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by IIW/C-III/SC III-B/WG-B1

Friction stir welding of aluminium
General requirements
Part 3
Qualification of friction stir welding operators

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Friction stir welding of aluminium - General Requirements — Part 3: Qualification of friction stir welding operators

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Foreword

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The International Organization for Standardization (ISO) draws attention to the fact that it is claimed that compliance with this document may involve the use of a patent concerning friction stir welding.

ISO takes no position concerning the evidence, validity and scope of this patent right.

The holder of this patent right has assured the ISO that it is willing to negotiate licences under reasonable and non-discriminatory terms and conditions with applicants throughout the world. In this respect, the statement of the holder of this patent right is registered with ISO. Information may be obtained from:

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Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights other than those identified above. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 25239-3 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.

Friction stir welding of aluminium - General Requirements — Part 3: Qualification of friction stir welding operators

1 Scope

This part specifies the requirements for the approval of welding operators for the friction stir welding (FSW) of aluminium. In this standard, the term aluminium refers to aluminium and its alloys.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

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

ISO 8596, *Ophthalmic optics – Visual acuity testing – Standard ophthotype and its presentation*

ISO 17636, *Non-destructive testing of welds – Radiographic testing of fusion-welded joints*

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/DIS 17640, *Non-destructive examination of welds – Ultrasonic examination of welded joints*

ISO 25239, *Welding – Friction stir welding of aluminium. Part 1 Vocabulary*

ISO 25239, *Welding – Friction stir welding of aluminium. Part 2 Design of weld joints*

ISO 25239, *Welding – Friction stir welding of aluminium. Part 4 Specification and qualification of friction stir welding procedures*

ISO 25239, *Welding – Friction stir welding of aluminium. Part 5 Quality and inspection requirements*

3 Terms and definitions

For the purposes of this Standard, the terms and definitions given in Part 1 and in ISO 857-1 apply.

4 Requirements

4.1 Friction stir welding operator qualification

Friction stir welding operators shall be qualified by one of the following tests, as detailed in 4.3:

- friction stir welding operator test (function test), see 4.3.1
- welding procedure test, see 4.3.2
- pre-production welding test or production test, see 4.3.3
- production sample test, see 4.3.4

In addition, the friction stir welding operator's knowledge of the welding unit to be used for the qualification is to be tested. See Annex A.

Any of the qualification tests can be supplemented by a test of knowledge related to welding technology. Such a test is recommended, but it is not mandatory. Annex B includes an example of such an examination.

The essential variables and the range of qualification are specified in subclauses of 4.2 and the validity in clause 5. Provided that the friction stir welding operator works according to an approved welding procedure specification (WPS), the range of qualification shall be limited only as specified in clause 4.2.

A suggested form for the friction stir welding operator's qualification certificate is shown in Annex C.

4.1.1 Physical requirements

Friction stir welding operators shall pass an eye examination according to ISO 8596 or equivalent. Vision shall be tested to these requirements, at least every two years.

The employer/manufacturer/ may establish additional, reasonable, and appropriate physical requirements for friction stir welding operators.

4.2 Essential variables and ranges of qualification

The qualification of friction stir welding operators is based on essential variables, as listed in this clause. For each essential variable, a range of qualification is defined. If the friction stir welding operator has to weld outside the range of qualification, then a new qualification test is required.

NOTE Friction stir welding is a mechanised process. However, because it is also a solid state welding process, the essential variables are different from those applicable to fusion welding processes.

4.2.1 Friction stir welding methods

For friction stir welding operators, a test made with any type of FSW method qualifies only that welding method. This clause applies to FSW methods that include, but are not limited to, robotic, single spindle, multiple spindles, self-reacting (bobbin) tool, retractable probe, or any other FSW method defined in the WPS used for that qualification test.

4.2.2 Automatic and robotic welding

The following changes require a new qualification:

- change from welding with a joint sensor to without. Welding without a joint sensor also qualifies welding with a joint sensor, but not vice versa.
- change from single-run to multi-run technique
- change of robotic type and system, including numerical control unit
- change from one type of welding machine to another. A test made with any type of machine qualifies only for that type of machine. The addition or deletion of jigs and fixtures, feeding units, and other ancillary equipment does not change the type of machine.

4.2.3 Parent materials

A test weld made in any aluminium alloy qualifies for all aluminium alloys.

A test weld of any parent material thickness qualifies all parent material thickness.

A test weld of any parent material form (including but not limited to sheet, plate, pipe, castings, forgings, or extrusions) qualifies for all parent material forms and for all pipe diameters.

4.2.4 Weld joint geometry

A test weld made in any weld joint geometry qualifies all weld joint geometries. For the purpose of friction stir welding operator qualification, only a butt joint is specified in this standard. A friction stir welding operator qualified on butt joints shall also be qualified for lap joints.

