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Welding — Micro joining of 2nd generation high temperature superconductors —

Part 2: Qualification for welding and testing personnel

Soudage — Micro-assemblage des supraconducteurs à haute température de deuxième génération —

Partie 2: Qualification du personnel en soudage et d'essai

Reference number
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Foreword

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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 Technical Committee ISO/TC 44, *Welding and allied processes*, Subcommittee SC 10, *Quality management in the field of welding*.

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.

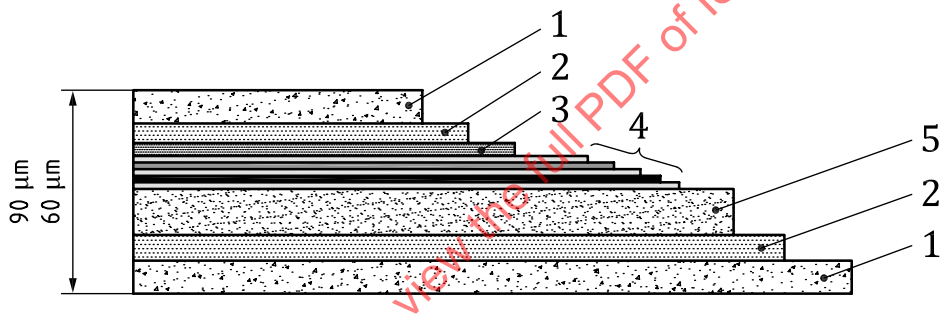
A list of all parts in the ISO 17279 series can be found on the ISO website.

Introduction

The increasing use of 2nd generation high temperature superconductors (2G HTSs) and invention of resistance-free joining on 2G HTSs have created the need for this document in order to ensure that joining is carried out in the most effective way and that appropriate control is exercized over all aspects of the operation. ISO standards for micro-joining and joint evaluation procedure are accordingly essential to get the best and uniform quality of 2G HTS joint.

A superconductor is a material that conducts electricity without resistance and has diamagnetism below critical temperature, T_c, critical magnetic field, B_c, and critical current density, J_c. Once set in motion, electrical current flows forever in a closed loop of superconducting material under diamagnetism.

A 2G HTS consists of multi-layers and its total thickness is around between 60 µm and 100 µm with or without surrounding copper stabilizer. The superconducting layer made from $ReBa_2Cu_3O_{7-x}$ (ReBCO, abbreviated term of $ReBa_2Cu_3O_{7-x}$) is only between 1 µm and 2 µm thick depending on manufacturer's specifications. Re stands for Rare Earth materials, of which gadolinium, yttrium and samarium are used for 2nd generation high temperature superconducting materials. Figure 1 shows schematic drawing of typical multiple layers with surrounded copper stabilizer, and the constituents and thicknesses of each layer in the 2G HTS. The two layers of No. 1 in Figure 1 does not exist in stabilizer-free 2G HTS.



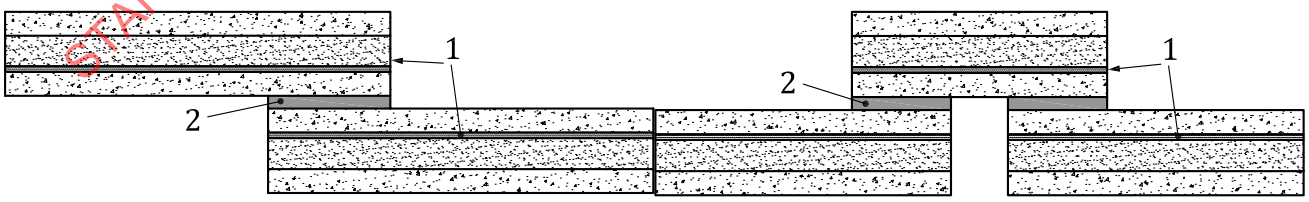
Key

1 20 µm Cu stabilizer
2 2 µm Ag overlayer
3 between 1 µm and 2 µm ReBCO super-conducting layer
4 5 buffing layers (total 160 nm)
5 50 µm hastelloy substrate

NOTE Not to scale.

Figure 1 — Typical 2G HTS multi-layers, and the constituents and thicknesses of each layer

Currently soldering, brazing or any filler is applied in superconducting industry as shown in Figure 2, which shows high electrical resistance at the joint providing fatal flaw in the superconductor.



