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Friction stir welding of aluminium
General requirements
Part 4
Specification and qualification of welding procedures

15 September. 2006

IIW Commission III

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ISO TC 44/SC IIW

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Secretariat:

Friction stir welding of aluminium - General Requirements — Part 4: Specification and qualification of welding procedures

Élément introductif — Élément central — Partie 4: Titre de la partie

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Foreword

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ISO 25239-4 was prepared by Technical Committee ISO/TC 44, *Welding and allied processes*, Subcommittee SC 10, *Unification of requirements in the field of metal welding*.

ISO 25239 consists of the following parts, under the general title *Friction stir welding of aluminium - General Requirements*:

— *Part 1: Vocabulary*

— *Part 2: Design of weld joints*

— *Part 3: Qualification of friction stir welding operators*

— *Part 4: Specification and qualification of welding procedures*

— *Part 5: Quality and inspection requirements*

Introduction

Welding processes are widely used in fabrication of engineered structures. During the second half of the twentieth century, welding of large structures was dominated by fusion welding processes wherein fusion is obtained by melting of the base metal and, usually, a filler metal. Friction stir welding, originating in the last decade of the twentieth century, is carried out entirely in the solid phase (no melting). There is an increasing need for friction stir welding standards. This standard focuses on friction stir welding of aluminium because, at the time this standard was created, the majority of commercial applications for friction stir welding involved aluminium. Examples include railway cars, consumer products, food processing equipment, aerospace, and marine vessels. Welding strongly influences the cost of fabrication and quality of such products. The increasing use of friction stir welding has created the need for a friction stir welding standard in order to assure that welding is carried out in the most effective way and that appropriate control is exercised over all aspects of the operation.

To this end, ISO is publishing this standard, which comprises five Parts. The first Part, entitled, Vocabulary, presents those terms and definitions specific to friction stir welding.

The second Part, entitled, *Design of Weld Joints*, presents the design requirements for friction stir weld joints in aluminium.

The third Part, entitled, *Qualification of friction stir welding operators*, specifies the requirements for the approval of welding operators for the friction stir welding of aluminium.

The fourth Part, entitled, *Specification and qualification of welding procedures*, specifies the requirements for the specification and qualification of welding procedures for the friction stir welding of aluminium.

The fifth Part, entitled, *Specification and qualification of welding procedures*, specifies a method to determine the capability of a manufacturer to use the friction stir welding process for production of aluminium products of the specified quality. It defines specific quality requirements but does not assign those requirements to any specific product group.

Welding procedure specifications are needed to provide a basis for planning welding operations and for quality control during welding. Welding is considered a special process in the terminology of standards for quality systems. Standards for quality systems usually require that special processes be carried out in accordance with written procedure specifications.

Preparation of a welding procedure specification provides the necessary basis for, but does not in itself ensure that the welds fulfil their requirements. Some deviations, notably imperfections and distortions, can be evaluated by non-destructive methods on the finished product.

Metallurgical deviations constitute a special problem. Because non-destructive evaluation of the mechanical properties is impossible at the present level of non-destructive technology, this has resulted in the establishment of a set of rules for qualification of the welding procedure prior to the release of the welding procedure specification to actual production. This ISO standard defines these rules.

Friction stir welding of aluminium - General Requirements — Part 4: Specification and qualification of welding procedures

1 Scope

This Part specifies the requirements for the specification and qualification of welding procedures for the friction stir welding of aluminium. In this standard, the term aluminium stands for aluminium and its alloys.

This standard does not apply to friction stir spot welding.

NOTE Service requirements, materials, or manufacturing conditions may require more comprehensive testing than is specified by this standard.

2 Normative References

This standard incorporates by dated or undated reference, provisions from other publications. These normative references are cited at the appropriate places in the text and the publications are listed hereafter. For dated references, subsequent amendments to or revisions of any of these publications apply to this standard only when incorporated in it by amendment or revision. For undated references, the latest edition of the publication referred to applies (including amendments).

