INTERNATIONAL STANDARD

ISO 25239-4

Second edition
2020-06

Friction stir welding — Aluminium —

Part 4: Specification and qualification of welding procedures

Soudage par friction-malaxage — Aluminium —

Partie 4: Descriptif et qualification des modes opératoires de soudage

Reference number
ISO 25239-4:2020(E)

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Foreword

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

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

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

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

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

This document was prepared by IIW, *International Institute of Welding*, Commission III, *Resistance Welding, Solid State Welding and Allied Joining Process*, in collaboration with the European Committee for Standardization (CEN) Technical Committee CEN/TC 121, *Welding and allied processes*, in accordance with the Agreement on technical cooperation between ISO and CEN (Vienna Agreement).

This second edition cancels and replaces the first edition (ISO 25239-4:2011), which has been technically revised.

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

— alternative process control methods (e.g. temperature control) have been included;

— the wording of the paragraph on thermal management and heat treatments has been improved;

— the definition for the extraction of test specimens has been modified for all test pieces and the figures have been revised accordingly;

— the requirement for testing transverse test specimens with as welded surfaces has been deleted;

— in Table 3, a new requirement on the minimum joint efficiency has been added for heat treatable alloys below 5 mm;

— the pWPS is now to be qualified in accordance with the defined acceptance levels included in ISO 25239-5;

— acceptance levels have been included in the WPQR form in Annex D.

A list of all parts in the ISO 25239 series can be found on the ISO website.

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

Introduction

Welding processes are widely used in the fabrication of engineered structures. During the second half of the twentieth century, fusion welding processes, wherein fusion is obtained by the melting of parent material and usually a filler metal, dominated the welding of large structures. In 1991, Wayne Thomas at TWI invented friction stir welding (FSW), which is carried out entirely in the solid phase (no melting).

The increasing use of FSW has created the need for this document in order to ensure that welding is carried out in the most effective way and that appropriate control is exercised over all aspects of the operation. This document focuses on the FSW of aluminium because, at the time of publication, the majority of commercial applications for FSW involved aluminium. Examples include railway carriages, consumer products, food processing equipment, aerospace structures, and marine vessels.

Friction stir welding — Aluminium —

Part 4: Specification and qualification of welding procedures

1 Scope

This document specifies the requirements for the specification and qualification of welding procedures for the friction stir welding (FSW) of aluminium.

In this document, the term "aluminium" refers to aluminium and its alloys.

This document does not apply to friction stir spot welding which is covered by the ISO 18785 series.

NOTE Service requirements, materials or manufacturing conditions can require more comprehensive testing than is specified in 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 4136, *Destructive tests on welds in metallic materials — Transverse tensile test*

ISO 5173, *Destructive tests on welds in metallic materials — Bend tests*

ISO 9017, *Destructive tests on welds in metallic materials — Fracture test*

ISO 15607:2019, *Specification and qualification of welding procedures for metallic materials — General rules*

ISO 17637, *Non-destructive testing of welds — Visual testing of fusion-welded joints*

ISO 17639, *Destructive tests on welds in metallic materials — Macroscopic and microscopic examination of welds*

ISO 25239-1, *Friction stir welding — Aluminium — Part 1: Vocabulary*

ISO 25239-5:2020, *Friction stir welding — Aluminium — Part 5: Quality and inspection requirements*

ISO/TR 25901 (all parts), *Welding and allied processes — Vocabulary*

ISO 80000-1:2009, *Quantities and units — Part 1: General*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 25239-1 and ISO/TR 25901 (all parts) apply.

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

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

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

4 Development and qualification of welding procedures

4.1 General

Qualification of welding procedures shall be performed prior to production welding.

The abbreviations listed in ISO 15607:2019, Table 1, shall apply.

The fabricator shall prepare a preliminary welding procedure specification (pWPS) and shall ensure that it is applicable for production using experience from previous production jobs and the general fund of knowledge of welding technology. The pWPS shall be prepared with the aim of achieving the required quality acceptance levels specified in ISO 25239-5:2020, Annex A.

A pWPS shall be used as the basis for the establishment of a welding procedure qualification record (WPQR). The pWPS shall be tested in accordance with one of the methods listed in Clause 5 (welding procedure test) or Clause 6 (pre-production welding test). Clause 5 shall be used when the production part or joint geometry is accurately represented by a standardized test piece or pieces, as shown in 5.2. Clause 6 shall be used when the production part or joint geometry is not accurately represented by the standardized test pieces, as shown in 5.2. The information required in a pWPS is given in 4.2.

For some applications, it can be necessary to supplement or reduce the content of the pWPS given in 4.2.

A welding procedure specification (WPS) covers a certain range of parent material thicknesses as well as a range of aluminium alloys.

Ranges and tolerances in accordance with the relevant International Standard (see Clause 2) and the fabricator's experience shall be specified when appropriate.

An example of a pWPS form for force and position controlled friction stir welding is shown in Annex A.

Alternative process control methods can be used such as temperature control. Essential variables of the alternative process control method need to be documented in the pWPS.

