt or other substances, or surface conditions detrimental to the welding process. The surfaces shall be regular, this being a determining factor in ensuring good reproducibility of the weld.

11.2 Cleaning requirements

A specific cleaning procedure (e.g. pickling) shall be determined according to the materials and precisely defined by each manufacturer in line with the design/engineering authority requirements.

The cleaning procedure used to prepare materials for welding procedure qualification shall be specified on the pWPS. For materials in group D, surface resistance requirements shall be specified by the design/engineering authority.

Time limits between cleaning and welding shall be specified in the pWPS or other manufacturing documentation.

11.3 Surface coatings

Surface coatings, specified by the design/engineering authority, shall be identified in the pWPS.

11.4 Assembly

Mating parts assembled for welding shall fit so that before the first and each subsequent weld is made, the surfaces to be joined by the weld are in contact with one another or can be made to contact one another by manual pressure.

12 Equipment requirements

12.1 Welding machines

The welding machine shall be qualified according to [Clause 13](#), calibrated and maintained according to manufacturer recommendations and/or any other requirements as defined by the design/engineering authority.

A preventative maintenance procedure shall be established and maintenance records kept.

12.2 Electrodes

All electrodes in use shall be permanently marked with the electrode material designator, as a minimum.

12.3 Shear testing machines

12.3.1 General

Shear testing machines shall be accurate to within $\pm 2\%$ of the indicated reading. The shear testing speed shall not exceed 13 mm/min.

12.3.2 Stationary shear testing machines

Stationary shear testing machines shall be calibrated for accuracy at intervals not to exceed one year.

12.3.3 Portable shear testing machines

Portable shear testing machines shall be calibrated for accuracy at intervals not to exceed two months.

12.4 Jigs and fixtures

Jigs and fixtures shall be so designed as to minimize the shunting of welding current through them instead of passing through the workpieces. All tooling that is required to locate welds or assist in the assembly of welded parts that passes through the magnetic field during the welding operation should be made of nonmagnetic materials insofar as possible.

13 Welding machines

13.1 Qualification requirements

13.1.1 General

Existing machine qualifications to other standards prior to the release of this document are considered qualified, unless otherwise specified by the design/engineering authority.

Prior to production, qualification shall be performed on each resistance spot or seam welding machine to determine its ability and consistency of operation. The purpose of qualification is to identify and verify the range of welding for which a welding machine may be considered capable. Welding conditions shall be documented on a WPS as part of a machine qualification test report. Typical examples of report forms are given in [Annexes A](#) and [B](#). Such forms may be modified or expanded as required. After approval is obtained, these reports shall be available for review.

Machines shall be qualified to meet the weld requirements for the most critical class (see [Clause 6](#)) in each material group (see [Clause 10](#)) for which it is intended to be used in production. A welding machine qualified to weld to the requirements of one class in a material group shall be automatically considered qualified for less critical classes in the same material group. A spot welding machine qualified for spot welding is also qualified for overlap spot welding. Machines used for class III foil welding may be qualified by establishing a WPS. Machines qualified to a class for seam welding shall be considered qualified for roll spot welding to the same class.

13.1.2 Method of welding machine qualification

13.1.2.1 General

No maintenance work or control adjustments are permitted during the welding of test specimens.

13.1.2.2 Test materials

Test materials for material groups A, B, C and D qualification may be any material from that group commonly used in production.

Qualification with material of group A qualifies for welding material of group A only.

Qualification with material of group B qualifies for welding material of group B only.

Qualification with material of group C qualifies for welding material of group C only.

Qualification with material of group D qualifies for welding material of group D only.

Qualification with a specific material of group E qualifies for welding with the same material only.

13.1.2.3 Test requirements

Weld tests listed in [13.2](#) shall be performed and shall meet applicable acceptance criteria. For each material group, two test sets shall be required: the high-end (thickest) machine qualification test and the low-end (thinnest) machine qualification test. Typically, the high-end and low-end machine qualification tests are each made up of two members of equal thickness. Alternatively, members of different thicknesses and/or a weld combination of more than two members may be used. The following requirements shall be used to determine the required machine qualification tests to cover production work.

- a) The total thickness of all members in a production weld combination shall not be more than the total thickness of all members in the high-end machine qualification test and shall not be less than the total thickness of all members in the low-end machine qualification test.
- b) The thinnest contact member (member in contact with the electrode) of any production weld combination shall not be thicker than the thinnest member in the high-end machine qualification test
- c) The thinnest contact member (member in contact with the electrode) of any production weld combination shall not be thinner than the thinnest member in the low-end machine qualification test.
- d) If a machine is used for a specific weld combination then it need only be qualified for that weld combination according to the quantities and methods specified in [13.2](#).

NOTE 1 For examples of the application of rules stated in this subclause, see [Annex D](#).

NOTE 2 If more than one welding machine of the same type is to be qualified, the extent of testing can be reduced at the discretion of the design/engineering authority.

13.1.2.4 Welding machine requalification

Requalification shall be required if the welding machine is rebuilt or if significant operational changes (e.g. replacement of main components, facility relocation and change of power supply) are made. The number of test specimens for sheet welding may be reduced (see [Table 2](#)).

Unless otherwise authorized by the design/engineering authority, when welding machine requalification is required, all WPS shall be requalified prior to production use.

Changes that do not require requalification of the welding machine are as follows:

- a) change of location within a plant, which maintains the same electrical circuit;
- b) general machine maintenance;
- c) replacement of parts, such as electrodes and electrode holders, which do not affect the pressure or power characteristics.

13.2 Test piece configuration and examination requirements

Tests shall be as specified in [Table 1](#) and as shown in [Figure 1](#) and [Figures 3](#) to [5](#).

Table 1 — Welding machine qualification test pieces and examination requirements

Class	Test piece	Amount per test set	Examination			
			Visual	Radiographic	Mechanical	Metallographic
Spot welds — Sheet						
I	Figure 1 a) or 1 b)	105 weld spots	all	all	100 shear	5 microsections
II	Figure 1 a) or 1 b)	105 weld spots	all	all	100 shear	5 macrosections
III	Figure 1 a) or 1 b)	53 weld spots	all	none	50 shear	3 macrosections
Spot welds — Foil						
I, II, III ^a	Figure 3	<i>l</i> = 300 mm continuous length of weld	all	none	peel	none
Seam welds — Sheet						
I	Figure 5	<i>l</i> = 600 mm continuous length of weld	all	all	none	8 microsections (4 transverse, 4 longitudinal)
II	Figure 5	<i>l</i> = 600 mm continuous length of weld	all	all	none	8 macrosections (4 transverse, 4 longitudinal)
III	Figure 5	<i>l</i> = 300 mm continuous length of weld	all	none	none	4 macrosections (2 transverse, 2 longitudinal)
Seam welds — Foil						
I, II, III ^a	Figure 4	<i>l</i> = 300 mm continuous length of weld	all	none	peel	none

^a Machines used for class III foil welding may be qualified by establishing a WPS.

For welding machine requalification, the number of test specimens for sheet welding may be reduced according to [Table 2](#).

Table 2 — Machine requalification test pieces and examination requirements

Class	Test piece	Amount per test set	Examination			
			Visual	Radiographic	Mechanical	Metallographic
Spot welds — Sheet						
I	Figure 1 a) or 1 b)	53 weld spots	all	all	50 shear	3 microsections
II	Figure 1 a) or 1 b)	53 weld spots	all	none	50 shear	3 macrosections
III	Figure 1 a) or 1 b)	28 weld spots	all	none	25 shear	3 macrosections
Seam welds — Sheet						
I	Figure 5	$l = 300$ mm continuous length of weld	all	all	none	4 microsections (2 transverse, 2 longitudinal)
II	Figure 5	$l = 300$ mm continuous length of weld	all	all	none	4 macrosections (2 transverse, 2 longitudinal)
III	Figure 5	$l = 150$ mm continuous length of weld	all	none	none	2 macrosections (1 transverse, 1 longitudinal)

14 Welding procedure (WPS)

14.1 Qualification requirements

14.1.1 General

Existing WPS qualifications to other standards prior to the release of this document are considered qualified, unless otherwise specified by the design/engineering authority.

Prior to production, a WPS shall be established to produce the minimum strength, nugget diameter or seam weld width or quality requirement specified in this document or as defined by the design/engineering authority. Qualification results shall be entered on the test report, which includes the settings used to weld the test specimens. Weld settings shall not be adjusted during the welding of the qualification test specimens. After qualification acceptance, production setups shall be allowed to deviate from the WPS as allowed by [15.2.4](#).

NOTE If production parts are used for qualification, design/engineering authority approval can be required.

14.1.2 Determination of weld settings

For each welding machine and each combination of relevant material conditions (such as alloy, heat treatment, surface conditions, geometry, material stack-up and thickness combinations), effective welding machine settings for test and production parts shall be determined. The conditions and parameters shall be defined on a pWPS before welding the qualification test pieces. Typical examples of report forms are given in [Annexes A](#) and [B](#). These shall be modified or expanded as required. After acceptance, production setups shall be made to the qualified pWPS, with the variation of [15.2.4](#) allowed.

14.1.3 Methods of welding procedure qualification

14.1.3.1 General

A welding procedure shall be qualified by one of the following methods.

14.1.3.2 Standard welding procedure qualification

Tests shall be conducted to demonstrate that on a given set of materials and a particular welding machine, the welding procedure produces resistance welds that conform to the requirements of [Tables 12 to 14](#) (sheet), [14.2](#) and [Clause 17](#).

14.1.3.3 Design allowable qualification

The design allowable qualification method shall be used when specific requirements are defined by the design/engineering authority. Tests shall be conducted to demonstrate that on a given set of materials and a particular welding machine, the welding procedure produces resistance welds that conform to these requirements.

The pWPS shall state that the design allowable qualification method was used and shall give reference to the specific requirements.

14.1.4 Thickness combination limits

Thickness combinations falling within the following limits shall not require a separate qualified welding procedure, provided the qualified average nugget diameter or seam weld width can be reproduced with a weld heat (current) setting that lies within $\pm 10\%$ of the value established by the original WPS; all other conditions being the same.