ISO 209-1, *Wrought aluminium and aluminium alloys – Chemical composition and forms of products – Part 1: Chemical composition*

ISO 857-1, *Welding and allied processes – Vocabulary – Part 1: Metal welding processes*

ISO 2107, *Aluminium and aluminium alloys – Wrought products – Temper designations*

ISO 3134-1, *Light metals and their alloys - Terms and definitions - Part 1: Materials*

ISO 3134-2, *Light metals and their alloys - Terms and definitions - Part 2: Unwrought products*

ISO 3134-3, *Light metals and their alloys - Terms and definitions - Part 3: Wrought products*

ISO 3134-4, *Light metals and their alloys - Terms and definitions - Part 4: Castings*

ISO 3134-5, *Light metals and their alloys - Terms and definitions - Part 5: methods of processing and treatment*

ISO 4136, *Destructive tests on welds in metallic materials – Transverse tensile test*

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

ISO 6520-1, *Welding and allied processes – Classification of geometric imperfections in metallic materials – Part 1: Fusion welding*

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

ISO 10042, *Welding – Arc-welded joints in aluminium and its alloys – Quality levels for imperfections*

ISO 13916, *Welding – Guidance on the measurement of preheating temperature, interpass temperature and preheat maintenance temperature*

ISO 14175, *Welding consumables – Shielding gases for arc welding and cutting*

ISO 15607, *Specification and qualification of welding procedures for metallic materials – General rules*

ISO 15613, *Specification and qualification of welding procedures for metallic materials – Qualification based on pre ―production test*

ISO 15614-2, *Specification and qualification of welding procedures for metallic materials – Welding procedure test － Part 2: Arc welding of aluminium and its alloys*

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 of aluminium and its alloys – General Requirements – Part 1: Vocabulary*

ISO/TR 17671-1, *Welding – Recommendations for welding of metallic materials – Part 1: General guidance for arc welding*

3 Terms and definitions

For the purposes of this standard, the terms and definitions given in ISO 209-1, ISO 857-1, ISO 3134-1, ISO 3134-2, ISO 3134-3, ISO 3134-4, ISO 3134-5, ISO 6520-1, ISO 10042, ISO 15607, ISO 15613, ISO 15614-2, ISO 25239-1and ISO/TR 17671-1 apply.

4 Symbols and abbreviated terms

For the purposes of qualification of welding procedures, the abbreviations listed in Table 1 of ISO 15607, apply.

5 Development and qualification of welding procedures

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

5.1 General

The manufacturer shall prepare a preliminary welding procedure specification (pWPS) and shall ensure that it is applicable for the actual production, using experience from previous productions and the general fund of knowledge of welding technology.

A pWPS shall be used as the basis for establishing of a welding procedure qualification record (WPQR) to be tested according to one of methods listed in Clause 6 (welding procedure test) or Clause 7 (pre-production welding test). The welded joint to which the welding procedure will relate in production shall be represented by making a standardized test pieces or pieces, as specified in 6.2. Where the production/joint geometry requirements do not represent the standardized test pieces as shown in 6.2, the use of Clause 7 shall be required.

The information required in a pWPS is given in 5.2.

NOTE For some applications, it may be necessary to supplement or reduce the list.

A welding procedure specification covers a certain range of material thickness and also covers a range of parent materials.

Ranges and tolerances, according to the relevant standard of the series (see Clause 2) and to the manufacturer's experience, shall be specified where appropriate.

An example of a pWPS form is shown in Annex A.

5.2 Technical content of preliminary welding procedure specification (pWPS)

5.2.1 Manufacture information

— identification of the manufacturer;

— identification of the preliminary welding procedure specification.

5.2.2 Parent material type and reference standard

5.2.3 Parent material dimensions

— thickness of the members comprising the welded joint;

— outside diameter of tube.

5.2.4 Equipment identification

— model;

— serial number;

— manufacturer.

5.2.5 Tool identification

— material;

— drawing or drawing number;

— trade name.

5.2.6 Clamping arrangement

— the method and type of jigging, fixtures, rollers, and backing;

— tack welding process and conditions when required. the pWPS shall indicate any required tack welding or tack welding prohibited;

— fusion tack welding shall be carried out in accordance with a welding procedure specification which is qualified in accordance with the relevant part of ISO 15614-2 or the relevant requirements.