4.2 Technical content of a pWPS

The following information, as a minimum, shall be included in a pWPS:

a) fabricator information:
   - identification of the fabricator;
   - identification of the pWPS;

b) parent material type(s), temper(s), and reference standard(s);

c) parent material dimensions:
   - thickness of the members comprising the welded joint;
   - outside diameter of tube;

d) equipment identification:
   - model;
   - serial number;
   - equipment fabricator;

e) tool identification:
   - material;

— drawing or drawing number;

f) clamping arrangement:

— method and type of jigging, fixtures, rollers, and backing (dimensions and material);

— tack welding process and conditions, when required;

— the pWPS shall indicate any required tack welding or prohibited tack welding;

— assembly requirements (i.e. welding gap, misalignment);

g) joint design:

— sketch of the welded joint design and dimensions;

— joint configuration;

— weld run sequence and direction;

— run-on and run-off plates, material type, reference standard, dimensions and method of attachment (if required);

— placement of exit hole;

h) joint preparation and cleaning methods;

i) welding details:

— method (basic, stationary shoulder, bobbin tool, etc.);

— tool motion (e.g. rotation in either the clockwise or anticlockwise direction, rotation speed including downward and upward motion);

— tool position (e.g. heel plunge depth) or axial force, as applicable;

— tool cooling (internal, external, cooling medium), if applicable;

— tilt angle;

— side tilt angle, lateral offset;

— dwell time at start of weld;

— dwell time at end of weld;

— weld overlap area (WOA) for a butt joint or lap joint in tube;

— lap joint: advancing or retreating side near the upper sheet edge, direction of welding, depth of probe penetration in lower sheet;

j) welding speed:

— welding speed, including details of any changes during welding;

— ramp-up/ramp-down or upslope/downslope speeds when applied;

k) welding position: applicable welding positions;

l) thermal management:

— details of any pre-weld heat treatment, if applicable;

— details of the preheating temperature, preheat maintenance temperature and/or interpass temperature for the base materials or the friction stir welding tool, if applicable (use of ISO 13916 is recommended);

— details of any postweld heat treatment (e.g. solution heat treatment, ageing, stress relieving), if applicable;

— details of any methods for managing the cooling rates (e.g. gas flows, liquid environments) applied prior, during or after welding, if applicable;

m) postweld (mechanical) processing: methods to correct distortion and straighten parts, removal of toe flash or any other postweld processing of the weldment.

5 Qualification based on a welding procedure test

5.1 General

The preparation, welding and testing of test pieces shall be in accordance with 5.2 and 5.3.

Fulfilment of the requirements of this document can also serve to qualify the welding operator (see ISO 25239-3).

5.2 Test pieces

5.2.1 Shape and dimensions of test pieces

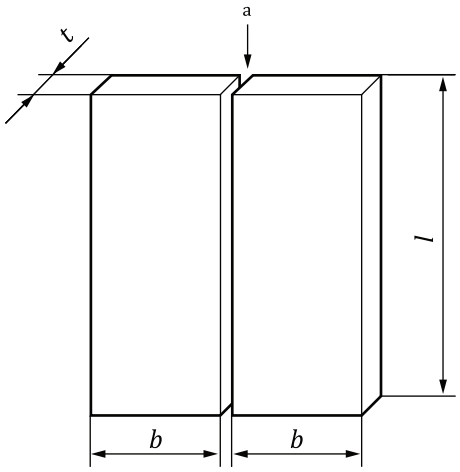
5.2.1.1 General

The length or number of test pieces shall be sufficient to allow all required tests to be performed.

Test pieces longer than the minimum size may be used to allow for the provision of extra specimens, for re-testing specimens or both (see 5.3.4).

The rolling direction or extrusion direction shall be marked on the test piece.

To produce a butt joint in flat material, the test piece shall be prepared in accordance with Figure 1. The length of the test piece should allow a weld length of at least 500 mm.



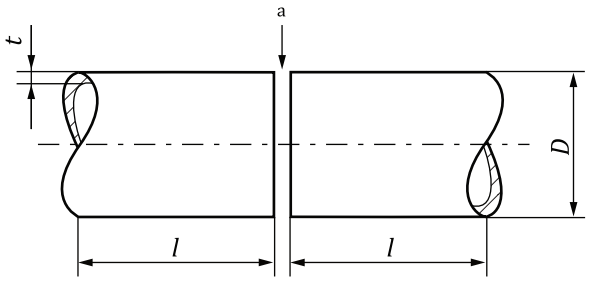
Key

b width of components
l length of components
t material thickness
[a] Joint preparation and fit-up, as specified in the pWPS.

Figure 1 — Test piece for a butt joint in sheet

5.2.1.2 Butt joint in tube

The test piece shall be prepared in accordance with Figure 2.