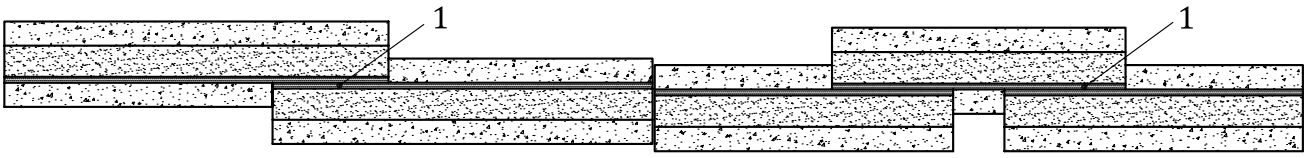
a) Lap joint **b) Bridge joint**

Key

1 superconducting layer
2 solder

Figure 2 — Soldering to join 2G HTS

However, this document focuses on the direct autogenous joining of between 1 µm and 2 µm-thick superconducting layers of 2G HTSs as shown in Figure 3 without filler metals and recovery of superconducting properties by oxygenation annealing process, which shows almost no electrical resistance at the joint.



a) Lap joint **b) Bridge joint**

Key

1 superconducting layer

Figure 3 — Direct autogenous joining of two superconducting layers of 2G HTSs for superconducting joint

Welding — Micro joining of 2nd generation high temperature superconductors —

Part 2: Qualification for welding and testing personnel

1 Scope

This document specifies the qualification requirements for personnel performing micro-joining and oxygenation anneling, and testing the 2G HTS test joints.

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 15607:2003, *Specification and qualification of welding procedures for metallic materials — General rules*

ISO 17279-1, *Welding — Micro-joining of 2nd generation high temperature superconductors — Part 1: General requirements for the procedure*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 17279-1 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 https://www.electropedia.org/

4 Symbols and abbreviated terms

The abbreviated terms listed in ISO 15607:2003, Table 1, relevant to joining procedure for 2G HTS shall apply.

5 Qualification of personnel performing micro-joining and oxygenation annealing

5.1 General

Manufacturers shall have at their disposal sufficient competent personnel for the 2G HTS micro-joining operations in accordance with specified requirements. The manufacturer shall be responsible for developing the training program, written practice, examination, and practical demonstrations for personnel performing the micro-joining in accordance with this document. These shall establish the capability of the personnel performing the required micro-joining and oxygenation annealing. Qualification records and certificates shall be kept up-to-date. The procedures for micro-joining and oxygenation annealing are presented in ISO 17279-1:2018, 5.4 to 5.6.

The essential variables and ranges of qualification and qualification requirements for personnel qualification are specified in 5.1 to 5.5 and the validity is specified in 5.6. If micro-joining and/or oxygenation-annealing is required outside the range of qualification, a new qualification test is required. The personnel who performs micro-joining and oxygenation annealing shall be successfully qualified for this specific method. The qualification is valid for that method only

5.2 Essential variables and range of qualification

The variables include joint design, joint width, joint materials, apparatuses, and micro-joining and oxygenation-annealing parameters.

A successful test joint made in specific joint design qualifies a personnel only for specific joint design. A change from one type of joint design to another type of joint design requires additional qualification.

A successful joint dimension of any specific material qualifies a personnel for only specific material dimension. A change from one joint dimension to another dimension requires additional qualification.

A successful test joint made with specific material qualifies a personnel for only specific superconducting material. A change from one superconducting material to another material requires additional qualification.

The apparatuses shall be periodically calibrated according to the manufacturer's specification. Only apparatuses with valid calibration and qualification shall be applied to the micro-joining and oxygenation annealing for personnel qualification. Table 1 shows essential variables of joint design, joint widths, superconducting materials and apparatuses. Table 2 shows essential variable parameters for micro-joining and oxygenation-annealing. These parameters provide sensitive to the joint quality and determine final joint quality. Any changes of essential variables qualified require re-qualification.