5.2.7 Joint design

— a sketch of the welded joint design and dimensions;

— weld run sequence and direction given on the sketch if applicable;

— run-on and run-off plates, if applicable. material type, reference standard and dimensions of run-on and run-off plates;

— placement of exit hole.

5.2.8 Joint preparation and cleaning methods

5.2.9 Welding details

— tool motion (for example, rotation in either the clockwise or anti-clockwise direction, rotation speed including ramp-up/ramp-down);

— heel plunge depth, downward force, as applicable;

— tilt angle;

— side tilt angle;

— standby time;

— joint configuration;

— lapped length between start and end of welds for a butt joint in tube;

— lap joint: advancing/retreating side near the top sheet edge, direction of welding.

5.2.10 Welding speed

— when required, ramp-up/ramp-down or upslope/downslope speeds should be applied.

5.2.11 Welding position

— applicable welding positions.

5.2.12 Pre-weld heat treatment

— when pre-weld heat treatment should be applied.

5.2.13 Preheating temperature

— when preheating should be applied;

— see also ISO 13916 for application of 5.2.13, 5.2.14 and 5.2.15;

— when preheating of tool should be applied.

5.2.14 Preheat maintenance temperature

— when preheat maintenance should be applied.

5.2.15 Interpass temperature

— when interpass heating should be applied.

5.2.16 Working temperature

— when working heating should be applied.

5.2.17 Shielding gas

— designation in accordance with ISO 14175 and, where applicable, the composition, manufacturer and name, and gas flow rate.

5.2.18 Post-weld processing

— solution heat treatment, aging, stress relieving (or the methods to correct distortion and straighten distorted parts), removal of flash, or any other post weld processing of the weldment;

— post-weld heat-treatment;

— the minimum time and temperature range for post-weld heat treatment or ageing shall be specified or reference shall be made to other standards which specify this information.

6 Qualification based on welding procedure test

6.1 General

The welding and testing of test pieces shall be in accordance with 6.2 and 6.3.

6.2 Test pieces

6.2.1 General

The welded joint to which the welding procedure will relate in production shall be represented by making a standardized test piece or pieces, as specified in 6.2.2.

6.2.2 Shape and dimensions of test pieces

6.2.2.1 General

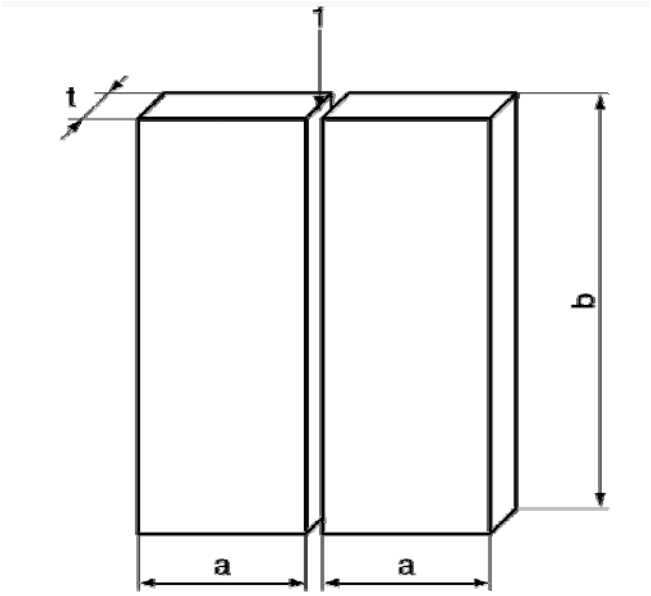
The length or number of test pieces shall be sufficient to allow all required tests to be carried out.

Test pieces, longer than the minimum size, may be prepared in order to allow for extra specimens or for re-testing specimens or both (see 6.3.4).

If required, the rolling or extrusion direction shall be marked on the test piece. The shape and minimum dimensions of the test piece shall be as follows.

6.2.2.2 Butt joint in sheet with full penetration

The test piece shall be prepared in accordance with Figure 1.