Key

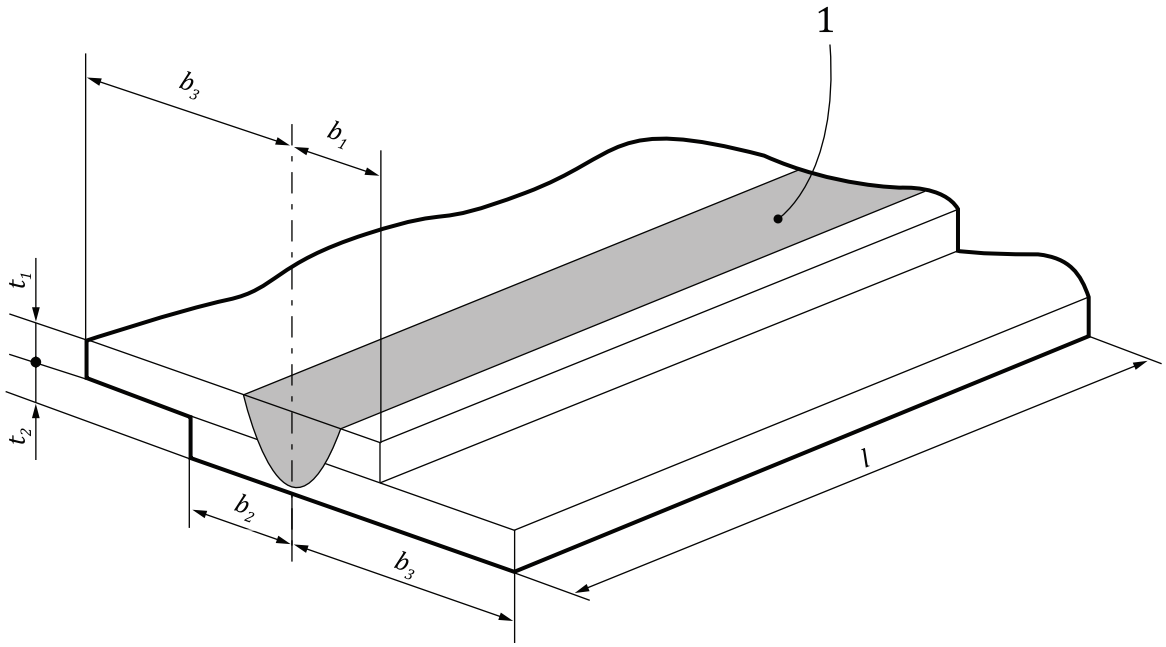
D outside diameter of tube
l length of components
t material thickness
[a] Joint preparation and fit-up, as specified in the pWPS.

Figure 2 — Test piece for a butt joint in tube

5.2.1.3 Lap joint

The test piece shall be prepared in accordance with Figure 3.

The weld may be either partial or full penetration through all the sheets.



Key

1 weld
b_1 edge to weld centreline distance of upper sheet, as specified in the pWPS
b_2 edge to weld centreline distance of lower sheet, as specified in the pWPS
b_3 distance between weld centre and edge of test piece
l length of components
t_1 parent material thickness of upper sheet
t_2 parent material thickness of lower sheet

Figure 3 — Test piece for a lap joint

5.2.2 Welding of test pieces

The test pieces shall be welded in accordance with the pWPS. If tack welds are to be consumed during friction stir welding of the production joint, then they shall be included in the test specimens. The location of tack welds shall be clearly marked on the test piece. Samples should be assessed from both tacked and un-tacked weld areas.

Welding of the test pieces shall be witnessed by an examiner.

5.3 Examination and testing of test pieces

5.3.1 Extent of testing

Testing includes both non-destructive testing (NDT) and destructive testing. Testing shall be performed in accordance with the requirements of Table 1 or Table 2. Annex B provides additional information on NDT.

Examination of the test results shall be verified by an examiner.

Table 1 — Examination and testing of the test pieces for butt joints (Figure 1, Figure 2)

Type of examination and testing	Extent of examination and testing
Visual testing[a]	100 %
Transverse tensile test[b]	Two test specimens
Transverse bend test for wrought materials (in accordance with 5.3.3.4)	Two root test specimens
Fracture test for cast materials or wrought/cast combinations (in accordance with ISO 9017)	Two face test specimens
Macroscopic examination	One test specimen
Additional tests (e.g. non-destructive)[d]	If required

[a] Discarded areas shall not be considered during testing, as shown in Figure 4.

[b] For a butt joint in tube, at least one transverse tensile test specimen should be taken from the WOA, if possible.

[c] For material over 12 mm in thickness, four transverse side-bend test specimens can be substituted for the two root and two face-bend test specimens. One longitudinal face-bend test specimen and one longitudinal root-bend test specimen can be substituted for the four transverse-bend test specimens.

[d] Additional tests shall be carried out in accordance with the relevant requirements of the design specification.

Table 2 — Examination and testing of the test pieces for lap joints (Figure 3)

Type of examination and testing	Extent of examination and testing
Visual testing[a]	100 %
Macroscopic examination	Two test specimens
Additional tests (e.g. peel test, shear test, hammer S-bend test, non-destructive test)[b]	If required

[a] Discarded areas shall not be considered during testing, as shown in Figure 6.

[b] Additional tests shall be carried out in accordance with the relevant requirements of the design specification. Information on the hammer S-bend test is given in Annex C.

Examination and testing of test pieces including tack welds or start/end areas of a butt joint in tube shall be in accordance with the design specification.

Specific service, material or manufacturing conditions can require more comprehensive testing in order to obtain additional test data.

5.3.2 Visual testing and acceptance levels

The test pieces shall be visually tested in accordance with ISO 17637 prior to extracting the test specimens. The extent of testing shall be as specified in Table 1 or Table 2.

The acceptance levels of ISO 25239-5:2020, Annex A, shall apply.