Table 1 — Essential variables required for qualification of joint, materials and apparatuses

Joint design	Joint width (mm)	Superconducting materials	Apparatuses for micro-joining and oxygenation-annealing
Lap or Bridge	3 mm, 4 mm, 6 mm, 12 mm, or specifications	YBCO, GdBCO, SmBCO, or specifications	Specific model or type changes, removal, addition or change of control systems

Table 2 — Essential variables required for qualification of micro-joining and oxygenation-annealing

Micro-joining	Oxygenation annealing
Removal of Cu stabilizer and or Ag overlayer	Heating rate
Chamber (furnace) internal vacuum level	Annealing temperature
Heating rate	Dwell time
Peak joining temperature	Oxygen flow rate
Mechanical pressure to the joint	Chamber (furnace) internal pressure
Dwell time at the peak joining temperature	Cooling rate to room temperature
Cooling rate to room temperature or oxygenation annealing temperature	

The range of qualification for other variables, except as listed in Table 1 and Table 2, shall be specified in the manufacturer's specification.

5.3 Qualification methods

5.3.1 Qualification based on standard test joint specimen

Test joint specimens shall be made in accordance with a WPS. The micro-joining and oxygenation annealing of test specimens shall be witnessed by an inspector or designated personnel. Removal of Cu stabilizer and or Ag overlayer shall also be the responsibility of the personnel for micro-joining and oxygenation annealing, since surface condition of superconducting layer impacts joint quality. Three specimens shall be tested for each joint design.

The test specimens shall be marked with the identification, by personnel performing micro-joining and oxygenation annealing or designated personnel before joining starts. The inspector may stop the micro-joining and/or oxygenation-annealing at any time during the test if it appears that the personnel for micro-joining and/or oxygenation-annealing does not have the skills to meet the requirements of this document.

The test specimens shown in ISO 17279-1:2018, Figure 4 and Figure 5, shall be used for the standard test joint. A personnel performing micro-joining and oxygenation-annealing who has successfully completed the provisions of 5.3.2 shall be considered qualified for the method (pressurized partial micro-melting diffusion or pressurized solid-state diffusion), joint design (lap or bridge), joint width, superconducting material, and type of micro-joining and oxygenation-annealing apparatuses used for the test.

The technical knowledge of micro-joining and oxygenation annealing and the apparatuses to be used shall be examined for personnel qualification, as per Annexes A and B.

5.3.2 Qualification by testing the test joints

ISO 17279-1:2018, 5.5.4 and Table 1, describe the test requirements for procedure qualification. In ISO 17279-1:2018, Table 1, only test methods of visual test, critical current test, I_c, and tensile test with reinforcement shall be tested on the test joints (see ISO 17279-3[1)] for test methods) for personnel qualification. Table 3 shows personnel qualification requirements. Joint critical current, I_c, is extremely important in superconductors. In addition, other testing methods described in ISO 17279-1:2018, 5.5.4.2 and Table 1, may be performed for the qualification if required by manufacturer.

Table 3 — Qualification requirements for personnel performing micro-joining and oxygenation annealing

Type of test	Extent of test	Confirmation of test
Visual test	3 joined specimens	Check that the joint is free from any imperfections and de-bonding, etc., and also check appearances and alignments, etc.
Critical current test, I_c, by four-point-probes	3 joined specimens	Check that the joint I_c is 80 % and higher to the virgin materials of 2G HTS, or that it$_c$ meets the manufacturer's specifications
Tensile test with reinforcement	3 joined specimens from the qualified I_c joined test specimen	Ccheck that joint tensile strength is equal to the virgin materials of 2G ReBCO HTS, or that it meets the manufacturer's specificatiosn and also check that joint strength shows the same I_c as the virgin materials of 2G ReBCO HTS

5.4 Re-qualification

If one of three specimens fails to meet the acceptance criteria in ISO 17279-1:2018, 5.9, or Table 3, the test shall be rejected. Two additional test specimens shall be joined using the same procedure and subjected to testing. If one of these extra specimens fails to meet the requirements, the personnel for

1) Under preparation.

micro-joining and oxygenation-annealing shall be required to have additional training before new tests are made.

If two of three specimens or all three specimens fail to meet the acceptance criteria in ISO 17279-1:2018, 5.9 or Table 3, the personnel for micro-joining and oxygenation-annealing shall be required to have additional training before new tests are made.