NOTE If only lap joints are being produced in a welding machine, then the friction stir welding operator may be qualified by welding a lap joint. Due to the inherent asymmetry of the friction stir welding process, and the influence of tool geometry on the weld quality of lap joints, this standard does not specify requirements for this type of joint. The specific requirements for friction stir welding operator qualification on lap joints shall be agreed by the contracting parties. Applicable parts of this standard may be used.

4.3 Qualification methods

4.3.1 Qualification based on welding test

A friction stir welding operator having successfully completed welding a test piece according to clause 4.4 shall be considered approved for the method and type of welding machine used, if the testing of the samples according to clause 4.4.1 is approved.

4.3.2 Qualification based on welding procedure testing

A friction stir welding operator having successfully completed a welding procedure test in accordance with clause 6 of Part 4 of this standard shall be considered approved for the method and type of welding machine used.

4.3.3 Qualification based on pre-production welding test or production test

A friction stir welding operator having successfully completed a pre-production welding test, in accordance with clause 7 of Part 4 of this standard, or a production test shall be considered approved for the method and type of welding machine used, if the testing of the samples according to clause 4.4.1 is approved by the examiner or examining body.

4.3.4 Qualification based on production sampling testing

A friction stir welding operator having successfully set up a production part shall be considered approved if representative samples of the items produced are approved by the examiner or the examining body. This testing of production samples is to be in accordance with the requirements of clause 4.4.1 or the requirements of the contracting parties, whichever is more stringent.

4.4 Test welds

Test welds shall be made in accordance with a qualified WPS, except when clause 4.3.2 applies. The welding and testing of test pieces shall be witnessed by the examiner or the examining body.

The test welds used for qualification of a friction stir welding operator shall have a length of at least 500 mm (20 inches). If the qualification is based on pre-production tests, production tests, or production sampling tests, and the product used has a shorter weld length than 500 mm, then the number of products tested must be such that the required weld length is met. However, no more than three products have to be tested.

The test pieces shall be marked with the identification of the examiner and the friction stir welding operator before welding starts.

The examiner or examining body may stop the test if the welding conditions are not correct or if it appears that the friction stir welding operator does not have the skill to fulfil the requirements of this standard.

4.4.1 Testing of test welds

4.4.1.1 Visual inspection

All test welds shall be 100% visually inspected according to ISO 17637 for surface and root defects and weld geometry. If so specified in the WPS, a maximum length of 50 mm (2 inches) at the start of the weld may be disregarded.

4.4.1.1.1 Acceptance criteria

The tool exit hole is to be examined. A deformed circle of material, the tool shoulder footprint, remains around the probe hole, which is caused by contact of the tool shoulder. The circumference of the deformed circle shall be at least 80 % complete. The tool exit hole shall have a symmetrical appearance and a smooth surface and be free of cracks or voids. The weld shall have an as-welded surface and be free of cracks or voids. The weld width shall not show any variations due to insufficient tool pressure. If a full penetration weld is specified, then there shall be no lack of penetration.

The misalignment of the parts to be joined shall not be more than 0,2t, or 0,5 mm, whichever is less.

NOTE The extent of the deformed circle gives an indication of weld quality. The extent of the deformed circle depends on i.e. the tool contact pressure and the type of alloy being welded. If so specified in the WPS the extent of the deformed circle may be less than 80%.

4.4.1.2 Non-destructive and destructive testing

4.4.1.2.1 Extent of testing

All butt welds shall be bend tested according to 4.4.1.2.3 or 100 % tested with an appropriate non-destructive volumetric testing method (radiography or ultrasound). Testing shall be in accordance with ISO 17636 or ISO/DIS 17640 (radiography and ultrasound, respectively).

One macro etch test shall be taken from the test weld(s).

4.4.1.2.2 Acceptance criteria for non-destructive testing

The weld shall have no voids. The weld shall have no cracks. If a full penetration weld is specified, then there shall be no lack of penetration.

4.4.1.2.3 Bend test

Two face and two root bend tests shall be taken from the test weld(s). For material thickness over 12 mm, four side bend tests may be substituted for face and root bend tests. The location of the specimen blanks shall be according to Figure 1. Testing shall be performed according to clause 6.3.3.4 of Part 4 of this standard.

If a partial penetration weld is specified in the WPS, then the specimen shall be machined, from the root side, to a thickness equal to the specified minimum weld penetration before testing.

During testing, the test specimens shall not reveal any imperfections in any direction. Flaws appearing at the edges of a test specimen during testing shall be ignored in the evaluation unless there is evidence that cracking is due to incomplete penetration or other flaw.