5.3.3 Destructive tests

5.3.3.1 General

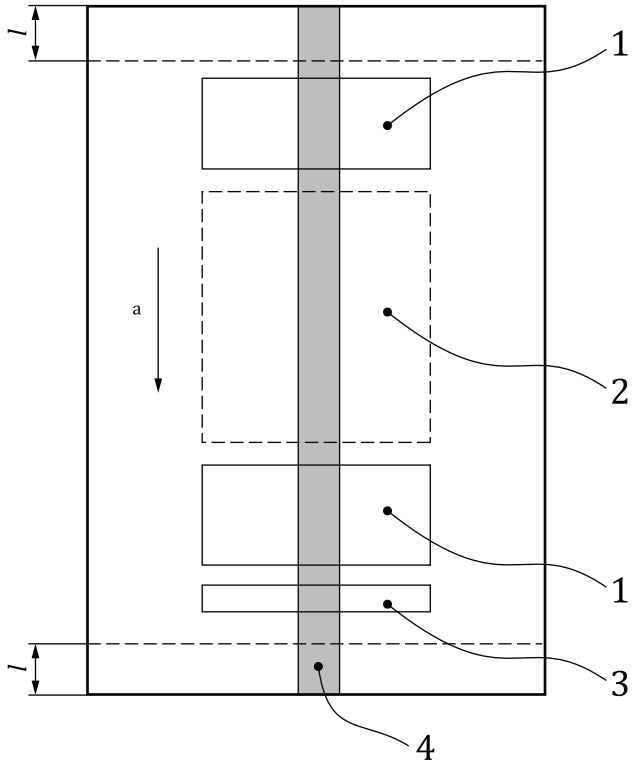
The extent of testing shall be as required in Table 1 and Table 2.

5.3.3.2 Location and extraction of test specimens

After the test piece has passed visual testing, test specimens shall be extracted.

The test specimens shall be located in accordance with Figure 4, Figure 5 or Figure 6.

The length discarded from each end of the test weld should be 50 mm or three times the weld penetration whichever is greater.

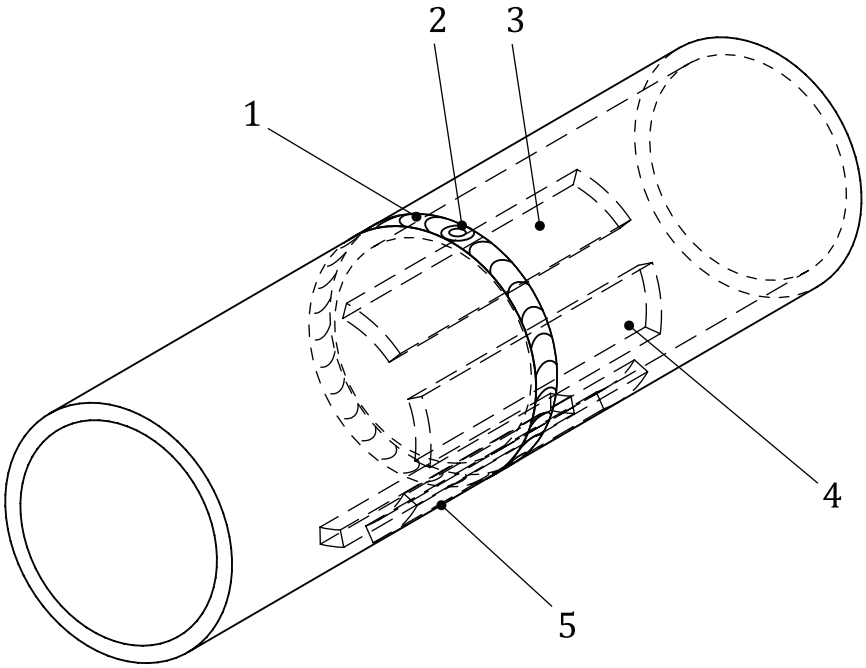


Key

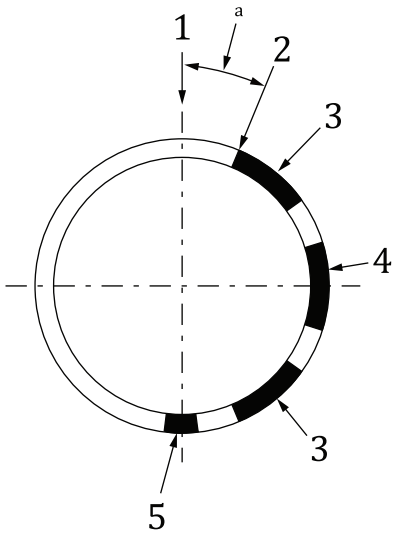
1 area for: one tensile test specimen; bend test specimens or fracture test specimens
2 area for additional test specimens, if required
3 area for one test specimen for macroscopic examination
4 weld
l length discarded from each end of the weld
a Direction of welding.

NOTE Not to scale. Start and stop of the weld are not shown in this figure.