- a) Foil. The variation in thickness (with regard to the original procedure) of either outer sheet is within $\pm 0,03$ mm and the variation in the sum of the thicknesses (with regard to the original procedure) of the combination is within $\pm 0,08$ mm.
- b) Outer sheet $\leq 1,02$ mm, inclusive:
 - 1) the variation in thickness of either outer sheet is within $\pm 0,10$ mm;
 - 2) the variation in the sum of the thicknesses of the combination is within $\pm 0,15$ mm.
- c) Outer sheet $> 1,02$ mm:
 - 1) the variation in thickness of either outer sheet is within $\pm 10\%$ for material groups D and E alloys, or $\pm 20\%$ for material groups A, B and C alloys;
 - 2) the variation in the sum of the thicknesses of the combination is within $\pm 10\%$.

14.1.5 Welding procedure specification (WPS)

After qualification, the WPS shall be available to machine operators and quality assurance (QA). The following parameters shall be included in the WPS and any changes of these critical parameters outside the allowable limits of [15.2.4](#) shall require requalification:

- a) force;
- b) electrode (geometry and material group);
- c) weld settings (time, current, number of cycles);
- d) surface preparation;
- e) weld overlap (number of spots in seam weld unit length) on seam welds;
- f) travel speed on roller seam welds.

The purpose of qualification is to replicate the results expected on production components; therefore, test conditions for qualification shall correspond with expected production conditions.

A suggested form for a WPS is given in [Annex B](#). Further information on WPS guidelines is given in ISO 15609-5.

14.1.6 Welding procedure requalification

Requalification of the WPS shall be required if the welding machine was requalified (see [13.1.2.4](#)) or if significant operational changes are made to the WPS as specified in [14.1.5](#).

Requalification of the WPS shall also be required if a change in the cleaning procedure produces different results (nugget and strength ranges) than the former method.

NOTE An existing WPS need not be requalified for another contract or design, provided all material conditions (such as alloy, heat treatment, surface conditions, geometry, material stack-up and thickness combinations) are equivalent as defined by the existing WPS.

Requalification of a welding procedure shall be required at any time if there is any reason to doubt the ability of a welding machine to produce satisfactory welds using the existing WPS.

14.2 Test piece configuration and examination requirements

Tests shall be as specified in [Tables 3 to 6](#) and as shown in [Figures 1 to 5](#). Welds shall be located within $\pm 1,5$ mm of the centre of the overlap. Test piece size tolerance shall be $\pm 1,5$ mm.

Table 3 — pWPS test pieces and examination requirements — Spot welds — Sheet

Type	Material group	Class	Test piece	Number of weld spots ^a	Examination			
					Visual	Radiographic	Mechanical ^a	Metallographic
Isolated or roll spot weld	A, B, C	I	Figure 1 a) or 1 b)	13	all	all	10 shear	3 microsections
		II	Figure 1 a) or 1 b)	8	all	all	5 shear	3 macrosections
		III	Figure 1 a) or 1 b)	5	all	none	3 shear	2 macrosections
	D, E	I	Figure 1 a) or 1 b)	25	all	all	20 shear	5 microsections
		II	Figure 1 a) or 1 b)	15	all	all	10 shear	5 macrosections
		III	Figure 1 a) or 1 b)	5	all	none	3 shear	2 macrosections
Close spaced welds	A, B, C, D, E	I	Figure 2	20	all	all	none	10 microsections
		II	Figure 2	10	all	all	none	5 macrosections
		III	Figure 2	3	all	none	none	3 macrosections

^a If more than two sheets are assembled, the mechanical tests are to be repeated for separate examination of each assembly joint face in the final configuration (two series of tests for assembly of three sheets, three series for four sheets, etc.; see [17.5.4](#)).

Table 4 — pWPS qualification test pieces and examination requirements — Spot welds — Foil

Material group	Class	Test piece	Examination			
			Visual	Radiographic	Mechanical	Metallographic
A, B, C, D, E	I	Figure 3	all	none	peel test min. 10 consecutive spot welds	4 microsections: randomly select four spot welds from a minimum of 10 welded
	II, III	Figure 3	all	none	peel test min. 10 consecutive spot welds	none

Table 5 — pWPS qualification test pieces and examination requirements — Seam welds — Sheet

Material group	Class	Test piece	Length of weld	Examination		
				Visual	Radiographic	Metallographic
A, B, C, D, E	I,	Figure 5	$l = 300$ mm continuous length of weld	all	all	4 transverse microsections (Tr) 4 longitudinal microsections (Lo)
	II	Figure 5	$l = 300$ mm continuous length of weld	all	all	4 transverse macrosections (Tr) 4 longitudinal macrosections (Lo)
	III	Figure 5	$l = 300$ mm continuous length of weld	all	none	1 transverse macrosections (Tr) 2 longitudinal macrosections (Lo)

Table 6 — pWPS qualification test pieces and examination requirements — Seam welds — Foil

Material group	Class	Test piece	Length of weld	Examination			
				Visual	Radiographic	Mechanical	Metallographic
A, B, C, D, E	I	Figure 4, 2 specimens required	$l = 300$ mm continuous length of weld	all	none	peel 17.5.3 a)	1 longitudinal microsection: 25 mm
	II, III	Figure 4, 2 specimens required	$l = 100$ mm continuous length of weld	all	none	peel 17.5.3 b) (75 mm mini- mum length)	1 longitudinal macrosection: 25 mm

15 Quality requirements for production

15.1 General

A WPS shall be available and used for each production joint.

15.2 Production witness testing

15.2.1 General

Periodic tests shall be conducted to determine if a particular welding machine, in combination with a specific welding procedure and other specific conditions used during production, produces resistance welds that conform to the requirements of this document. Documentation of these tests shall be contained in an individual register (logbook) for each resistance welding machine and shall be available for review.

15.2.2 Witness test specimens

Qualification and production witness test specimens shall conform to the production parts they represent with respect to material, thickness, overlap, configuration, and surface condition or preparation. Production witness specimens shall be run with production weld conditions using either qualification specimens or a simulation of the production part.

When production conditions exist that were not applied during qualification, but cause machine settings to differ from qualification settings so as to exceed the permitted parameter adjustments (see [15.2.4](#)), the qualification shall be run again with the subject critical production conditions included. Examples of such production conditions include, but are not limited to, magnetic material in the machine throat, curvature of the part, spot spacing and part (overlap) width.

15.2.3 Surface resistance

A daily check shall be made of the surface resistance, in microohms, for material group D welds when running production parts. A minimum of five readings shall be made on the production parts or on samples typical of the material being welded and its surface condition and preparation. The details of the method of obtaining the surface resistance measurement shall be the same as those used for the pWPS qualification or cleaning procedures and the values of the surface resistance shall not exceed the limits of consistency and maximum values established at that time.

Use of existing material cleaning and etching process control/monitoring may be substituted for the surface resistance checks as deemed appropriate by the design/engineering authority.

Use of in-process weld control monitoring capable of detecting when a surface resistance shift outside of the specification range occurs may be substituted for the surface resistance checks as deemed appropriate by the design/engineering authority.

15.2.4 Parameter adjustments

Welding parameters (see [14.1.5](#)) may be varied by $\pm 5\%$ from the established WPS values, or by $\pm 10\%$ when only one setting is adjusted. When adjustments are made during production, welding parameters shall stay within this range, and within $\pm 5\%$ of the parameters used for the witness test specimens.

If satisfactory welding cannot be maintained within these limits of adjustment, welding shall be stopped and the welding machine shall be checked for faulty operation. If it can be shown that conditions other than those controlled by the qualified welding procedure were the cause of the faulty welding and that

after their correction the original qualified welding procedure is capable of producing acceptable welds, the establishment of a new qualified welding procedure shall not be required (see [15.3.2](#)).

NOTE For roller seam weld electrode diameter, variations > 5 % can be permissible with the agreement of the responsible design/engineering authority.

15.2.5 Production witness test specimen configuration and examination

15.2.5.1 General

The following witness tests shall accompany the welding of production parts. The witness test specimens duplicate the production parts in all conditions controlled by the qualified welding procedure and the drawing. Results of these tests shall be maintained in an individual register (logbook) by each welding machine.

15.2.5.2 Witness test

Production witness test specimens shall be as follows:

- a) preproduction witness test: witness test specimens taken at the start of each work day or before a new production lot is welded or before welding is resumed after a machine shutdown;
- b) intermediate witness test: witness test specimens taken during production welding or before or after minor welding equipment change;

EXAMPLE Examples of minor equipment changes are electrode change or fixture change.

- c) postproduction witness test: witness test specimens taken at the end of each production work day or after the completion of a production lot.

Depending on the weld class, production parts shall be accompanied by witness tests according to [Table 7](#).

Table 7 — Witness test requirements

Class	Preproduction test	Intermediate test			Postproduction test
		Periodica	Before minor equipment change	After minor equipment change	
I	required	every 60 min	required	required	required ^b
II	required	every 120 min	required	required	required ^c
III	required	not required	not required	required	not required

^a Intermediate test periodic time starts with the first production weld in the lot. Time is calculated as continuous machine-on time and not actual time the current is flowing through the part.

^b Test not required if welding of production lot is completed within 30 min of the last witness test.

^c Test not required if welding of production lot is completed within 60 min of the last witness test.

Each test lot shall consist of the number and configuration of test specimens and method of examination as specified in [Table 8](#). Any of the quantities specified may be made on a simulation of the production joint or a production part.

For production witness specimens or parts sectioned for intermediate or post production tests, if acceptance criteria are not met, all work completed since the previous conforming production witness test shall be segregated until a final decision is reached by the design/engineering authority.