Key

1 Joint preparation and fit-up as detailed in the preliminary welding procedure specification

a Minimum value 150 mm

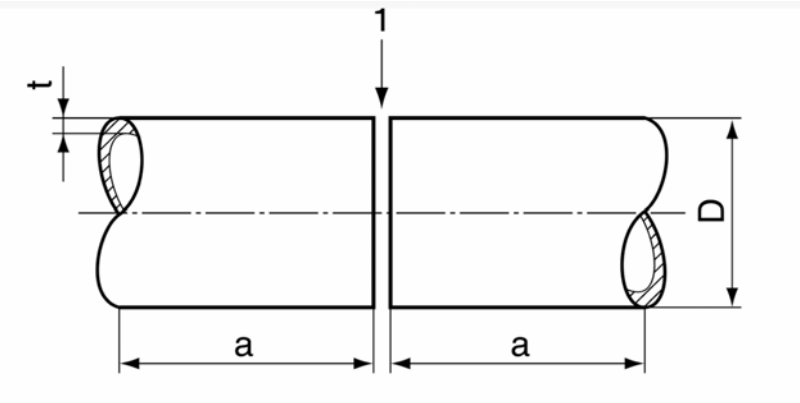
b Minimum value 500 mm

t Material thickness

Figure 1 — Test piece for a butt joint in sheet with full penetration

6.2.2.3 Butt joint in tube with full penetration

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



Key

1 Joint preparation and fit-up as detailed in the preliminary welding procedure specification

a Minimum value 150 mm

D Outside diameter of tube

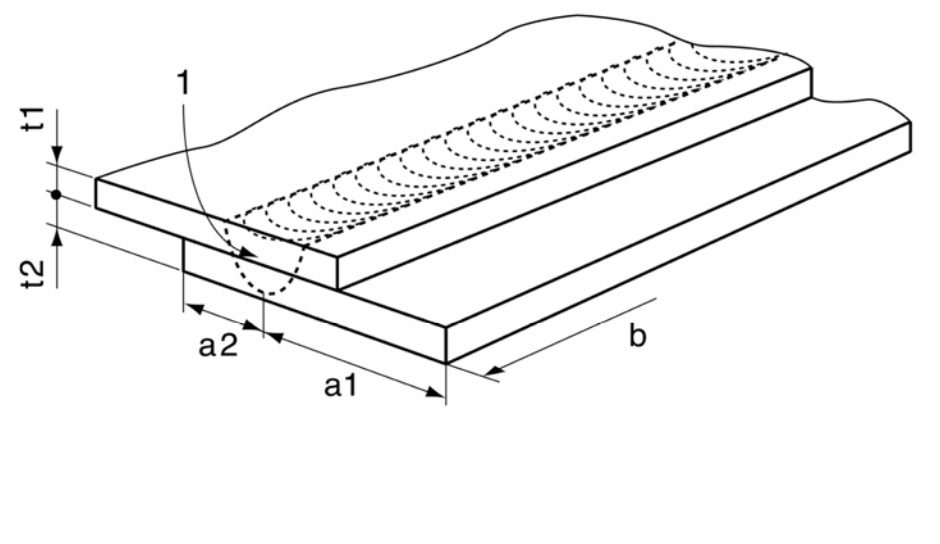
t Material thickness

Figure 2 — Test piece for a butt joint in tube with full penetration

6.2.2.4 Lap joint

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

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



Key

1 Joint preparation and fit-up as detailed in the preliminary welding procedure specification

a1 Minimum value 150 mm

a2 Value as detailed in the preliminary welding procedure specification

b Minimum value 500 mm

t_1 and t_2 Material thicknesses

Figure 3 — Test piece for a lap joint

6.2.3 Welding of test pieces

The test pieces shall be welded in accordance with the preliminary welding procedure specification. If tack welds are to be consumed during friction-stir-welding of the production joint, then they shall be included in the test piece. The location of tack welds shall be clearly marked on the test piece.

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

6.3 Examination and testing of test pieces

6.3.1 Extent of testing

Testing includes both non-destructive testing (NDT) and destructive testing, which shall be performed in accordance with the requirements of Table 1 and Table 2.