Figure 4 — Location of test specimens for a butt joint in flat material



a) 3D-view



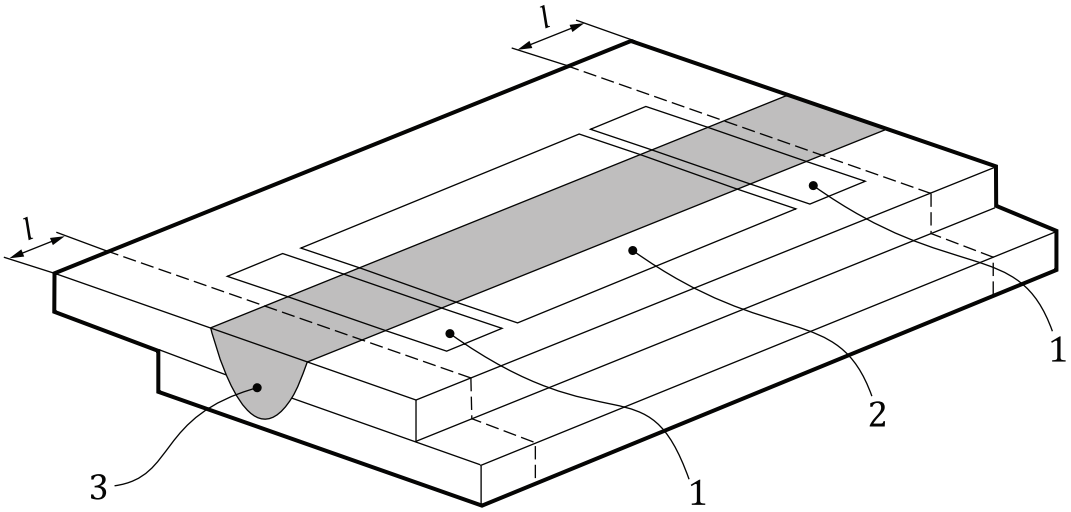
b) End view

Key

1 start of weld
2 end of weld
3 area for: one tensile test specimen; bend test specimens or fracture test specimens
4 area for additional test specimens, if required
5 area for one test specimen for macroscopic examination
[a] WOA yielding one tensile test specimen, if possible.

NOTE Not to scale. Welding direction is clockwise.

Figure 5 — Location of test specimens for a butt joint in tube



Key

1 area for one test specimen for macroscopic examination

2 area for peel test, shear test, hammer S-bend test specimens (see Annex C), if required

3 weld

l length discarded from each end of the weld

NOTE Not to scale. Start and stop of the weld are not shown in this figure.

Figure 6 — Location of test specimens in a lap joint

5.3.3.3 Transverse tensile test and acceptance levels

For butt joints, transverse tensile testing of test specimens shall be performed in accordance with ISO 4136.

For non-heat-treatable alloys and pure aluminium, the ultimate tensile strength of the test specimen shall not be less than the corresponding specified minimum value of the parent material in the "O" condition required in the relevant International Standard (see Table 3).

For heat-treatable alloys, the specified tensile strength, $\sigma_{min,w}$, of the welded test specimen in the postweld condition shall satisfy the minimum requirement:

$$\sigma_{min,w} = \sigma_{min,pm} \times f_e \quad (1)$$

where

$\sigma_{min,pm}$ is the specified minimum tensile strength of the parent material required in the relevant International Standard;

f_e is the joint efficiency factor (see Table 3).

For combinations of different aluminium alloys, the lower $\sigma_{min,w}$ value of the two alloys shall be required.

In order to determine conformity to the f_e values in Table 3, f_e values calculated from Formula (1) shall be rounded in accordance with the rules specified in ISO 80000-1:2009, Annex B.

Table 3 — Minimum efficiency for tensile strength of butt joints

Material type	Temper condition of parent material before welding[a,b]	Postweld condition	Joint efficiency factor f_e
Pure aluminium	All temper conditions	As welded	1,0[d]
Non-heat-treatable alloys	All temper conditions	As welded	1,0[d]
Heat-treatable alloys (equal and below 5 mm weld penetration)	T4	Natural ageing[c]	0,8
	T4	Artificial ageing[c]	0,8[e]
	T5 and T6	Natural ageing[c]	0,7
	T5 and T6	Artificial ageing[c]	0,8[e]
Heat-treatable alloys (above 5 mm weld penetration)	T4	Natural ageing[c]	0,7
	T4	Artificial ageing[c]	0,7[e]
	T5 and T6	Natural ageing[c]	0,6
	T5 and T6	Artificial ageing[c]	0,7[e]

[a] Refer to ISO 2107.

[b] For parent material in tempers not shown, $\sigma_{min,w}$ shall be in accordance with the design specification.

[c] Ageing conditions shall be in accordance with the design specification.

[d] Irrespective of the actual parent material temper used for the test, $\sigma_{min,pm}$ is based on the specified minimum tensile strength of the "O" condition.

[e] Higher properties can be achieved if a full postweld heat treatment is applied; $\sigma_{min,w}$ shall be in accordance with the design specification.

5.3.3.4 Bend test and acceptance levels

Bend test should be performed in accordance with the design specification.

Otherwise for butt joints, the test specimens and bend testing shall be in accordance with ISO 5173. The advancing and retreating sides of the test specimens should be marked prior to testing. For all parent materials, the minimum bend angle shall be 180°, using the calculated former diameter based on the parent material elongation as per Formula (2):

For elongation >5 %:

$$d = \frac{100 \times t_s}{\Delta l} - t_s \tag{2}$$

where

d is the maximum former diameter, in millimetres;

t_s is the thickness of the bend test specimen (includes transverse side bends), in millimetres;

Δl is the minimum tensile elongation, expressed as a percentage, required by the material specification (for combinations of different alloys, the lowest individual value shall be used).