Table 8 — Production witness test lots and examination requirements

Class	Specimen	Minimum amount per test lot ^a	Examination		
			Visual	Mechanical ^a	Metallographic
Spot welds — Sheet					
I	Figure 1 a) or Figure 1 b)	3 weld spots	all	shear	3 microsections
II	Figure 1 a) or Figure 1 b)	3 weld spots	all	shear	3 macrosections
III	Figure 1 a) or Figure 1 b)	3 weld spots	all	shear	3 macrosections
Spot welds — Sheet — Close spaced					
I	Figure 2	10 weld spots	all	none	1 longitudinal and 1 transverse microsections ^b
II	Figure 2	10 weld spots	all	none	1 longitudinal and 1 transverse macrosections ^b
III	Figure 2	10 weld spots	all	none	1 longitudinal and 1 transverse macrosections ^b
Spot weld — Foil					
I	Figure 3	3	all	peel 17.5.2 a)	none
II	Figure 3	1	all	peel 17.5.2 a)	none
III	Figure 3	1	all	peel 17.5.2 b)	none
Seam welds — Sheet					
I	Figure 5	<i>l</i> = 75 mm of continuous weld	all	none	2 transverse 1 longitudinal microsections
II	Figure 5	<i>l</i> = 75 mm of continuous weld	all	none	2 transverse 1 longitudinal macrosections
III	Figure 5	<i>l</i> = 75 mm of continuous weld	all	none	2 transverse 1 longitudinal macrosections
Seam welds — Foil					
I	Figure 4	1	all	peel 17.5.3 a)	none
II	Figure 4	1	all	peel 17.5.3 b)	none
III	Figure 4	1	all	peel 17.5.3 b)	none

For production witness testing, shear test may be substituted by destructive chisel test in accordance with ISO 10447:2015, 5.1, and only with the approval of the engineering authority.

^a The default examination for production witness welds is metallographic, but when mechanical tests are used for the examination of witness production weld compliance of spot welds established by the standard pWPS qualification, three welds will be added for metallographic examination (see [17.4](#)) to the preproduction witness test for class I and class II welding, and three welds will be added for metallographic examination every fourth periodic intermediate witness test for class I. For class III, shear testing may be used instead of metallographic examination.

^b At least 4 weld spots in a longitudinal section and 1 weld spot in the transverse section shall be evaluated.

15.2.6 Alternate testing requirements in lieu of production witness testing

As an alternative to the testing requirements of [Table 7](#), real time non-destructive SPC system may be used when approved by the design/engineering authority. As a minimum, the SPC system shall address: part fitup, precleaning, electrode monitoring, and in-process monitoring of critical process parameters. This system of controls shall include, but is not limited to, real time adaptive controls or in-process NDT methods. Destructive testing shall still be used to establish and verify that this SPC system is capable of identifying welds complying with strength or size requirements with 99,5 % reliability.

15.3 Production parts

15.3.1 Examination requirements

Production parts shall, as a minimum requirement, be subjected to the inspection requirements according to [Table 9](#), unless otherwise specified in the design documents. The acceptance criteria in accordance with [Clause 17](#) shall be met.

Table 9 — Production parts inspection requirements

Class	Number of welds to be inspected	
	Visual examination	Radiographic examination
I	all	all
II	all	none
III	all	none

15.3.2 Deterioration of welding quality

If investigation of imperfections in welding indicates that welding quality has deteriorated due to clear causes (e.g. swaged or improperly cleaned tips), and those causes are corrected so that acceptable welds (compared to qualification requirements) are made, qualification of a new WPS will not be required. Under conditions where the welding machine does not produce acceptable welds within the permitted parameter adjustments, the welding machine qualification shall be voided and the welding machine shall be requalified. All class I WPS qualification for that welding machine shall be discarded and new qualification shall be established.

15.3.3 Tack welds

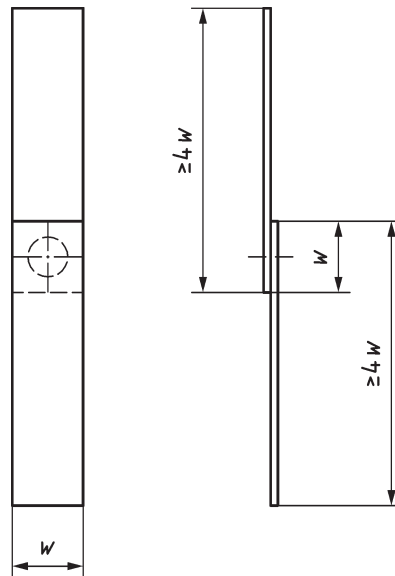
Tack welds shall be produced by resistance welding, unless other processes are approved by the design/engineering authority.

Tack welds shall not be used on class I welds unless they are permitted on engineering drawings or applicable documents and are finally removed, or completely covered by subsequent production welding. Tack welds do not require testing and only need be of sufficient strength to fulfil their temporary function. They are not subject to this document, provided the finished welds meet the specified requirements.

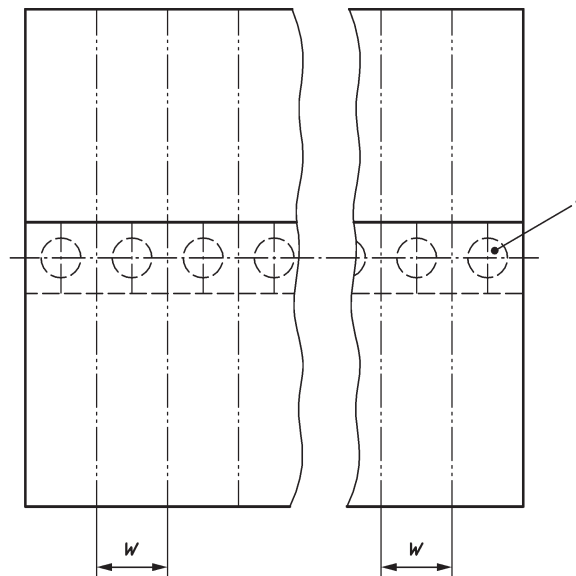
16 Test pieces

16.1 Standard test pieces

Standard test pieces according to [Figures 1, 2, 3, 4](#) and [5](#) shall be used for the welding machine and the welding procedure qualification test. For material group D (see [Clause 10](#)), multi-weld spot test specimen shall be used. For other material groups, the use of multi-weld spot test specimen is optional.



a) Single weld spot test specimen



b) Multi weld spot test specimen

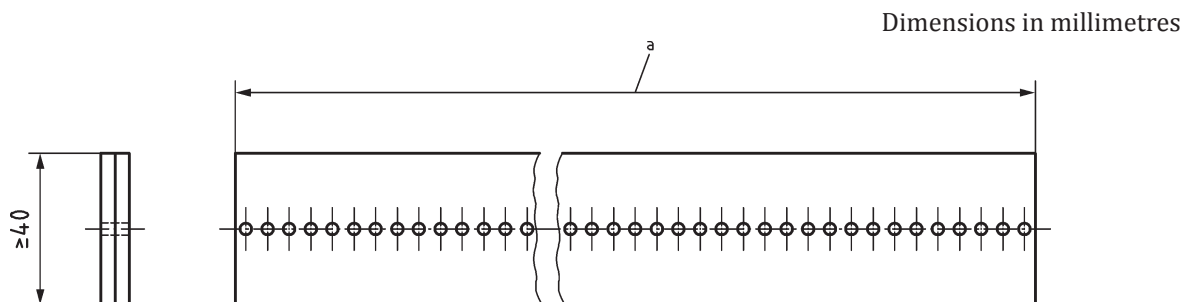
Key

- w test specimen width/overlap
- a First weld spot to be identified and discarded.

Range of thickness, t , of the thinner sheet being tested ^b	w
$0,20 \text{ mm} < t \leq 0,75 \text{ mm}$	$\geq 17 \text{ mm}$
$0,75 \text{ mm} < t \leq 2,50 \text{ mm}$	$\geq 25 \text{ mm}$
$2,50 \text{ mm} < t \leq 3,20 \text{ mm}$	$\geq 32 \text{ mm}$
$t > 3,20 \text{ mm}$	$\geq 38 \text{ mm}$

^b For the testing of multiple joint member combinations, extra test piece(s) shall be added (see [Figure 12](#))

Figure 1 — Spot welds in sheet

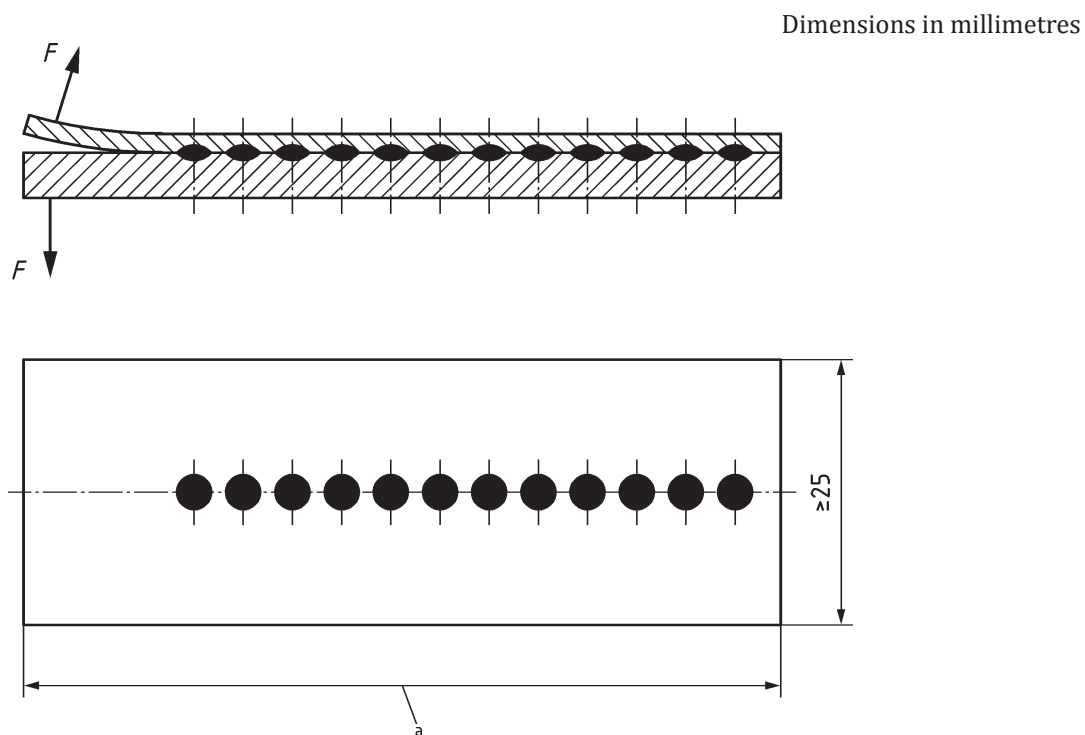


Weld pitch to be in accordance with the subject production part.