5.5 Qualification examination and examination report

The results of all testing shall verify that the personnel for micro-joining and oxygenation-annealing passed the qualification examination. This shall be documented. The format of the documentation shall be decided by the manufacturer. A suggested test report is shown in Table 4 and Annex C. The documentation can be on paper or electronic media.

Table 4 — Test report for personnel qualification

Examinee	Joint design		Width	Superconducting material	Visual testing	Critical current (I_c) testing	Tensile testing with reinforcement
	Lap	Bridge	mm				
A	X		4	YBCO	P	F	F
B		X	6	GdBCO	P	P	P
C	X		12	SmBCO	F	P	P
NOTE P: passed or qualified, F: failed.							

5.6 Period of validity

5.6.1 Initial qualification

The personnel qualification for micro-joining and oxygenation-annealing is valid from the date when the required examination has been carried out and acceptable results are available. The qualification is valid for a period of 2 years, the period of validity ending on the last day of the month.

5.6.2 Confirmation of the validity

The qualifications of the personnel for micro-joining and oxygenation-annealing shall be confirmed every 6 months by the person responsible for welding activities or examiner/examining body or employer. This confirms that the welder has worked within the range of qualification and extended the validity of the qualification for a further 6-month period.

5.6.3 Prolongation of qualification

The personnel qualification for micro-joining and oxygenation-annealing can be extended every 2 years by an examiner. Before the certification is extended, the relevant specifications of this document shall be satisfied and the following conditions shall be confirmed:

— all records and evidence used to support prolongation shall be traceable to the personnel for micro-joining and oxygenation-annealing and shall identify the WPS(s) used in production;

— evidence used to support extension shall be the tests in 5.2 and 5.3, passed during the previous 6 months. Evidence relating to prolongation shall be retained for a minimum of 2 years.

6 Qualification of personnel performing the test joints testing

6.1 General

Manufacturers shall have at their disposal sufficient competent personnel for the testing of 2G HTS micro-joined and oxygenation annealed specimen in accordance with specified requirements. The manufacturer shall be responsible for developing the training program, written practice, examination, and practical demonstrations for personnel performing the test joints testing in accordance with this document and manufacturer's requirements. These shall establish the capability of the personnel performing the required testing. Qualification records shall be kept up-to-date.

In order to be able to understand test results even when not involved in or responsible for the micro-joining and oxygenation annealing, the personnel shall have good technical knowledge of:

— superconducting material;

— joint designs specified in ISO 17279-1:2018, Figures 4 and 5;

— micro-joining and oxygenation annealing techniques and procedures, described in ISO 17279-1:2018, 5.5.3.

The personnel shall have technical background and knowledge on the testing methods and evaluations of test results [see ISO 17279-3]. Hands-on experiences on operations of the testing equipment are required.

6.2 Essential variables and range of qualification

The qualification for personnel performing testing the test joints is based on essential variables. Qualified ranges are defined by the manufacturer or the manufacturer's designated personnel or body. Micro-joining and oxygenation annealing outside the range of qualification requires a new qualification. The personnel shall be successfully qualified for this specific method. The qualification is valid for that method only.

Testing equipment is very sensitive to the joint test quality. The equipment shall be periodically calibrated according to the manufacturer's specification. Only equipment with valid calibration shall be applied to the tests. A change from one type of test equipment to another type requires additional training to operate. Any alteration, addition or removal of critical components such as gauges, regulators and controllers of the testing equipment requires re-qualification.. The personnel shall be trained with modified equipment if test equipment is modified. Only calibrated and/or qualified test equipment shall be used for the tests. Provided that the personnel works in accordance with an operation manual or testing specifications determined by manufacturer or tester developer, the range of qualification shall be limited only as specified in the manual or specification. The range of qualification for other variables shall be specified in the manufacturer's specification.

6.3 Qualification methods

The qualification methods for personnel shall be defined by manufacturer or manufacturer's designated personnel or body. The standard test joint specimen specified in ISO 17279-1:2018, Figures 4 and 5, with known test results can be used to qualify the personnel, or any superconductor virgin specimen without joint can be used for the personnel qualification.