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	2 test specimens
Transverse bend test for wrought materials [b]	2 root test specimens
Fracture test for cast materials or wrought/cast combinations [c]	2 face test specimens
Macroscopic examination	1 test specimen

[a] This testing shall be carried out to avoid discarded areas, as shown in Figure 4.

[b] Two root and two face-bend test specimens may be substituted by four side-bend test specimens for t above 12 mm, or by two longitudinal weld bend-test specimens.

[c] See ISO 9017

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	100% [a]
Macroscopic examination	2 test specimens
Additional tests (e.g. peel test, shear test, hammer "S" bend test)	if required [b]

[a] This testing shall be carried out to avoid discarded areas, as shown in Figure 6.

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

NOTE 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 may require more comprehensive testing than is specified by this clause in order to gain more information and to avoid repeating the welding procedure test at a later date just to obtain additional test data.

6.3.2 Visual testing

Visual testing in accordance with 6.3.1 and Table 1 and Table 2 shall be carried out on the test pieces prior to cutting of the test specimens and in accordance with ISO 17637.

6.3.2.1 Acceptance levels

Excess penetration, linear misalignment, root concavity, and continuous undercut shall be within the specified limits of level B in ISO 10042, and toe flash, underfill, irregular width, irregular surface, and other imperfections shall be within the specified limits of the relevant requirements or the design specification.

6.3.3 Destructive tests

6.3.3.1 General

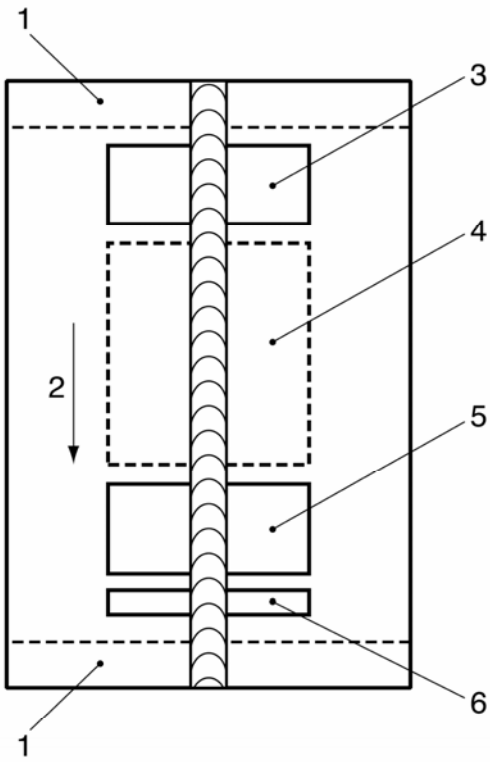
The extent of testing shall be as required by Table 1 and Table 2.

6.3.3.2 Location and extraction of test specimens

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

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

It is acceptable to take the test specimens from locations avoiding areas that have imperfections within the acceptance limits for the visual testing method used.



Key

1 Discard at least 50 mm from each end of the test weld

2 Direction of welding

3 Area for: —1 tensile test specimen
—bend test specimens or fracture test specimens

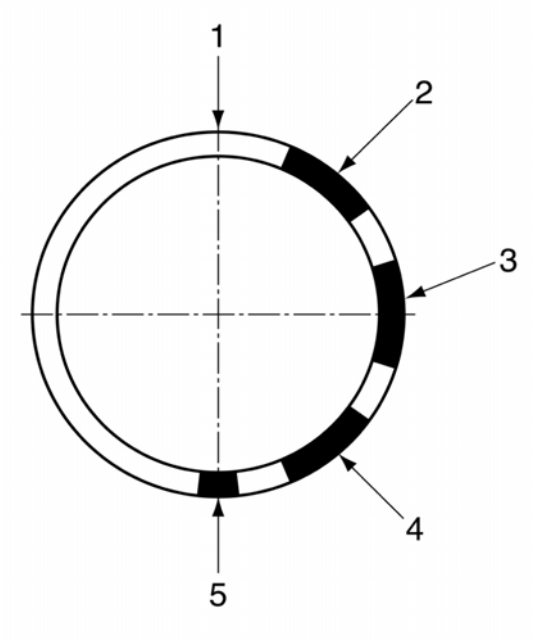
4 Area for additional test specimens, if required

