
**Welding — Micro joining of second
generation high temperature
superconductors —**

**Part 3:
Test methods for joints**

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*Soudage — Micro-assemblage des supraconducteurs à haute
température de deuxième génération —
Partie 3: Méthode d'essai des assemblages*

ISO 17279-3:2021

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ISO copyright office
CP 401 • Ch. de Blandonnet 8
CH-1214 Vernier, Geneva
Phone: +41 22 749 01 11
Email: copyright@iso.org
Website: www.iso.org

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

A list of all parts in the ISO 17279 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.

Official interpretations of ISO/TC 44 documents, where they exist, are available from this page: <https://committee.iso.org/sites/tc44/home/interpretation.html>.

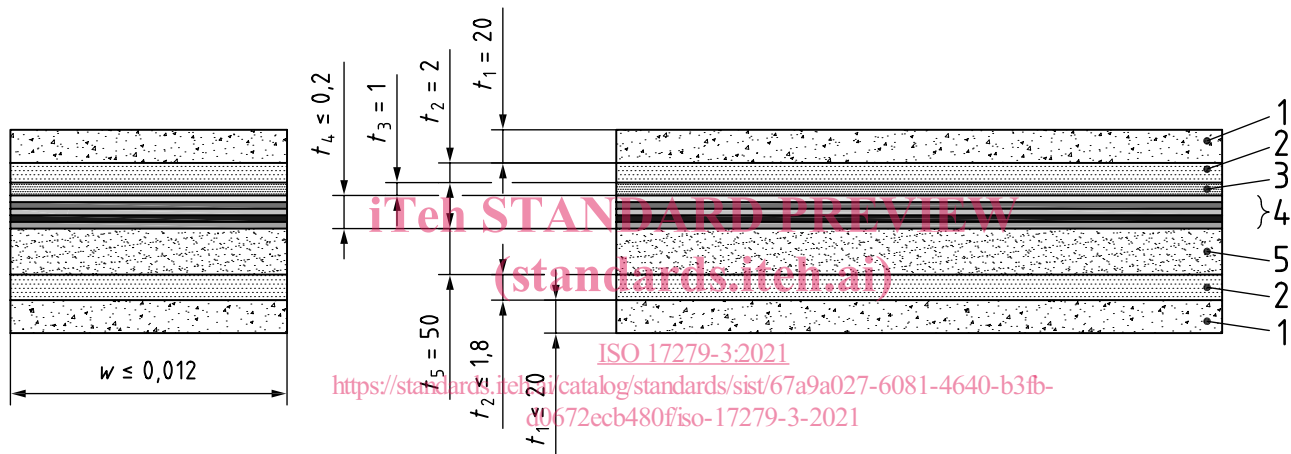
Introduction

The increasing use of second-generation high temperature superconductors (2G HTSs) and invention of resistance-free joining on 2G HTSs have created the need for the ISO 17279 series in order to ensure that joining is carried out in the most effective way and that appropriate control is exercised 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.

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.

2G HTS constitutes of multi-layers and total thickness is around 60 μm to 90 μm and the superconducting layer made from REBa₂Cu₃O_{7-x} is only 1 μm to 3 μm thick depending on manufacturer's specifications. [Figure 1](#) shows schematic drawing of typical multiple layers, and the constituents and thicknesses of each layer in the 2G HTS.

Dimensions in micro-meters



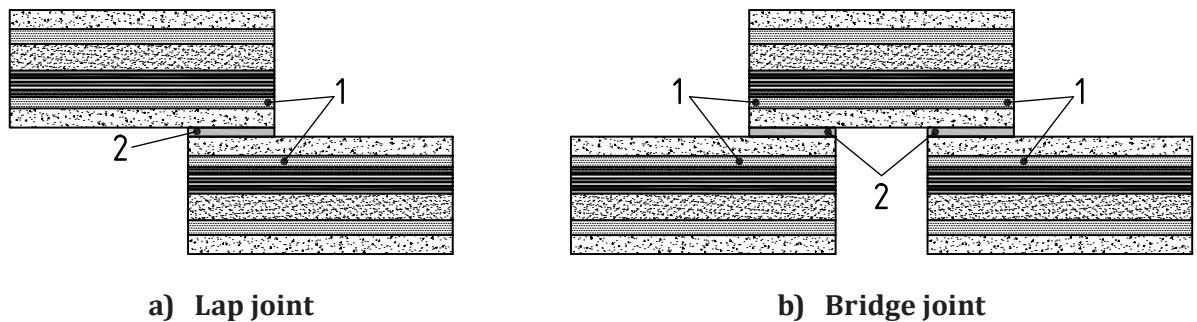
Key

1	Cu stabilizer	t_1	thickness of layer 1
2	Ag overlayer	t_2	thickness of layer 2
3	REBCO-superconducting layer	t_3	thickness of layer 3
4	buffer stack	t_4	thickness of layer 4
5	hastelloy®C-276 substrate	t_5	thickness of layer 5

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 applying in superconducting industry as shown in [Figure 2](#), which shows high electrical resistance at the joint providing fatal flaw in the superconductor.