Test items for the qualification are basically to confirm electrical and magnetic properties and profiles by four-point-probes test, field-decay test, in-field test, critical magnetic field test, critical current density distribution test, tensile test and bend test, and to confirm microstructures, morphologies, and characteristics of joint materials by microscopes or X-ray diffraction test and also to confirm integrity by visual test, tensile test and bend test (see ISO 17279-3 and ISO 17279-1:2018, 5.5.4.2 to 5.5.4.11).

The tests shall be performed on the standard test joint specimen or any superconductor virgin specimen without joint. Table 5 shows mandated personnel qualification requirements. Joint critical

current, I_c, is extremely important for the superconductors. Other methods described in ISO 17279-3 and ISO 17279-1:2018, 5.5.4, can be performed for personnel qualification, as required.

Table 5 — Personnel qualification requirements

Type of test	Qualification requirements
Visual test	Education, training and qualification test: according to the requirements of the manufacturer or designated organization Vision requirements: Near vision (Jaeger), colour-blindness, colour contrast identification shall be tested and acceptance criteria shall be according to the requirements of the manufacturer or designated organization
Critical current, I_c, test by four-point-probes	Education, training and qualification test: according to the requirements of the manufacturer or designated organization
Tensile test with joint reinforcement	Education, training and qualification test: according to the requirements of the manufacturer or designated organization

6.4 Re-qualification

If personnel fail to meet the qualification requirements specified in Table 5, they shall be un-qualified and required to have additional training to be re-qualified.

6.5 Qualification examination and examination record

The results shall verify that the personnel passed the qualification examination and be documented. All qualified items shall be recorded. The format of the documentation shall be decided by the manufacturer. A suggested record is shown in Annex D. Table 4 can be used for record. The documentation can be on paper or electronic media.

6.6 Period of validity

6.6.1 Initial qualification

The personnel qualification is valid from the date when the required examination has been carried out and acceptable results are available. The qualification is valid for a period of 2 years, the period of validity ending on the last day of the month.

6.6.2 Confirmation of the validity

The qualifications of the personnel for micro-joining and oxygenation-annealing shall be confirmed every 6 months by the person responsible for welding activities or examiner/examining body or employer. This confirms that the welder has worked within the range of qualification and extended the validity of the qualification for a further 6-month period.

6.6.3 Prolongation of qualification

The personnel qualification can be extended every 2 years by a supervisor. Before the certification is extended, the relevant specifications of this document shall be satisfied and the following conditions shall be confirmed:

— all records and evidence used to support prolongation shall be traceable to the personnel;

— evidence used to support prolongation shall be the tests in 6.2 and 6.3, passed during the previous 6 months. Evidence relating to prolongation shall be retained for a minimum of 2 years.

7 Third-party check

During the entire process for qualification of personnel performing micro-joining and oxygenation annealing, and testing the test joints, the responsible person, as a third party from the quality assurance (QA) team, may review all documents and monitor the whole process according to a developed check list (see Annex E). If there are any findings during reviewing and monitoring, the findings can be directly notified to the president or responsible personnel in the organization by issuing NCR (Non-Conformance Report).

Annex A
(normative)

Functional knowledge of micro-joining and oxygenation annealing apparatus

A.1 General

This annex specifies the knowledge of the apparatuses required by personnel performing micro-joining and oxygenation annealing apparatus to ensure that procedures are followed and common practices are complied with.

A.2 Sequences and procedures

The personnel performing micro-joining and oxygenation annealing shall understand the procedure requirements and the influence of parameters involved. In particular, the personnel shall be knowledgeable about the following:

a) joint preparation and joint representation:
   1) conformity to the WPS for joint preparation;
   2) cleanliness of the specimens to be joined;

b) joint imperfections:
   1) identification of joint imperfections;
   2) identification of causes of joint imperfections;
   3) prevention of joint imperfections and remedial action necessary;

c) qualification for personnel performing micro-joining and oxygenation annealing, including its range;

d) process operation:
   1) knowledge of procedures or sequences;
   2) knowledge of operation of the micro-joining and oxygenation annealing apparatuses and understanding of the signals given by the apparatuses;
   3) operation of auxiliary apparatuses (oxygen tank, etc.);
   4) specimens set-up;
   5) setting and adjustment of parameters within the WPS;
   6) application of safety procedures and precautions;
   7) initiation of start and stop procedures.