5 Area for: —1 tensile test specimen
—bend test specimens or fracture test specimens

6 Area for: —1 macro test specimen

NOTE Not to scale

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



Key

1 start/end area

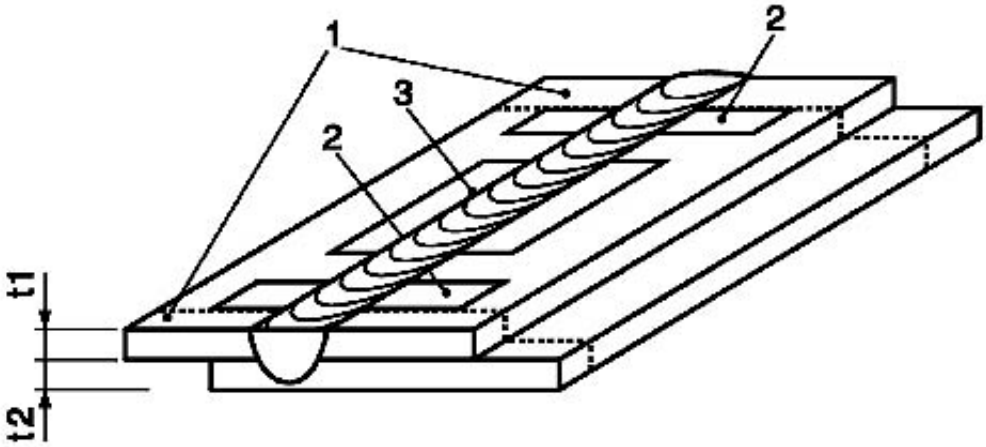
2 Area for: —1 tensile test specimen
—bend test specimens or fracture test specimens

3 Area for: —additional test specimens if required
4 Area for: —1 tensile test specimen
—bend test specimens or fracture test specimens

5 Area for: —1 macro test specimen

NOTE Not to scale

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



Key

1 Discard at least 50 mm from each end of the test weld

2 Area for: —2 macro test specimens

3 Area for: —peel test, shear test, hammer “S” bend test specimens if required

NOTE Not to scale

Figure 6 — Location of test specimens in a lap joint

6.3.3.3 Transverse tensile test

Test specimens and testing for transverse tensile testing of butt joints shall be in accordance with ISO 4136, except that the surface of the test specimens shall be in the as-welded condition. Advancing/retreating sides of the test specimens shall be marked prior to testing.

6.3.3.3.1 Acceptance levels

The ultimate tensile strength of the test specimen shall not be less than the corresponding specified minimum value for the parent material required in the relevant standard, in the “O” condition for pure aluminium and non heat treatable alloys, see Table 3.

For heat treatable alloys, the ultimate tensile strength Rm (w) of the welded test specimen in the as post-weld condition shall satisfy the following minimum requirement:

$$Rm\ (w) = Rm\ (pm) \times T \qquad (1)$$

where

Rm (pm) is the specified minimum tensile strength of the parent material required in the relevant standard,

T is the joint efficiency factor, see Table 3.

For combinations between different aluminium alloys, the lowest Rm (w) value of the two alloys shall be required.

For purpose of determining conformance to these T values in Table 3, calculated T values from equation (1) shall be rounded off, in accordance with rules for rounding.

Table 3 — Efficiency for tensile strength of butt joints

Material type	Temper condition of parent material before welding[a, b]	Post-weld condition[c]	Joint efficiency factor (T)
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	T4	Natural ageing	0,7
	T4	Artificial ageing	0,7[e]
	T5 and T6	Natural ageing	0,6
	T5 and T6	Artificial ageing	0,7[e]
Other alloys	All temper conditions	—[f]	—[f]

[a] See ISO 2107

[b] For parent material in other tempers not shown in the Table, Rm (w) shall be in accordance with the design specification.