Such proximity may require more power than other spot welds.

^a Length as necessary, see [Tables 3](#) and [8](#).

Figure 2 — Close spaced spot welds in sheet



Key

F force

For witness specimens test and pWPS qualification, weld pitch in accordance with the production part. For welding machine qualification, weld pitch shall be such that every weld spot is clearly separated.

^a Length as necessary, see [Tables 4](#) and [8](#).

Figure 3 — Spot welds in foil

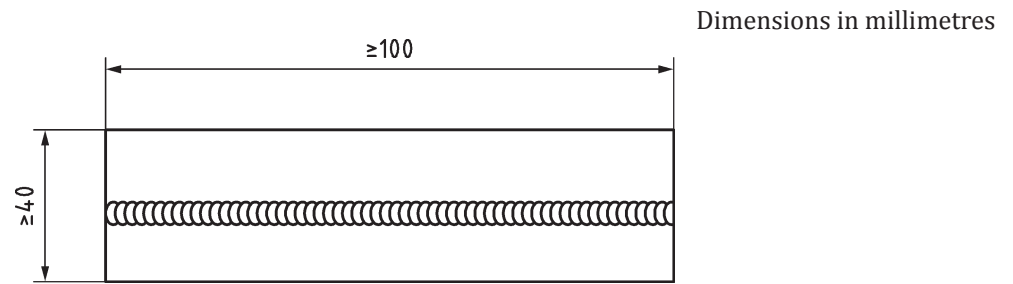
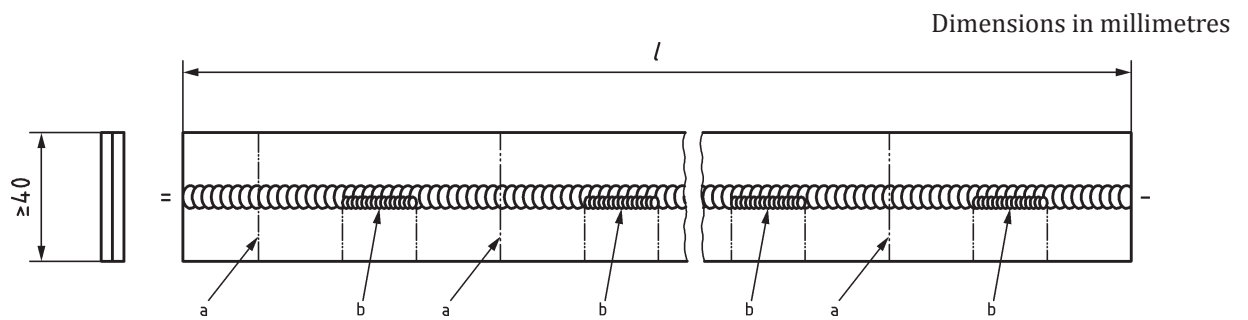


Figure 4 — Seam welds in foil



Key

- l* length of test specimen (see [Table 1](#) for machine qualification, [Table 2](#) for machine requalification, [Table 5](#) for pWPS qualification, and [Table 8](#) for production witness test specimen)
- a Transverse section.
- b Longitudinal section (≥ 25 mm).

Figure 5 — Seam welds in sheet

16.2 Test pieces for specific purposes

If the standard test pieces according to [Figures 1 to 5](#) differ from the parts to be welded with regard to the

- a) geometry (e.g. curved with $r < 80$ mm),
- b) material form (e.g. casting),
- c) welding over or adjacent to existing resistance or fusion welds,
- d) minimum edge distance,
- e) overlap distance,
- f) surface preparation (including shot peening, chemical milling, or other surface preparation), and
- g) heat-treatment condition,

additional samples from the original component or simulated parts shall be tested. The welding coordinator shall define the tests and the number of test specimens required to establish a correlation to the results obtained from the standard test pieces (see [Figures 1 to 5](#)). If deemed necessary by the welding coordinator, the correlation shall be given in the WPS.

17 Examination, testing and acceptance criteria

17.1 General

This clause defines weld acceptance criteria for welding machine qualification, pWPS qualification and production tests conducted in conformance with the standard qualification method on material groups A, B, C and D. For design allowable qualification, the design/engineering authority shall specify on the engineering drawing which tests to perform and appropriate acceptance criteria for pWPS qualification and for production.

Imperfection types other than those mentioned in this document shall be referred to the design/engineering authority.

For material group E, the acceptance criteria shall be defined by the responsible design/engineering authority.

The imperfections shall be randomly distributed and not clustered in one area, in one part, or in one group of parts.

When imperfections exceed the quantity limited by [17.2](#) to [17.4](#), but do not exceed twice that quantity limit, the manufacturer may use standard repair procedures to make repairs without recourse to salvage or materials review action. All standard repair welding procedures shall be clearly identified as such. Standard repair procedures shall be approved by the design/engineering authority.

17.2 Visual examination

17.2.1 Visible imperfections in test specimens or production parts

Production parts and test specimens for machine qualification, pWPS qualification and production witness test shall not exhibit any imperfections exceeding the specified values in [Table 10](#).

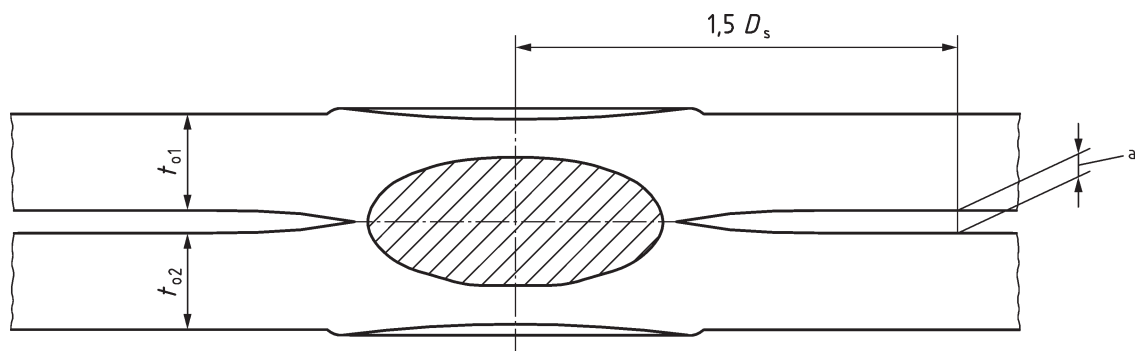
Table 10 — Visible external imperfections

External weld imperfection	Acceptable percentage of test specimens or spots in a welded joint exhibiting weld imperfection		
	Class I	Class II	Class III
Cracks	not permitted	not permitted	not permitted
Surface pits with diameter greater than 1,60 mm	not permitted	not permitted	10 %
Surface pits with diameter less than or equal to 1,60 mm	3 %	5 %	10 %
Expulsion spatter and surface fusion	3 %	5 %	10 %

17.2.2 Sheet separation between welded members

Sheet separation between members is not acceptable when it exceeds a) or b) measured at a distance as shown in [Figure 6](#):

- > 15 % of the summed thickness of the outer sheet and the one adjacent to it, or 0,15 mm, whichever is the greater, or
- > 0,08 mm between foil and the member adjacent to it.



- Maximum sheet separation between welded members at $1,5 D_s$; for D_s , see [Table 11](#).

Figure 6 — Sheet separation between welded members

17.2.3 Electrode indentation

Electrode indentation, e_u or e_l (see [Figure 7](#)), is not acceptable if its depth exceeds the following limitations:

- sheet; class I: $0,1 t_0$ or 0,13 mm; whichever is the greater;
- sheet; class II: $0,15 t_0$ or 0,13 mm; whichever is the greater;
- sheet; class III: $0,2 t_0$ or 0,13 mm; whichever is the greater;
- When aerodynamic smoothness is a requirement, the electrode indentation shall not exceed 0,10 mm on sheet.

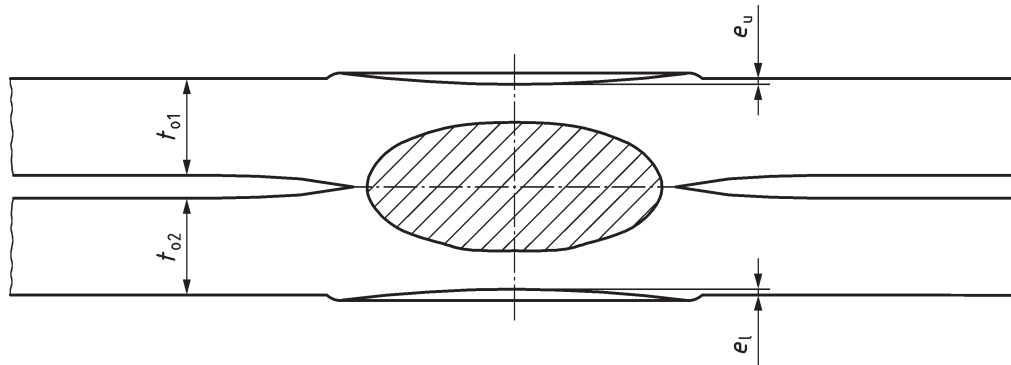
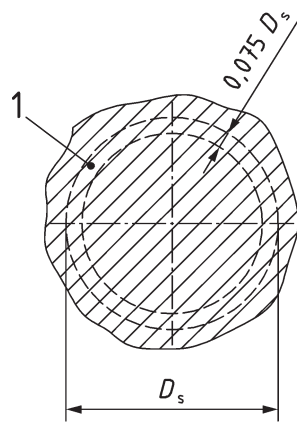


Figure 7 — Electrode indentation

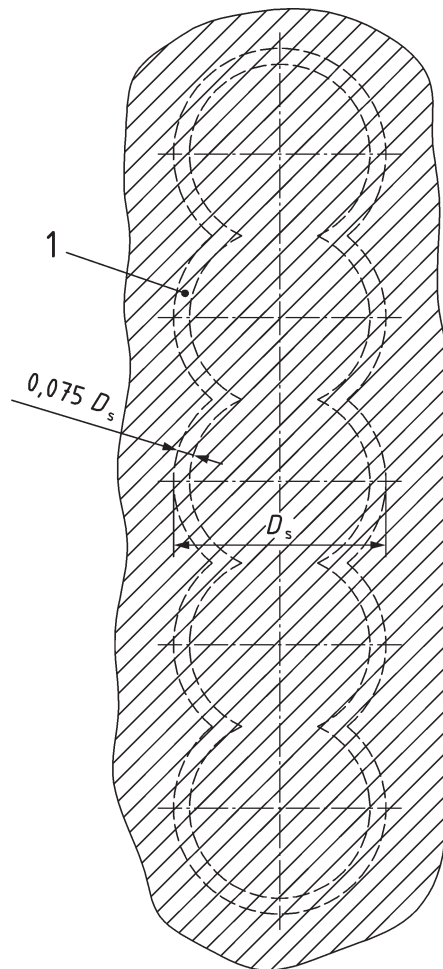
17.3 Radiographic examination

All class I test and production welds and class II test welds shall be examined for compliance with the following.