4.4.1.2.4 Macro etch test

One macro etch test specimen blank shall be taken from the test weld(s). The location of the specimen blank shall be according to Figure 1. Testing shall be in accordance with ISO/DIS 17639.

The etched section shall be examined by eye or with a low-powered lens (maximum 10x magnification). The section shall not contain any void, crack, lack of fusion, or incomplete penetration.

4.4.2 Re-testing

If the welded assembly fails to meet the requirements of 4.4.1, then the test shall be rejected. A duplicate assembly may be welded using the same procedure and be subjected to examination. If the second assembly fails to meet the requirements, then the friction stir welding operator shall be required to have additional training before a new test is made.

If a bend test specimen fails to meet the requirements, then two additional test specimens shall be prepared from the same welded assembly and tested. If both retests are acceptable, then the friction stir welding operator shall be qualified. If one or both retests are not acceptable, then the friction stir welding operator is not qualified.

4.4.3 Test record

The results of all testing shall be documented.

NOTE The format of the documentation is to be decided by the manufacturer. The documentation may be on paper or electronic media.

5 Certificate

It shall be verified that the friction stir welding operator passed the qualification test. All essential variables shall be recorded on the certificate. If the test piece(s) fail(s) any of the required tests, no certificate shall be issued.

The certificate shall be issued under the sole responsibility of the examiner or examining body and shall contain all the information detailed in Annex C. The format of Annex C is recommended to be used as the friction stir welding operator's qualification test certificate. If any other form of friction stir welding operator's qualification test certificate is used, it shall contain the information required in Annex C.

NOTE In some countries, an examiner may be employed by the company performing friction stir welding.

5.1 Period of validity

5.1.1 Initial qualification

The friction stir welding operator's qualification is valid from the date of welding of the test pieces, provided the required tests have been carried out and acceptable test results are available.

The welding operator's qualification test certificate is valid for a period of two years, the period of validity ending on the last day of the month.

5.1.2 Confirmation of the validity

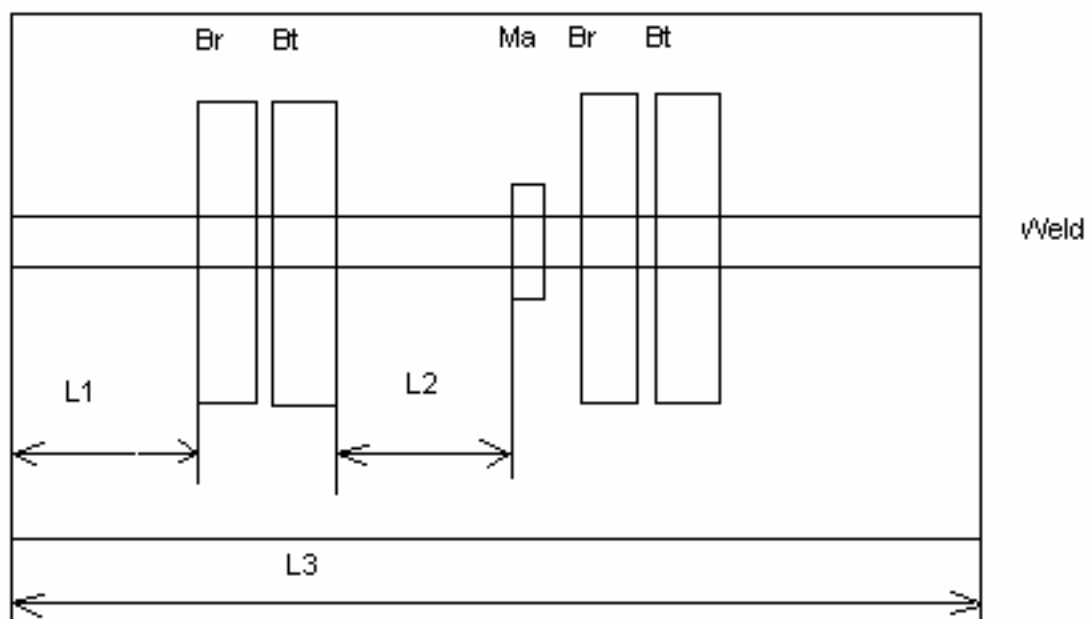
The welding coordinator or the responsible personnel of the employer shall confirm that the welding operator has been working within the initial range of qualification. This shall be confirmed every six months. If such a confirmation is not given, the qualification expires and the welding operator shall be required to pass a new qualification test before resuming friction stir welding.

5.1.3 Prolongation of qualification

Operator's qualification test certificates according to this standard can be prolonged every two years by an examiner/examining body.