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

[d] Rm (pm) is based on the specified minimum tensile strength of the "O" condition, irrespective of the actual parent material temper used for the test.

[e] Higher properties may be achieved if post-weld full heat treatment is applied. Rm (w) shall be in accordance with the design specification.

[f] The post-weld ageing conditions and Rm (w) shall be in accordance with the design specification.

6.3.3.4 Bend test

Test specimens and testing for bend testing of butt joints shall be in accordance with ISO 5173. The advancing and retreating sides of the test specimens shall be marked prior to testing.

For all parent materials, the bend angle shall be 180° using the calculated former diameter based upon the parent material elongation as follows:

For elongation > 5%

$$d = \frac{100 \times ts}{A} - ts \qquad (2)$$

where

d is the maximum former diameter (mm) ;

ts is the thickness of the bend test specimen (this includes side bends) (mm) ;

A is the minimum tensile elongation required by the manufacturer material specification (for combination between different alloys the lowest individual value shall be used) (%).

For 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.

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

A smaller former diameter may be used.

6.3.3.4.1 Acceptance levels

During testing, the test specimens shall not reveal any one single imperfection > 3 mm in any direction.

Imperfections appearing at the corners of a test specimen during testing shall be ignored in the evaluation.

6.3.3.5 Macroscopic examination

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.

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

6.3.3.5.1 Acceptance levels

Incomplete root penetration, cavity, elongated cavity, and lack of penetration shall be within the specified limits of level B in ISO 10042, and hooking and other imperfections shall be within the specified limits of the relevant requirements or the design specification.

6.3.4 Re-testing

If the test piece fails to comply with any of the requirements for visual testing specified in 6.3.2, then one further 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 done in accordance with 6.3.3 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.

6.4 Range of qualification

6.4.1 General

Each of the conditions given in 6.4 shall be met.

Addition, deletion or changes outside of the ranges specified shall require a new welding procedure test.

6.4.2 Related to the manufacturer

A qualification test carried out by a manufacturer is valid for welding in workshops or sites under that manufacturer's technical and quality control.

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

6.4.3 Preheating temperature

The upper limit of qualification is the preheating temperature that was measured at the start of the welding procedure test. The lower limit is 30°C below the measured preheating temperature, as specified in the qualified welding procedure specification.

6.4.4 Interpass temperature

The upper limit of qualification is the highest interpass temperature reached during the welding procedure test. The lower limit of qualification is 30°C below the interpass temperature, as specified in the qualified welding procedure specification.

6.4.5 Other variables

The range of qualification for other variables shall be specified in the qualified welding procedure specification.

6.5 Welding procedure qualification record (WPQR)

The welding procedure qualification record (WPQR) is a statement of the results of assessing each test piece including re-tests. The relevant items listed for the qualified welding procedure specification shall be included, together with details of any features that would be rejectable by 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 examining body and the preliminary welding procedure specification (pWPS) is also qualified and then the qualified welding procedure specification (WPS) is issued.

A standard WPQR format shall be used. An example of a WPQR format is shown in Annex B.

7 Qualification based on pre-production welding test

7.1 General

The pre-production welding test shall be carried out in accordance with the relevant part of Clause 6 as modified by this clause.

7.2 Test pieces

Preparation and welding of the test pieces shall be carried out under the general conditions of production welding which they shall represent with shapes and dimensions of the test piece simulating the actual welding conditions of the structure. This includes welding positions and other essential items, e.g. stress conditions, heating effects, limited access, edge condition.

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

7.3 Examination and testing of test pieces

The testing of the test pieces shall be carried out in accordance with the relevant part of Clause 6.

In general, the following tests are to be preformed at least.

— visual testing (100%);

— macroscopic examination (number depends on the geometry of the structure).

7.4 Range of qualification

Any qualification issued under this standard is limited to the type of joint used in the pre-production test.

The range of qualification is generally in accordance with the relevant parts of Clause 6.4 for welding.

7.5 Welding procedure qualification record (WPQR)

An example of a standard WPQR format, which shall be used, is shown in Annex B.