- a) For cracks and expulsion spatter, see [Table 10](#) for acceptance limits.
- b) No cavity shall have a linear dimension greater than 15 % of the nugget diameter or seam weld width as specified in [Table 11](#).
- c) No cavity shall extend into the outer annulus of a width which is equal to $0,075 D_s$ which is the required clear annulus as shown in [Figure 8](#). As an alternative, the minimum nugget diameter or seam weld width as determined from metallographic examination of production witness test specimens may be applied to determine the required clear annulus.
- d) Cavities in the nugget shall not have an aggregate area greater than 5 % of the nugget or seam weld area (based on the required nugget diameter or seam weld width as specified in [Table 11](#)) in materials of group D, or 10 % in materials of groups A, B and C.
- e) The nuggets shall be consistent in diameter and shape.



a) Nomenclature diagram of spot weld



b) Nomenclature diagram of seam weld

Key

1 required clear annulus

D_s minimum required nugget diameter or seam weld width

NOTE Clear annulus size definition is different for metallographic inspection versus radiographic inspection. This is based on different nugget diameter/seam weld width definitions, which refer to actual sizes for metallographic inspection and minimum sizes as per [Table 11](#) for radiographic inspection.

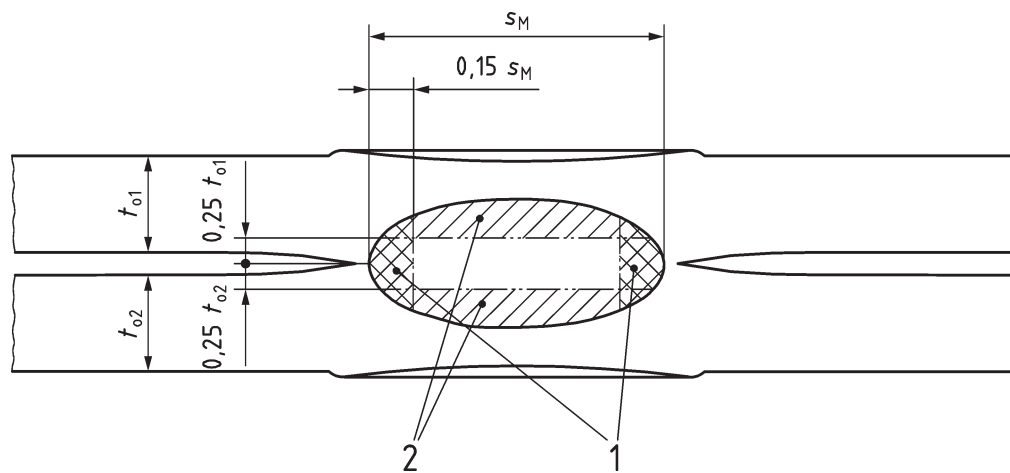
Figure 8 — Nomenclature diagram of spot weld and seam weld

17.4 Metallographic examination

17.4.1 General

The metallographic examination and acceptance criteria are applicable to welding machine qualification test specimens, standard pWPS qualification test specimens and production witness test specimens. Examination and acceptance criteria apply to production parts in the event of a test. Metallographic nomenclature is shown in [Figures 8](#) and [9](#). Test specimens shall be cross-sectioned, polished and etched as closely as possible through the centre of the weld for examination. For aluminium and aluminium alloys, polishing shall be performed wet with a suitable procedure.

Microsections shall be examined at a minimum magnification of 20×. Macrosections shall be examined at a minimum of 10× magnification.



Key

- 1 required clear annulus zone
- 2 required clear penetration zone
- s_M actual nugget diameter or seam weld width, as determined by metallographic examination

NOTE Clear annulus size definition is different for metallographic inspection versus radiographic inspection. This is based on different nugget diameter/seam weld width definitions, which refer to actual sizes for metallographic inspection and minimum sizes as per [Table 11](#) for radiographic inspection.

Figure 9 — Nomenclature for metallographic spot weld sections and seam weld transverse sections

17.4.2 Electrode indentation

Electrode indentation, e_u or e_l (see [Figure 7](#)), is not acceptable if its depth exceeds the following limitations:

- a) sheet; class I: $0,1 t_o$ or 0,13 mm; whichever is the greater;
- b) sheet; class II: $0,15 t_o$ or 0,13 mm; whichever is the greater;
- c) sheet; class III: $0,2 t_o$ or 0,13 mm; whichever is the greater;
- d) foil; class I: $0,3 t_o$;
- e) foil; class II and III: $0,4 t_o$;
- f) when aerodynamic smoothness is a requirement, the electrode indentation shall not exceed 0,10 mm on sheet.

17.4.3 Internal imperfections

Inclusions, cavities and instances of incomplete fusion are acceptable within the nugget of metallographic sections, except when the weld contains the following:

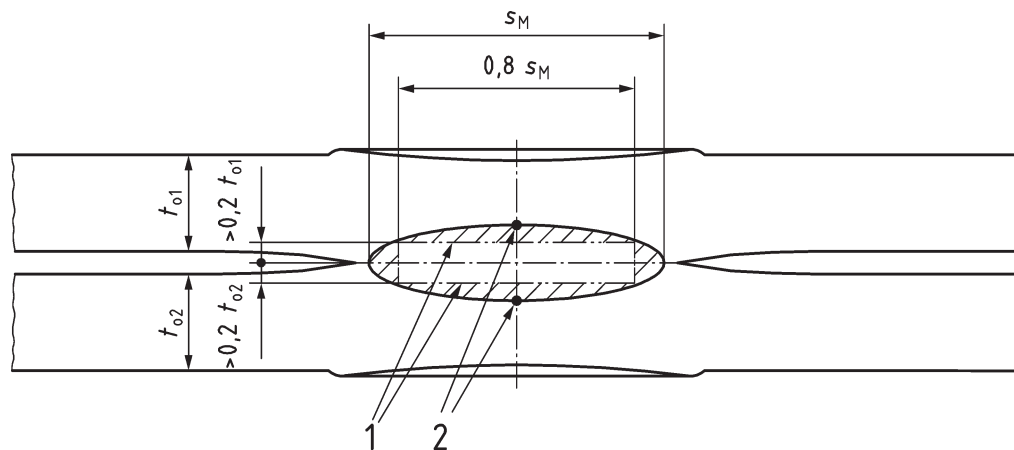
- an imperfection within the clear annulus zone of the nugget (see [Figure 9](#));
- an imperfection extending into the clear penetration zone of an outer sheet (see [Figure 9](#));
- an imperfection with its largest dimension exceeding 15 % for class I and class II welds, and 25 % for class III welds of the nugget diameter or seam weld width as specified in [Table 11](#).

Any crack in the metallographic section is not acceptable. Coring outside a nugget is not acceptable unless permitted at the discretion of the responsible design/engineering authority.

17.4.4 Nugget penetration

17.4.4.1 General

At least 80 % of the measured nugget diameter or seam weld width shall exceed the minimum nugget penetration requirement. Maximum nugget penetration shall be measured at the maximum extent into the outer sheets (see [Figure 10](#)).



Key

- minimum nugget penetration
- maximum nugget penetration

Figure 10 — Nugget penetration

17.4.4.2 Minimum nugget penetration

Nugget penetration shall comply with the following.

- In two equal-thickness members, nugget penetration shall exceed 0,2 times the thickness of each member into each member.
- In two unequal-thickness members, nugget penetration shall exceed 0,2 times the thickness of the thinner member into each member.
- In three or more thicknesses, nugget penetration into the outer members shall exceed 0,2 times the thickness of the thinner outer member.

17.4.4.3 Maximum nugget penetration

Nugget penetration shall not exceed:

- a) material groups A, B and C: 90 % for all classes;
- b) material group D: 80 % for class I and class II welds, 90 % for class III welds.

17.4.5 Nugget diameter or seam weld width

17.4.5.1 General

17.4.5.1.1 Welding machine qualification and pWPS qualification

The nugget diameter or seam weld width of all required metallographic sections shall be measured for each interface plane and recorded. From the values of each plane, the average dimension and the lowest dimension in the test group shall be entered on the test record form. For peel test of class I foils, in addition to requirements of [Table 11](#), the largest nugget diameter or seam weld width shall be not more than 120 % of the smallest nugget diameter or seam weld width.

NOTE Average nugget diameter or seam weld width is recorded for comparison of production witness specimen nugget diameter or seam weld width for class I and class II (see [17.4.5.1.2](#)).

17.4.5.1.2 Production witness test specimens

Nugget diameter or seam weld width shall be measured on metallographic sections. Nugget diameter or seam weld width may also be measured on peel test specimens when approved by the design/engineering authority. When metallographic testing is not required according to [Table 8](#), then nugget diameter or seam weld width shall be measured on the peel, shear or chisel test specimens.

Class I welds shall be within ± 10 % of the average nugget diameter or seam weld width recorded for pWPS qualification or no more than 0,50 mm smaller than the qualification average, when the average is larger than 5,08 mm. Class II welds shall be within ± 20 % of the pWPS qualification nugget diameter or seam weld width average.