For an elongation ≤5 %, annealing shall be carried out before testing. The former diameter shall be calculated with the elongation given by the specified "O" temper conditions.

If the bend tests fail due to grain growth that occurred during the annealing process, additional bend tests shall be performed in accordance with Table 1, except that new test parameters shall be in accordance with the design specification.

Values of d shall be rounded down to the nearest whole number.

A smaller former diameter can be used.

During testing, the test specimens shall not reveal any single crack >3 mm in any direction as assessed by the unaided eye. Cracking appearing at any edge of a test specimen during testing shall be ignored in the evaluation unless there is evidence that it is due to incomplete penetration or a cavity.

5.3.3.5 Macroscopic examination and acceptance levels

The test specimen shall be prepared and examined in accordance with ISO 17639 on one side to clearly reveal the weld region.

The macroscopic examination shall include unaffected parent material. Macroscopic examination before etching shall reveal no defects.

Care should be taken when etching certain alloys to avoid producing false indications.

The acceptance levels of ISO 25239-5:2020, Annex A, shall apply. Other imperfections shall be within the specified limits of the relevant requirements or the design specification.

5.3.4 Re-testing

If the test piece fails to comply with any of the requirements for visual testing specified in 5.3.2, an additional test piece shall be welded and subjected to the same examination. If this additional test piece does not comply with the requirements, the welding procedure test has failed.

If any test specimen fails to comply with the requirements for destructive tests performed in accordance with 5.3.3, but only due to weld imperfections, then two further test specimens shall be tested for each one that failed. The additional test specimens shall be taken from the same test piece if there is sufficient material or from a new test piece. Each additional test specimen shall be subjected to the same tests as the initial test specimen that failed. If either of the additional test specimens fails to comply with the requirements, then the welding procedure test has failed.

5.4 Range of qualification

5.4.1 General

Each of the conditions given in 5.4.2 to 5.4.3 shall be met.

Additions, deletions or changes outside the ranges specified shall require a new welding procedure test to be performed.

5.4.2 Related to the fabricator

A qualification test carried out by a fabricator is valid for welding on the same type of welding machine installed in workshops or sites under that fabricator's technical and quality control.

Welding is considered to be carried out under the same technical and quality control conditions as long as the fabricator who performed the welding procedure test retains complete responsibility for all corresponding welding.

5.4.3 Other variables

The range of qualification for other variables shall be specified in the WPS.

5.5 Welding procedure qualification record

The WPQR is a statement of the results of assessing each test piece, including re-tests. The relevant items listed in the WPS shall be included, together with details of any features that would be rejectable, in accordance with the requirements of 5.3. If the test results are acceptable, then the WPQR is qualified and shall be signed and dated by the examiner or representative of the examining body. In addition, the pWPS is also qualified. A WPS shall be issued.

If the tests results also meet the criteria of any other acceptance levels, the pWPS is also qualified for those acceptance levels.

A standard format for the WPQR shall be used. An example of a WPQR form is shown in Annex D.

6 Qualification based on pre-production welding test

6.1 General

The pre-production welding test shall be carried out in accordance with the relevant subclauses of Clause 6, unless modified by 6.2 to 6.5.

Fulfilling the requirements of this document can also serve to qualify the welding operator (see ISO 25239-3).

6.2 Test pieces

Preparation and welding of test pieces shall be performed under the general conditions of production welding. The test pieces shall be designed so that their shapes and dimensions simulate the actual welding conditions of the structure. This should include essential items (e.g. stress conditions, heating effects, limited access and edge condition).

When actual components are used, jigs and fixtures shall be those that are used in production.

6.3 Examination and testing of test pieces

The test pieces shall be tested in accordance with 5.2 to 5.5, as relevant.

The following tests, as a minimum, shall be performed:

— visual testing (100 %);

— macroscopic examination (one or more macros shall be performed depending on the geometry of the structure).

6.4 Range of qualification

Any WPS issued in accordance with this document is limited to the type of joint used in the pre-production welding test.

The range of qualification is generally in accordance with 5.4.2 or 5.4.3 for welding.

6.5 Welding procedure qualification record

The WPQR is a statement of the results of assessing each test piece, including re-tests. The relevant items listed in the WPS shall be included, together with details of any features that would be rejectable, in accordance with the requirements of 6.3. If the test results are acceptable, then the WPQR is qualified and shall be signed and dated by the examiner or representative of the examining body. In addition, the pWPS is also qualified. A WPS shall be issued.

If the tests results also meet the criteria of any other acceptance levels, the pWPS is also qualified for those acceptance levels.

A standard format for the WPQR shall be used. An example of a WPQR form is shown in Annex D.