Annex B
(normative)

Knowledge of micro-joining and oxygenation annealing technology

B.1 General

This annex describes the job knowledge that personnel performing micro-joining and oxygenation annealing requires to ensure that the WPS is 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 mandatory and should be recorded on the certificate of personnel performing micro-joining and oxygenation annealing.

It is proposed that only general objectives or categories of job knowledge be standardized. The actual questions that are used should be drawn up by the individual manufacturer, employer or engineering authority, and should include questions on areas covered in B.2 relevant to the qualification of personnel performing micro-joining and oxygenation.

The job knowledge of personnel performing micro-joining and oxygenation can be accomplished by any of the following methods or combinations of these methods:

— written objective tests (combinations of multiple choice and descriptions), 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 method used in the test.

B.2 Requirements

The personnel performing micro-joining and oxygenation should have knowledge of:

a) joining and oxygenation annealing apparatuses:
   1) identification and assembly of essential components;
   2) selection of correct micro-joining tools;
   3) the principles of the apparatuses;
   4) maintenance of the equipment;

b) micro-joining and oxygenation annealing processes:
   1) the apparatuses and control systems;
   2) setting and controlling of micro-joining and oxygenation annealing parameters;
   3) correct alignment of the materials to be joined;
   4) influence of parameters on the micro-joining and oxygenation annealing processes;
   5) inspection of micro-joining tools and equipment;

6) causes and appearance of micro-joint imperfections;

c) 2G HTS parent materials, including their identification;

d) safety and accident prevention:

1) electrical risk;

2) mechanical risk;

e) knowledge of micro-joint testing.

Annex C
(informative)

Data report for micro-joining and oxygenation annealing, and testing of the test joints

Report No.:_____

Manufacturer's WPS No.:_____

Examiner or examining body:_____

Name of person performing micro-joining and oxygenation annealing:_____

Name of person performing testing:_____

Date:_____

ISO standard and or test standard:_____

Micro-joint details (including photos if necessary):_____

Photo	Photo	Photo

Micro-joining and oxygenation-annealing unit:_____

Micro-joining

Joint type:_____ Materials:_____ Joint width:_____

Removal of Cu stabilizer and or Ag overlayer:_____

Heating method:_____ Chamber internal vacuum:_____

Peak temperature:_____ Dwell time at peak temperature:_____

Heating rate:_____ Cooling rate:_____

Pressure to the joint:_____

Other:_____

Oxygenation annealing

Chamber internal pressure:_____ Oxygen flow rate:_____

Temperature:_____ Heating rate:_____

Dwell time:_____ Cooling rate:_____

Other:_____

Visual test

Appearance:_____ Imperfections:_____

Alignments:_____ De-bonding of joint:_____

Any specific:_____

Critical current (I_c) test

Critical current, I_c:_____ Critical current density, J_c:_____

Index number, n:_____ Cyclic thermal shock characteristic:_____

Cryogenic coolant applied:_____

Other:_____

Field-decay test

Test duration:_____ Joint resistance:_____

Other:_____

In-field test

Applied conditions:_____

Other:_____

Tensile test

Applied load:_____

Room temperature without reinforcement:_____ 77 K without reinforcement:_____

Room temperature with reinforcement:_____ 77 K with reinforcement:_____

Other:_____

Bend test

Minimum bending diameter:_____ Bending angle:_____

Room temperature without reinforcement:_____ 77 K without reinforcement:_____

Room temperature with reinforcement:_____ 77 K with reinforcement:_____

Other:_____

Critical magnetic field test

Applied conditions:_____

Other:_____

Critical current density distribution test

Applied conditions and technique:_____

Other:_____

Microscopic and X-ray diffraction test

Applied conditions and technique:_____

Other:_____

==========

Date:_____

Name and signature:_____

Title:_____

Annex D
(informative)

Test results

Report No.:_____

Manufacturer's WPS No.:_____

ISO standard No. and or test standard:_____

Visual test	
Personal data:	
Education, training and qualification:	
Vision:	Near vision (Jaeger):
Colour-blindness:	Colour contrast identification:
Others:	

Item	**Results**

Four-point-probes test	
Personal data (education, training and qualification):	
Item	**Results**

Field-decay test	
Personal data (education, training and qualification):	
Item	**Results**

In-field test	
Personal data (education, training and qualification):	
Item	**Results**