All welds shall meet the minimum nugget diameter or seam weld width requirements as specified in [Table 11](#). For thicknesses not listed in [Table 11](#), the nugget diameter or seam weld width shall be interpolated.

Table 11 — Minimum required nugget diameter or seam weld width, D_s

Dimensions in millimetres

Thickness of thinner sheet	D_s	Thickness of thinner sheet	D_s	Thickness of thinner sheet	D_s
0,03	0,25	0,45	2,29	1,60	5,08
0,05	0,38	0,50	2,54	1,80	5,33
0,08	0,50	0,55	2,68	2,00	5,72
0,10	0,76	0,65	3,05	2,30	6,10
0,12	0,89	0,70	3,30	2,50	6,35
0,16	1,02	0,80	3,56	2,80	6,60
0,18	1,14	0,90	3,81	3,20	7,11
0,20	1,27	1,00	4,06	3,60	7,62
0,25	1,52	1,10	4,32	4,10	8,13
0,30	1,78	1,20	4,57	4,60	8,64
0,40	2,16	1,40	4,82	4,80	8,89

17.4.5.2 Spot welds

The minimum nugget diameter for spot welds shall be as specified in [Table 11](#). In welds of two members of unequal thickness, the thinner member shall determine the required minimum nugget diameter at the faying surface. In three or more thickness welds, the thinner of the two outer members shall determine the minimum nugget diameter from [Table 11](#), unless load carrying members are identified for the qualification combinations, such as in [Figures 12 a\)](#) and [12 b\)](#). In this case, the lesser thickness of the two load carrying members shall identify and be the determinant of minimum nugget diameter for each interface lying between them. Each nugget shall be measured at the subject interface plane on the metallographic section through the centre of the nugget. Foil weld size may be measured by the size of the fractured peel test specimen instead of a metallographic section, when the foil is an outer member.

17.4.5.3 Seam welds

Width of seam welds (either continuous weld or intermittent weld) shall be determined by transverse sections and shall comply with the requirements specified in [Table 11](#). On the longitudinal cross-section, the height of the melted zone at the intersection between successive nuggets shall be a minimum of $0,2 t_0$ on either side of the joint face (see [Figure 11](#)).

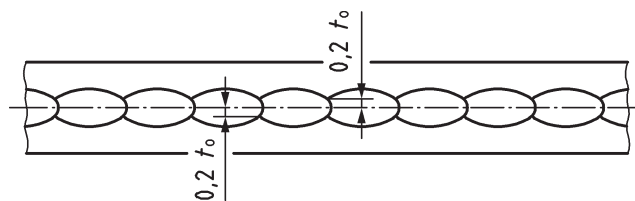


Figure 11 — Seam weld overlap requirement

17.5 Mechanical testing

17.5.1 Spot welds — Sheet

17.5.1.1 Welding machine qualification test specimen and pWPS qualification test specimen

- a) Each and every shear test specimen, such as [Figure 1 a\)](#) or [Figure 1 b\)](#), shall equal or exceed the minimum shear force specified in [Tables 12 to 14](#).
- b) The average shear force shall equal or exceed the applicable minimum average shear force specified in [Tables 12 to 14](#).
- c) Consistency requirements for materials of groups A, B and C: for class I and class II welds, each of 90 % of the number of welds tested shall have shear force values within 10 % of the lot average. Each of the remaining 10 % of the welds shall have shear force values within 20 % of the lot average. All class III welds shall be within 33 % of the lot average.
- d) Consistency requirements for materials of group D: for class I and class II welds, 90 % of the number of welds tested shall have shear force values within 12,5 % of the lot average. Each of the remaining 10 % of the welds shall have shear force values within 25 % of the lot average. All class III welds shall be within 35 % of the lot average.

Table 12 — Shear force requirements for spot weld sheet specimens — Material groups A and B — Steel, nickel and cobalt alloys

Thickness of thinner sheet <i>t</i> mm	Ultimate strength, R_m MPa							
	< 620		$620 \leq R_m < 1\,034$		$1\,034 \leq R_m \leq 1\,275$		> 1 275	
	Shear force per weld spot N							
	min.	min. avg.	min.	min. avg.	min.	min. avg.	min.	min. avg.
0,22	440	555	580	710	780	935	890	1 090
0,25	510	625	710	865	910	1 135	1 090	1 355
0,30	665	825	890	1 090	1 225	1 510	1 555	1 825
0,40	955	1 155	1 310	1 625	1 780	2 200	2 135	2 645
0,45	1 110	1 355	1 510	1 845	2 200	2 670	2 625	3 225
0,50	1 245	1 535	1 735	2 135	2 355	2 915	2 825	3 490
0,55	1 470	1 800	2 000	2 445	2 715	3 360	3 245	4 025
0,60	1 650	2 000	2 200	2 700	3 000	3 700	3 600	4 450
0,65	1 780	2 200	2 355	2 915	3 225	3 980	3 870	4 780
0,70	2 070	2 555	2 825	3 400	3 805	4 690	4 560	5 605
0,80	2 515	3 090	3 445	4 250	4 650	5 695	5 560	6 870
0,90	3 070	3 825	4 090	5 070	5 580	6 870	6 670	8 230
1,00	3 625	4 450	4 735	5 825	6 495	8 005	7 785	9 565
1,10	4 470	5 515	5 715	7 050	7 985	9 830	9 340	10 895
1,20	4 850	6 000	6 150	7 600	8 650	10 500	10 000	12 500
1,30	5 315	6 560	6 695	8 250	9 450	11 655	10 900	13 345
1,40	6 495	8 005	7 875	9 720	11 340	13 990	12 810	15 790
1,60	7 830	9 650	9 385	11 545	13 745	16 970	15 790	19 460
1,80	9 250	11 385	11 275	13 900	16 590	20 440	18 680	22 905
2,00	10 920	13 455	13 365	16 480	19 615	24 195	21 575	26 690
2,30	12 830	15 835	15 635	19 280	22 640	27 910	24 910	30 690
2,50	14 680	18 105	17 790	21 680	25 445	31 360	28 020	34 470
2,80	16 880	20 795	20 215	24 955	28 310	34 940	31 135	38 255
3,20	19 125	23 620	22 530	27 800	31 490	38 830	34 630	42 700

Table 13 — Shear force requirements for spot weld sheet specimens — Material group C — Titanium alloys

Thickness of thinner sheet <i>t</i> mm	Ultimate strength, R_m MPa			
	< 689,5		≥ 689,5	
	Shear force per weld spot N			
	min.	min. avg.	min.	min. avg.
0,25	710	935	910	1 180
0,30	890	1 155	1 225	1 600
0,40	1 310	1 710	1 780	2 310
0,45	1 510	1 980	2 180	2 825
0,50	1 735	2 270	2 355	3 070
0,55	2 000	2 600	2 715	3 535
0,60	2 160	2 820	2 945	3 855
0,65	2 355	3 070	3 225	4 205
0,70	3 380	3 670	3 805	4 940
0,80	3 445	4 450	4 515	6 050
0,90	4 090	5 340	5 580	7 250
1,00	4 735	6 160	6 495	8 450
1,10	5 715	7 430	7 985	10 410
1,20	6 175	7 930	8 685	11 310
1,30	6 695	8 495	9 450	12 275
1,40	7 875	10 230	11 340	14 765
1,60	9 385	12 145	13 345	17 345
1,80	10 625	13 855	15 035	19 570
2,00	12 010	15 610	16 945	22 060
2,30	13 520	17 590	19 080	24 775
2,50	15 035	19 550	21 170	27 445
2,80	16 835	21 905	23 665	30 245
3,20	18 770	24 420	26 465	34 250

Table 14 — Shear force requirements for spot weld sheet specimens — Material group D — Aluminium and magnesium alloys

Thickness of thinner sheet <i>t</i> mm	Ultimate strength, R_m MPa							
	< 135		$135 \leq R_m < 240$		$240 \leq R_m < 386$		≥ 386	
	Shear force per weld spot N							
	min.	min. avg.	min.	min. avg.	min.	min. avg.	min.	min. avg.
0,25	—	—	—	—	225	290	265	335
0,30	90	110	135	175	290	380	335	425
0,40	225	290	310	400	445	555	490	625
0,45	290	380	380	490	510	645	555	710
0,50	355	445	445	555	600	755	625	780
0,55	425	535	535	665	690	865	710	890
0,60	490	625	645	825	780	890	825	1 045
0,65	540	685	705	900	840	1 020	885	1 115
0,70	600	755	780	980	910	1 155	995	1 200
0,80	735	935	935	1 180	1 045	1 310	1 155	1 445
0,90	865	1 090	1 135	1 425	1 225	1 535	1 355	1 710
1,00	1 000	1 270	1 335	1 670	1 380	1 735	1 535	1 935
1,10	1 155	1 445	1 555	1 955	1 645	2 070	1 800	2 270
1,20	1 225	1 535	1 665	2 085	1 770	2 230	1 950	2 400
1,30	1 310	1 645	1 780	2 225	1 910	2 400	2 070	2 600
1,40	1 510	1 890	2 110	2 645	2 290	2 870	2 470	2 980
1,60	1 755	2 200	2 535	3 180	2 715	3 400	2 980	3 635
1,80	2 000	2 515	2 780	3 600	3 200	4 005	3 670	4 605
2,00	2 335	2 935	3 400	4 270	3 805	4 760	4 560	5 715
2,30	2 645	3 315	3 870	4 850	4 450	5 560	5 580	6 985
2,50	3 000	3 660	4 180	5 225	5 205	6 515	6 630	8 295
2,80	3 270	4 090	4 450	5 580	5 960	7 450	7 915	9 895
3,20	3 490	4 380	4 670	5 850	7 228	9 050	9 430	11 785
3,60	—	—	—	—	8 540	10 675	11 230	14 055
4,10	—	—	—	—	10 585	13 565	13 880	17 345
4,60	—	—	—	—	13 345	16 680	16 570	20 730
4,80	—	—	—	—	14 410	18 015	17 950	22 440

17.5.1.2 Production witness test specimens

The test lot average of the shear forces shall be not less than the applicable value shown in [Tables 12 to 14](#) and no weld shall be less than the applicable minimum value shown in [Tables 12 to 14](#). In addition, for class I, the test lot average shall be not less than 0,9 times of the average of the shear forces achieved in WPS qualification.