Before prolongation of the certification takes place, 5.1.2 needs to be satisfied and also the following conditions need to be confirmed:

- all records and evidence that are used to support prolongation shall be traceable to the welding operator and shall identify the WPS(s) used in production;
- evidence used to support prolongation shall be of a volumetric nature (radiographic testing or ultrasonic testing) or for destructive testing (fracture or bends) made on two welds during the previous six months. Evidence relating to prolongation needs to be retained for a minimum of two years. The test results shall demonstrate that the welding operator has reproduced the original test conditions;
- the welds satisfy the acceptance levels for imperfections as specified in clause 4.4.1.

**Key**

The direction of welding is from left to right.

$L1 \geq 50$ mm (measured from the start of the weld)

$L2 \geq 50$ mm

$L3 \geq 500$ mm (the length shall be sufficient to give 500 mm of weld length)

The width of the test piece shall be sufficient for extracting the bend tests.

Br – Root bend test

Bt – Face bend test

Ma – Macro etch test

Figure 1 — Location of destructive test specimens

Annex A **(normative)**

Functional knowledge of the friction stir welding unit

A.1 General

This Annex outlines the knowledge that a welding operator shall have of the welding unit to ensure that procedures are followed and common practices are complied with.

A.2 Welding sequences/procedures

Appreciation of the welding procedure requirements and the influence of welding parameters

A.3 Joint preparation and weld representation

- conformance of joint preparation to the WPS
- cleanliness of edges to be welded

A.4 Weld imperfections

- identification of weld imperfections
- causes of weld imperfections
- prevention of weld imperfections and remedial action

A.5 Friction stir welding operator approval

The welding operator shall be aware of the range of approval.

A.6 Process operation

- knowledge of programming (if relevant)
- knowledge of the control system and signals given by this system
- tool motion
- auxiliary equipment
- jigs, fixtures, and set-up
- parameters and adjustment within the given procedures
- safety regulations and precautions, start and stop procedures

Annex B (informative)

Knowledge of welding technology

B.1 General

This Annex outlines the job knowledge that a welding operator should have to ensure that the procedures are followed and that common practices are complied with. The job knowledge discussed in this Annex is presented at the most basic level.

A test of job knowledge is recommended, but it is not mandatory.

However, some countries may require that the welding operator undergo a test of job knowledge. If the job knowledge test is carried out, it should be recorded on the welding operator's certificate.

Because of different training programs in various countries, it is only proposed to standardize general objectives or categories of job knowledge. The actual questions used should be drawn up by the individual country, employer, or the engineering authority, but should include questions on areas covered in B.2, relevant to the welding operator's approval test.

Testing of a welding operator's job knowledge can be accomplished by any of the following methods or combinations of these methods:

- written objective tests (multiple choice). This test may be given on paper or on a computer.
- oral questioning following a set of written questions

The test of job knowledge is limited to the matters related to the welding method used in the test.

B.2 Requirements

B.2.1 Welding equipment

- identification and assembly of essential components
- selection of correct welding tools
- cooling system (if any)
- maintenance of the equipment

B.2.2 Welding process

- control system
- setting and controlling of parameters
- correct alignment and travel of welding head
- influence of parameters on the welding process

- inspection of welding tools
- causes and appearance of weld imperfections

B.2.3 Parent materials

- identification of materials

B.2.4 Safety and accident prevention

- electrical risk
- mechanical risk
- noise risk

B.2.5 Visual examination of welds

- Knowledge of visual examination

Annex C (informative)

Qualification test certificate for FSW operators

Manufacturer's WPS number: _____ Examiner or examining body: _____

WPS reference number (if applicable): _____ Examiner/examining body reference number: _____

Name of welding operator: _____

Method of identification: _____ Photograph (if required)

Date and place of birth: _____

Employer: _____

Code/testing standard: _____

Job knowledge: Acceptable/not tested (delete as appropriate)

Weld details: _____ Welding method: _____

Welding unit/machine: _____

Joint sensor: _____

Single run/multirun technique: _____

Single/multiple spindle: _____

Further information available in WPS number: _____

Place a check mark on which of the following the qualification is based on:

_____ Test welding in accordance with 4.3.1

_____ Welding procedure test in accordance with 4.3.2

_____ Pre-production or production test in accordance with 4.3.3

_____ Production sample testing in accordance with 4.3.4

For results of the qualification tests, see test report number: _____

Place _____ Date _____ Examiner or examining body _____

The qualification is valid until: _____

Confirmation of the validity by employer/welding coordinator for the following 6 months (refer to 5.1.2)

_____	_____	_____
Date	Signature	Title

Prolongation of qualification by examiner or examining body for the following 2 years (refer to 5.1.3)

_____	_____	_____
Date	Signature	Title

Bibliography

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

ISO 14732, *Welding personnel – Approval testing of welding operators for fusion welding and of resistance weld setters for fully mechanized and automatic welding of metallic materials*

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