Annex A
(informative)

Preliminary welding procedure specification (pWPS)

Manufacturer's pWPS No.: _____

Manufacturer's WPQR No.: _____

Friction stir welding operator's name: _____

Parent material type and reference standard (s): _____

Parent material thickness (mm): _____

Outside diameter of tube (mm): _____

Equipment identification: _____

Tool identification (Sketch)* :

Clamping arrangement (Sketch)* :

Tack welding: _____

Joint preparation and cleaning methods: _____

Joint design

Joint design and joint configuration	Welding sequences
(Sketch)*	

Welding Details

Run	Tool motion, rotation speed (r/min)	Heel plunge depth (mm) or downward force (kN)	Tilt angle (°)	Side tilt angle (°)	Standby time (s)	Welding speed (mm/min) , others

Welding position: _____

Pre-weld heat treatment: _____

Preheating temperature (°C): _____ Preheat maintenance temperature (°C): _____

Interpass temperature (°C): _____

Working 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* _____

.....

Manufacturer

Name, date and signature

* if required

Annex B
(informative)

Welding procedure qualification record form (WPQR)

Welding procedure qualification – Test certificate
Manufacture; _____ Address:_____
Manufacturer's pWPS No.:_____
Manufacturer's WPQR 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):
Post-weld 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
		_____ Examiner or examining body Print name and date

Record of weld test

Manufacture: _____ Address: _____
Manufacturer's pWPS No.:_____
Manufacturer's WPQR No.: _____
Examiner or examining body:_____
Reference No.: _____

Friction stir welding operator's name:_____
Parent material type and reference standard (s):_____
Parent material thickness (mm):_____Outside diameter of tube (mm):_____
Equipment identification: _____
Tool identification (Sketch)*
Clamping arrangement (Sketch)*
Tack welding: _____
Joint preparation and cleaning methods: _____

Joint design and joint configuration	Welding sequences
(Sketch)*	

Welding Details

Run	Tool motion, rotation speed (r/min)	Heel plunge depth (mm) or downward force (kN)	Tilt angle (°)	Side tilt angle (°)	Standby time (s)	Welding speed (mm/min), others

Welding position: _____
Pre-weld heat treatment: _____
Preheating temperature (°C):_____
Preheat maintenance temperature (°C): _____
Interpass temperature (°C): _____
Working 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*:_____

_____
Manufacturer
Name, date and signature

_____
Examiner or examining body
Name, date and signature

_____
Examiner or examining body
Print name and date

* if required

Test results

Manufacture: _____Address: _____
Manufacturer's pWPS No.:_____
Manufacturer's WPQR No.: _____
Test laboratory's reference No.:_____
Examiner or examining body:_____
Reference No.: _____

Visual testing

Acceptable	Unacceptable	Report No.

Macroscopic examination

Acceptable	Unacceptable	Report No.

Destructive tests

Tensile tests Required: Yes No

Type/No.	Rm(w) (N/mm^2)	Rm(pm) (N/mm^2)	T: Rm(w)/Rm(pm)	Fracture location	Remarks
Requirement					
1		-----			
2		-----			

Rm(w) : Tensile strength of test specimen Rm(pm) : Tensile strength of parent material

Bend tests Required: Yes No

Type/No.	Bend side	Former diameter *d* (mm)	Result

Other tests*: _____
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: _____

_____ _____
Examiner or examining body Examiner or examining body
Name, date and signature Print name and date

* if required

Annex C
(informative)

Non-destructive testing

When required, non-destructive testing should be carried out on the test pieces prior to cutting of the test specimens.

Depending upon joint geometry, materials and the requirements for work, the non-destructive testing should be carried out as required in accordance with ISO 3452 (penetrant testing), ISO 17636 (radiographic testing), ISO 17640 (ultrasonic examination). If there are stringent requirements for the weld integrity, then specific methods may have to be developed, such as phased-array ultrasonic testing or eddy-current testing.

Bibliography

[1] ISO 3452, *Non-destructive testing − Penetrant testing − General principles*

[2] ISO 17636, *Non-destructive testing of welds − Radiographic testing of fusion welded joints*

[3] ISO 17640, *Non-destructive examination of welds − Ultrasonic examination of welded joints*