The span between the lowest and highest shear force values from the test specimens shall be less than 35 % of the applicable production test lot average.

EXAMPLE Measured tensile shear forces:

— 3 400 N

— 3 100 N

— 3 700 N

Mean value: \bar{a}

$$\bar{a} = \frac{10\,200\text{ N}}{3} = 3\,400\text{ N}$$

Span, S ; $S = 3\,700\text{ N} - 3\,100\text{ N} = 600\text{ N}$

$$\%S = \frac{600\text{ N} (S)}{3\,400\text{ N} (\bar{a})} \times 100 = 17,6\%$$

17.5.2 Spot welds — Foil

For the pWPS qualification test specimen, production witness test specimens and welding machine qualification test specimen, the following mechanical criteria apply. The test specimen configuration is shown in [Figure 3](#).

- a) Class I and class II: the peel test run shall cause a button (plug) pull-out failure in at least 95 % of the welds tested. The remaining 5 % may fail at the interface plane, but there shall be evidence of fusion at the interface in each case.
- b) Class III: peel tests shall cause a button (plug) pull-out failure in at least 85 % of the welds tested. The remaining 15 % may fail at the interface plane, but there shall be evidence of fusion at the interface in each case.

17.5.3 Seam welds — Foil

For the pWPS qualification test specimen, production witness test specimens and welding machine qualification test specimen, the following mechanical criteria apply.

- a) Class I: the weld specimen shall be tested in peel. Failure shall occur by tearing of the metal adjacent to the weld nugget for more than 95 % of the weld length. The remaining portion of the weld length may fail by fracture across the weld in the faying plane, but continuous fusion shall be evident.
- b) Class II and class III: the weld specimen shall be tested in peel. Failure shall occur by tearing of the metal adjacent to the weld nugget for more than 85 % of the weld length. The remaining portion of the weld length may fail by fracture across the weld in the faying plane, but continuous fusion shall be evident.

17.5.4 Multiple members test specimen

If more than two members are assembled, the mechanical tests shall be repeated for separate examination of each assembly joint face (two series of tests for assembly of three sheets, three series for four sheets, and so on; see [Figure 12](#)). For peel tests on foils, the same principle applies.

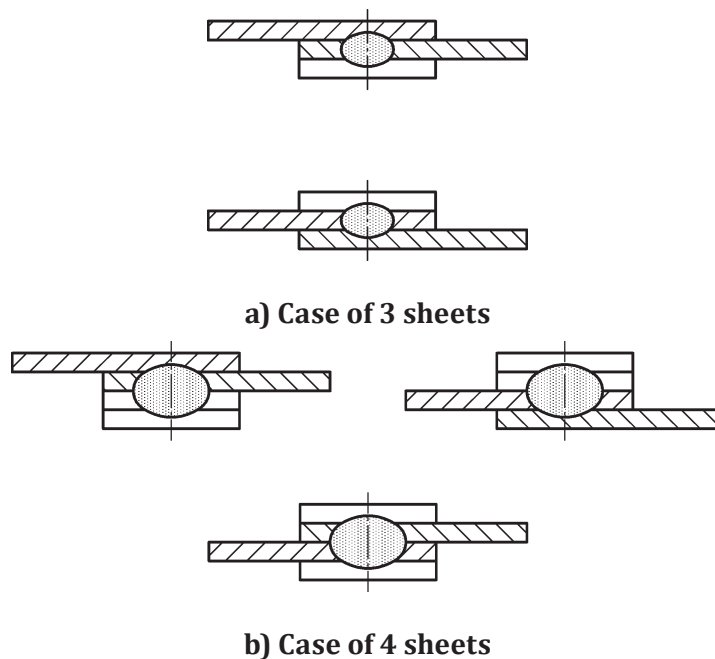


Figure 12 — Tests on assemblies of more than two sheets — Tensile shear test on each joint face

18 Welding procedure qualification record (WPQR)

Documentation of the qualification tests (see [Clause 14](#)), including the welding parameters, shall be contained in a completed WPQR, which should be made available to the quality assurance (QA) personnel. For a suggested form, see [Annex C](#).

The WPQR shall detail the results of examination according to [Clause 17](#). The examination page shall have a formal indication of the success or failure to meet the acceptance criteria applicable to the subject material combination.

Annex A
(informative)

Machine qualification test report form

A.1 For resistance spot welding machine

BS ISO 16338:2017
ISO 16338:2017(E)

Company:
 Manufacturer of the machine:
 Machine type:
 Manufacturer of controller:
 Controller type:
 Material group:
 Qualified for class:

Date:
 Location of machine:
 Machine serial number:
 Nominal power: kVA
 Controller serial number:

Test pieces welded	Test material designation, material condition:		
	Thickness combination:	mm +	mm
	Surface treatment:	according to specification:	
Electrodes	Electrode material designation:	Electrode material type according to:	
	Tip diameter (upper/lower):	mm	External cooling <input type="checkbox"/> yes <input type="checkbox"/> no
	Convexity radius (upper/lower):	mm	
Distance in height between electrode arms:	mm	Electrode arm length:	mm
Weld pitch (centre to centre):	mm	Approximate weld spot sequence:	weld spots/min
Parameter settings, see WPS No:			
Record of current/electrode force/time-measurements (optional):			

Examination of welded test pieces according to ISO 16338

Visual examination pass fail Radiographic examination pass fail Metallographic examination pass fail

Test report No. Test report No. Test report No.

Shear force, in newtons (N), and nugget diameter, in millimetres (mm), of spot No. (for multiple spot test pieces, the first spot shall be discarded from each test piece produced)	1	23	45	67	89
	2	24	46	68	90*
	3	25	47	69	91
	4	26	48	70*	92
	5	27	49	71	93
	6	28	50	72	94
	7	29	51	73	95
	8	30*	52	74	96
	9	31	53	75	97
	10*	32	54	76	98
	11*	33	55	77	99
	12	34	56	78	100
	13	35	57	79	101
	14	36	58	80	102
	15	37	59	81	103
	16	38	60	82	104
	17	39	61	83	105
	18	40	62	84	
	19	41	63	85	
	20	42	64	86	
	21	43	65	87	
	22	44	66	88	
Subtotal, in N					

*Weld spot designated for metallographic examination.

	Shear force	Nugget diameter	
Sum of all measured values	N	mm	
average value of the measured values	N	mm	
smallest value measured	N	mm	<input type="checkbox"/> pass
highest value measured	N	mm	
variation	%	%	<input type="checkbox"/> failed
permitted average value	N	not applicable	
permitted minimum value	N	mm	

Welding coordinator

A.2 For seam welding machine

Company: _____ Date: _____
 Manufacturer of the machine: _____ Location of machine: _____
 Machine type: _____ Machine serial number: _____
 Manufacturer of controller: _____ Nominal power: _____ kVA
 Controller type: _____ Controller serial number: _____
 Material group: _____
 Qualified for class: _____

Test pieces welded	Test material designation, material condition: Thickness combination: mm + mm Surface treatment: according to specification:		
Electrodes	Electrode material designation: Diameter: mm Convexity radius (upper/lower):	Electrode material type according to: External electrode cooling <input type="checkbox"/> yes <input type="checkbox"/> no Continuous electrode cleaning <input type="checkbox"/> yes <input type="checkbox"/> no	
Distance in height between electrode arms: mm	Electrode arm length: mm		
Weld pitch: mm, or length of 10 weld spots: mm	Welding speed: m/min		
Parameter settings, see WPS No: _____ Record of current/electrode force/time-measurements (optional): _____			
Examination of welded test pieces according to ISO 16338			
Visual examination <input type="checkbox"/> pass <input type="checkbox"/> fail	Radiographic examination <input type="checkbox"/> pass <input type="checkbox"/> fail	Mechanical testing <input type="checkbox"/> pass <input type="checkbox"/> fail <input type="checkbox"/> not applicable	Metallographic examination <input type="checkbox"/> pass <input type="checkbox"/> fail <input type="checkbox"/> not applicable
Test report No. _____	Test report No. _____	Test report No. _____	Test report No. _____

Welding coordinator

Annex B (informative)

WPS form

Date	Welding procedure specification for resistance welded metal parts				Identification No./issue				
Part No.:					Drawing-No:				
Machine		Manufacturer: Machine type:			Serial number of machine(s):				
Machine qualification according to ISO 16338	Material group		A	B	C	D			
	Class								
	Thickness [mm]								
	Qualification reference No.:								
Workpiece	Sheet sequence	Material	Thickness [mm]	Surface treatment		Surface resistance [$\mu\Omega$]			
	top								
	1								
	2								
	3								
	4 bottom								
Maximum time between surface treatment and welding					h				
Electrodes		Material designation	Material type	Electrode radius [mm]	Seam wheel diameter [mm]	Tip diameter for spot welding/ seam wheel width for seam welding [mm]	External cooling		
							yes	no	
	top								
	bottom								
	Electrode holder			Seam length for 10 weld spots (LR)			max [mm]		
Distance height between electrode arms		[mm]	Electrode arm length			[mm]			
Machine settings	Air supply		[bar]						
	Main pressure (pi)		[bar]		Transformer setting		parallel		
	Back pressure (pc)		[bar]				series		
	Cleaning pressure		[bar]						
Programme settings	programme number/revision/date (parameter description attached)								
Remarks									
Approved by:			Welding Coordinator:						

Annex C (informative)

Forms for welding procedure qualification record (WPQR) — Examples

Company:
Manufacturer of weld machine:
Material:

Date:
Machine type:
Thickness combination(s):

Examination of welded test pieces according to ISO 16338:

Visual examination	<input type="checkbox"/>	pass	Radiographic examination	<input type="checkbox"/>	pass	Metallographic examination	<input type="checkbox"/>	pass
	<input type="checkbox"/>	fail		<input type="checkbox"/>	fail		<input type="checkbox"/>	fail
Test report No.			Test report No.			Test report No.		
Peel test result	<input type="checkbox"/>	pass						
	<input type="checkbox"/>	fail						
Test report No.								