Annex A
(informative)

Example of a form for preliminary welding procedure specification (pWPS) and welding procedure specification (WPS)

Fabricator's pWPS No.: _____

Fabricator's WPQR No.: _____

Friction stir welding operator's name: _____

Parent material type, temper and reference standard(s): _____

Parent material thickness (mm): _____

Outside diameter of tube (mm): _____

Equipment identification (model, serial number, and fabricator): _____

Tool identification (sketch)[1)]: _____

Clamping arrangement (sketch)[1)]: _____

Tack welding: _____

Joint preparation and cleaning methods: _____

Joint design

Joint design and joint configuration	Welding sequences
(Sketch)[1)]	

Welding details

Run	Tool motion, rotation speed r/min	Axial force or Heel plunge depth kN or mm	Depth of probe penetration in lower sheet[1)] mm	Tilt angle °	Side tilt angle °	Dwell time s	Welding speed mm/min	Others

Welding position: _____

Postweld processing: _____

Other information[1)]: _____

Fabricator: _____

Name, date and signature: _____

1) If required.

Annex B
(informative)

Non-destructive testing

When non-destructive testing (NDT) is required, it should be performed on the test pieces before the test specimens are cut from them.

Depending on the joint geometry, parent materials, and work requirements, NDT, if required, should be performed in accordance with ISO 3452 (penetrant inspection), ISO 17636 (radiographic testing), and ISO 17640 (ultrasonic examination). If there are stringent requirements for weld integrity, it can be necessary to develop specific methods (e.g. phased-array ultrasonic testing or eddy-current testing).

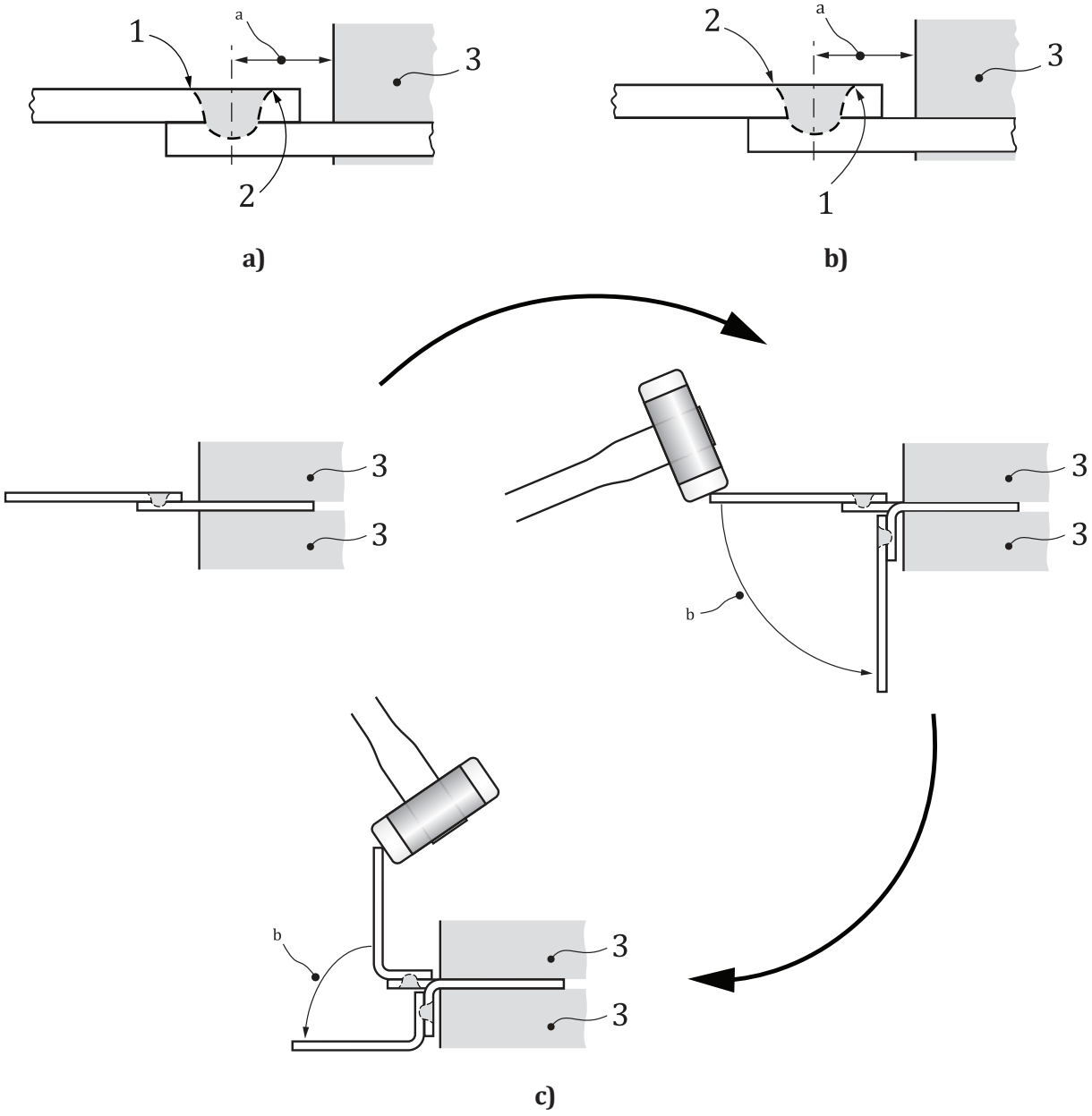
Annex C
(informative)

Hammer S-bend test of lap welds

The hammer S-bend test of lap welds has proven to be a sensitive method for qualitatively determining whether a weld contains imperfections, e.g. sheet thinning or hooks. Since this is a qualitative test, the appropriate distance from the centre of the weld to the vice (or holding clamp) should be adjusted to compensate for the ductility or lack of ductility and the thickness of the material being tested. For more ductile materials, the distance from the weld centre to the vice should be less than the distance for less ductile materials.