Metallographic examination (micro or macro, as applicable):									
Transverse section	Nugget diameter [mm]				Penetration [%]				Sheet separation ^a :
	Combination				upper		lower		
	1 + 2	2 + 3	3 + 4	4 + 5	max.	min. ^b	max.	min. ^b	
1T									
2T									
3T									
4T									
Required ^c									
Longitudinal section	Nugget diameter [mm]				Penetration [%]				Electrode indentation ^d :
	Combination				upper		lower		
	1 + 2	2 + 3	3 + 4	4 + 5	max.	min. ^e	max.	min. ^e	
1L									
2L									
3L									
4L									
Required ^c									
This qualification is valid for:					Welding coordinator (Name, date, signature):				
<input type="checkbox"/> Class I <input type="checkbox"/> Class II <input type="checkbox"/> Class III									
^a See ISO 16338:2016, 17.2.2. ^b Measured at 80% of seam weld width (see ISO 16338:2016, 17.4.4.1). ^c See ISO 16338:2016, Table 11. ^d See ISO 16338:2016, 17.2.3. ^e Measured according to ISO 16338:2012, 17.4.4.3.									

Company:
Manufacturer of weld machine:
Material:

Date:
Machine type:
Thickness combination(s):

Examination of welded test pieces according to ISO 16338:

Visual examination pass fail Radiographic examination pass fail Metallographic examination pass fail

Test report No. Test report No. Test report No.

Shear strength [N] for combination (as applicable):									
Test piece	1 + 2	2 + 3	3 + 4	4 + 5	Test piece	1 + 2	2 + 3	3 + 4	4 + 5
1					11				
2					12				
3					13				
4					14				
5					15				
6					16				
7					17				
8					18				
9					19				
10					20				
Σ (N)					Σ (N)				
Combination						1 + 2	2 + 3	3 + 4	4 + 5
Mean shear force: Σ (N)/Number of test pieces									
Required shear forces ^a						Minimum			
						Minimum average			
Highest measured shear force									
Lowest measured shear force									
Span (Highest – Lowest measured shear force)									
% Span = $\frac{\text{Span}}{\text{Mean value}} \times 100$						Actual			
						Required ^b			
Metallographic examination (micro or macro, as applicable):									
Test piece	Nugget diameter [mm]				Penetration [%]				Sheet separation ^d : Electrode indentation ^e :
	Combination				upper		lower		
	1 + 2	2 + 3	3 + 4	4 + 5	max.	min. ^c	max.	min. ^c	
1									
2									
3									
4									
5									
Required ^f									
This qualification is valid for:					Welding coordinator (Name, date, signature):				
<input type="checkbox"/> Class I <input type="checkbox"/> Class II <input type="checkbox"/> Class III									
a	See ISO 16338:2016, Table 12, 13 or 14.								
b	See ISO 16338:2016, 17.5.1.2.								
c	Measured at 80 % of nugget diameter (see ISO 16338:2016, 17.4.3.1).								
d	See ISO 16338:2016, 17.2.2.								
e	See ISO 16338:2016, 17.2.3.								
f	See ISO 16338:2016, Table 11.								

Annex D (informative)

Commentary on machine qualification

D.1 General

This annex is intended to clarify the machine qualification requirements set forth in [13.1.2.3](#). The basis for the qualification limits defined by [13.1.2.3](#) is determined by two factors:

- a) total weld combination thickness;
- b) thinnest contact member (member in contact with the electrode).

The production weld combination limits of each material group for a resistance welding machine are defined by these two factors.

D.2 Background

The intent of the machine qualification test is to demonstrate that a particular welding machine has the ability to consistently produce welds meeting the requirements for the desired class of welds over a range of assembly thicknesses (see [Table D.1](#)). The qualification test serves as a means of establishing the application range of each welding machine. Generally, it is best to select two members of equal thickness to establish the upper (thickest) and lower (thinnest) qualification limits that cover the thickness range of welded assemblies expected in production. However, when more than two members are to be welded, it may be necessary to qualify using multiple member assemblies. Typically, this situation represents the upper machine qualification limit.

D.3 Table of examples

See [Table D.1](#).

Table D.1 — Table of examples

Dimensions in millimetres

Example No.	Production weld combination in question — Stack up from top to bottom	Is production weld combination covered by machine qualifications?	Machine qualifications — low and high
1	0,4 – 0,2 (0,6 Combined thickness)	NO	0,4 – 0,4 (0,8 combined thickness) and 2,0 – 2,0 (4,0 combined thickness)
2	0,4 – 1,0 (1,4 Combined thickness)	YES	
3	1,0 – 1,0 (2,0 Combined thickness)	YES	
4	1,0 – 2,0 (3,0 Combined thickness)	YES	
5	2,2 – 2,2 (4,4 Combined thickness)	NO	
6	3,0 – 1,0 (4,0 Combined thickness)	YES	
7	0,3 – 0,2 – 0,2 – 0,4 (1,1 Combined thickness)	NO	
8	1,0 – 0,2 – 0,2 – 0,2 – 2,0 (3,6 Combined thickness)	YES	
9	0,2 – 0,2 (0,4 Combined thickness)	NO	0,2 – 0,3 (0,5 combined thickness) and 1,6 – 3,1 (4,7 combined thickness)
10	0,3 – 0,3 (0,6 Combined thickness)	YES	
11	1,8 – 1,8 (3,6 Combined thickness)	NO	
12	1,2 – 3,3 (4,5 Combined thickness)	YES	
13	1,0 – 0,2 – 0,2 – 1,0 (2,4 Combined thickness)	YES	
14	1,8 – 1,2 – 1,2 (4,2 Combined thickness)	YES	
15	1,6 – 3,1 (4,7 Combined thickness)	YES	
16	2,0 – 1,4 – 1,4 (4,8 Combined thickness)	NO	
17	0,5 – 0,2 (0,7 Combined thickness)	NO	0,5 – 0,5 (1,0 combined thickness) and 1,6 – 1,6 – 1,6 (4,8 combined thickness)
18	0,5 – 0,2 – 0,2 (0,9 Combined thickness)	NO	
19	0,5 – 0,5 (1,0 Combined thickness)	YES	
20	0,5 – 1,0 (1,5 Combined thickness)	YES	
21	1,2 – 2,5 (3,7 Combined thickness)	YES	
22	2,0 – 0,6 – 2,0 (4,6 Combined thickness)	NO	
23	1,6 – 3,1 (4,7 Combined thickness)	YES	
24	1,8 – 2,5 (4,3 Combined thickness)	NO	

D.4 Explanation of examples

Dimensions are in millimetres.

EXAMPLE 1 The thinnest production weld contact member (0,2) is thinner than the thinnest contact member from the low-end machine qualification test (0,4). Also, the total combined thickness of production weld combination (0,6) is less than that of the low-end machine qualification test (0,8),

EXAMPLE 2 All requirements of [13.1.2.3](#) are met.

EXAMPLE 3 All requirements of [13.1.2.3](#) are met.

EXAMPLE 4 All requirements of [13.1.2.3](#) are met.

EXAMPLE 5 The thinnest production weld contact member (2,2) is thicker than the thinnest contact member from the high-end machine qualification test (2,0). Also, the total combined thickness of production weld combination (4,4) is greater than that of the high-end machine qualification test (4,0).

EXAMPLE 6 All requirements of [13.1.2.3](#) are met.

EXAMPLE 7 The thinnest production weld contact member (0,3) is thinner than the thinnest contact member from the low-end machine qualification test (0,4).

EXAMPLE 8 All requirements of [13.1.2.3](#) are met.

EXAMPLE 9 The total combined thickness of production weld combination (0,4) is less than that of the low-end machine qualification test (0,5).

EXAMPLE 10 All requirements of [13.1.2.3](#) are met.

EXAMPLE 11 The thinnest production weld contact member (1,8) is thicker than the thinnest contact member from the high-end machine qualification test (1,6).

EXAMPLE 12 All requirements of [13.1.2.3](#) are met.

EXAMPLE 13 All requirements of [13.1.2.3](#) are met.

EXAMPLE 14 All requirements of [13.1.2.3](#) are met.

EXAMPLE 15 All requirements of [13.1.2.3](#) are met.

EXAMPLE 16 Total combined thickness of production weld combination (4,8) is greater than that of the high-end machine qualification test (4,7).

EXAMPLE 17 The thinnest production weld contact member (0,2) is thinner than the thinnest contact member from the low-end machine qualification test (0,5). Also, total combined thickness of production weld combination (0,7) is less than that of the low-end machine qualification test (1,0).

EXAMPLE 18 The thinnest production weld contact member (0,2) is thinner than the thinnest contact member from the low-end machine qualification test (0,5).

EXAMPLE 19 All requirements of [13.1.2.3](#) are met.

EXAMPLE 20 All requirements of [13.1.2.3](#) are met.

EXAMPLE 21 All requirements of [13.1.2.3](#) are met.

EXAMPLE 22 The thinnest production weld contact member (2,0) is thicker than the thinnest contact member from the high-end machine qualification test (1,6).

EXAMPLE 23 All requirements of [13.1.2.3](#) are met.

EXAMPLE 24 The thinnest production weld contact member (1,8) is thicker than the thinnest contact member from the high-end machine qualification test (1,6).

Bibliography

- [1] ISO 10447:2015, *Resistance welding — Testing of welds — Peel and chisel testing of resistance spot and projection welds*
- [2] ISO 14732, *Welding personnel — Qualification testing of welding operators and weld setters for mechanized and automatic welding of metallic materials*
- [3] ISO 14373:2015, *Resistance welding — Procedure for spot welding of uncoated and coated low carbon steels*
- [4] ISO 15609-5, *Specification and qualification of welding procedures for metallic materials — Welding procedure specification — Part 5: Resistance welding*
- [5] IIW IAB-252-11, *IIW Guideline Personnel with Responsibility for Welding Coordination: Minimum Requirements for the Education, Examination and Qualification*

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