It is recommended that the hammer S-bend test be performed on two test specimens. The first test specimen should have the advancing side of the weld nearer to the hammer [Figure C.1 a)]. The second test specimen should have the retreating side nearer to the hammer [Figure C.1 b)].

This test does not replace other quantitative tests.



Key

1 advancing side of weld
2 retreating side of weld
3 vice
a Clamp edge to weld centreline distance.
b Direction of swinging hammer.

NOTE The large arrows indicate the sequence of testing.

Figure C.1 — Unrestrained hammer S-bend test method

Annex D
(informative)

Example welding procedure qualification record form (WPQR)

Fabricator's WPQR No.: _____

Welding procedure qualification — Test certificate

Fabricator: _____

Address: _____

Fabricator's pWPS No.: _____

Examiner or examining body: _____

Reference No.: _____

Code/testing standard: _____

Date of welding: _____

Friction stir welding operator's name: _____

Parent material type and reference standard(s): _____

Parent material thickness (mm): _____

Outside diameter of tube (mm): _____

Joint design (sketch): _____

Postweld heat treatment: _____

Other information: _____

The signature below certifies that the test welds were prepared, welded and tested satisfactorily in accordance with the requirements of the code/testing standard indicated above.

Location	Date of issue	Examiner or examining body Name, date and signature

Record of weld test

Fabricator: _____

Address: _____

Fabricator's pWPS No.: _____

Fabricator's WPQR No.: _____

Examiner or examining body: _____

Reference No.: _____

Friction stir welding operator's name: _____

Parent material type, temper and reference standard(s): _____

Parent material thickness (mm): _____

Outside diameter of tube (mm): _____

Tool identification (sketch)[2)]: _____

Clamping arrangement (sketch)[2)]: _____

Equipment identification: _____

Tack welding: _____

Joint preparation and cleaning methods: _____

Joint design

Joint design and joint configuration	Welding sequences
(Sketch)[2)]	

Welding details

Run	Tool motion, rotation speed r/min	Axial force or Heel plunge depth kN or mm	Depth of probe penetration in lower sheet[2)] mm	Tilt angle °	Side tilt angle °	Dwell time s	Welding speed mm/min	Others

2) If required.

Pre-weld heat treatment: _____

Preheating temperature (°C): _____

Preheat maintenance temperature (°C): _____

Interpass temperature (°C): _____

Shielding gas: _____ Designation: _____ Gas flow rate (l/min): _____

Post-weld processing: _____

Post-weld heat treatment (time, temperature, method, heating and cooling rates): _____

Other information[3)]: _____

Test results

Fabricator: _____

Address: _____

Fabricator's pWPS No.: _____

Fabricator's WPQR No.: _____

Test laboratory's reference No.: _____

Examiner or examining body: _____

Reference No.: _____

Visual testing

Designation of imperfection in accordance with ISO 25239-5:2020, Annex A	Acceptance level in accordance with ISO 25239-5:2020, Annex A	Acceptable	Unacceptable	Report No.

Macroscopic examination

Designation of imperfection in accordance with ISO 25239-5:2020, Annex A	Acceptance level in accordance with ISO 25239-5:2020, Annex A	Acceptable	Unacceptable	Report No.

3) If required.

Destructive tests

Tensile tests required: Yes/No

Type/No.	$\sigma_{min,w}$ N/mm^2	$\sigma_{min,pm}$ N/mm^2	f_e $\sigma_{min,w}/\sigma_{min,pm}$	Fracture location	Remarks
Requirement					
1		—			
2		—			

$\sigma_{min,w}$: Tensile strength of test specimen

$\sigma_{min,pm}$: Tensile strength of parent material

Bend tests required: Yes/No

Type/No.	Bend side	Former diameter d mm	Result

Other tests[4]: _____

Remarks: _____

Tests carried out in accordance with the requirements of: _____

Laboratory report reference No.: _____

Test results were acceptable/not acceptable (delete as appropriate)

Test carried out in the presence of: _____

4) If required.

Bibliography

[1] ISO 2107, *Aluminium and aluminium alloys — Wrought products — Temper designations*

[2] ISO 3452 (all parts), *Non-destructive testing — Penetrant inspection*

[3] ISO 13916, *Welding — Measurement of preheating temperature, interpass temperature and preheat maintenance temperature*

[4] ISO 17636 (all parts), *Non-destructive testing of welds — Radiographic testing*

[5] ISO 17640, *Non-destructive testing of welds — Ultrasonic testing — Techniques, testing levels, and assessment*

[6] ISO 18785 (all parts), *Friction stir spot welding — Aluminium*

[7] ISO 25239-2, *Friction stir welding — Aluminium — Part 2: Design of weld joints*

[8] ISO 25239-3, *Friction stir welding — Aluminium — Part 3: Qualification of welding operators*

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