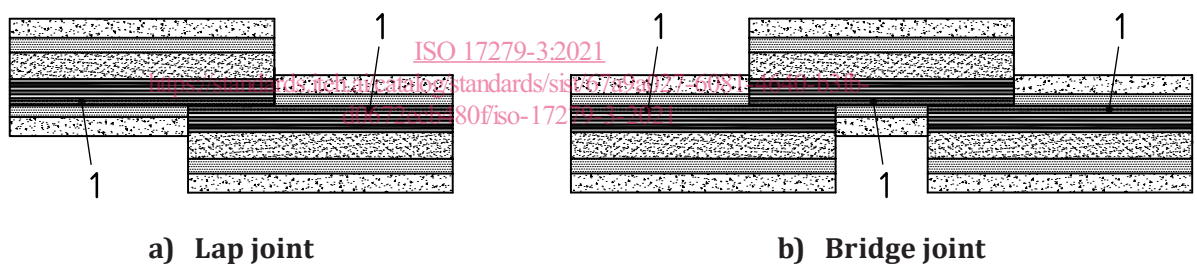


Key

- 1 REBCO-superconducting layer
- 2 solder

Figure 2 — Soldering to join 2G HTS

However, the ISO 17279 series focuses on the direct autogenous joining of 1 μm to 3 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 none electrical resistance at the joint.



Key

- 1 REBCO-superconducting layer

Figure 3 — Direct autogenous joining of 1 μm to 3 μm thick superconducting layers of 2G HTSs for superconducting joint

ISO 17279-1 specifies requirements for the qualification of 2G HTS joining procedure. 2G HTS joints should be capable of performing required electric, magnetic and mechanical properties and free from serious imperfections in production and in service. To achieve that goal, it is necessary to provide controls during design and fabrication.

ISO 17279-2 specifies requirements for the qualification of personnel performing welding and testing.

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Welding — Micro joining of second generation high temperature superconductors —

Part 3: Test methods for joints

1 Scope

This document specifies the requirements for the test methods for joint of micro-joining of 2G HTS to fulfil the requirements of ISO 17279-1 and ISO 17279-2.

This document specifies test methods for determining the capability of joints for the production of the specified quality. It defines specific test requirements, but does not assign those requirements to any specific product group.

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 17279-1:2018, *Welding — Micro joining of 2nd generation high temperature superconductors — Part 1: General requirements for the procedure* ISO 17279-3:2021

ISO 15607:2019, *Specification and qualification of welding procedures for metallic materials — General rules* <https://standards.iteh.ai/catalog/standards/sist/67a9a027-6081-4640-b3ff-60672ccc4801/iso-17279-3-2021>

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 17279-1 and ISO 15607 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 Test methods for joint

4.1 General

ISO 17279-1:2018, 5.5.4, describes requirements for qualification of test personnel, for test methods, witness during testing and retesting. Especially, ISO 17279-1:2018, Table 1, shows the type of testing, the extent of testing, the confirmation of testing, and required tests for the procedure qualification according to ISO 17279-1. ISO 17279-1:2018, 5.9, requires the acceptance criteria of the tests. The manufacturer can have at their disposal sufficient competent personnel for the testing and operating the test equipment, or can contract the specific tests to the specialized organizations. The manufacturer can witness the tests from specimen preparation to data acquisition and analysis according to manufacturer's quality assurance requirements.

The operating procedures and cautions of the test equipment shall be applied when the equipment is used for testing according to this document. The operator of the specific equipment shall establish the capability to perform the required test, and calibration and qualification of the test equipment shall

be maintained up-to-date according to an appropriate quality management program. Qualification records and certificates shall be kept up-to-date.

The tests except visual testing shall be performed at the cryogenic environment and do not purport to address the safety concerns associated with its use. It is the responsibility of whoever uses this method to establish appropriate safety and health practices prior to use.

4.2 Visual testing

4.2.1 General

This subclause defines the method of visual testing of materials and joints used in 2G HTS.

4.2.2 Qualification of test personnel

Testing shall be conducted by qualified personnel. Personnel qualification shall be done according to an appropriate quality management program. Personnel conducting visual testing shall annually pass an examination where their vision, with or without correction, meets the Jaeger J2 near vision test at a distance not less than 30,5 cm as well as a colour perception test. The vision examination records shall be maintained for the current year and shall be available for review.

4.2.3 Test equipment

Calibrated instruments shall be used for testing, wherever required, this includes all necessary measuring instruments and gauges.

4.2.4 Surface condition and preparation

The surface for the test shall be uniform and smooth and shall be clean and free of scale, rust, oil, grease, detrimental oxides and other deleterious foreign materials such as Ag or Cu spots of 2G HTS. The surfaces of the finished joints shall be suitable to permit proper testing. All joint preparations shall meet drawing specified dimensions (whether provided via dimensions on the drawing or in a welding specification). If no dimensions are provided as part of the drawing or ordering documents, the dimensions shall meet dimensions specified by approved welding procedure specification (WPS).

4.2.5 Testing

Testing shall be performed in accordance with a written procedure or method applicable under testing. The testing area shall include the joint and the accessible adjacent heat-affected zone (HAZ) for some distance from the joint edge of the base metal. The testing shall be in the after joining and final heat-treated condition (oxygenation annealing), or otherwise required, and be free of all coatings and other surface conditions such as paint, plating, etc. The joints shall be tested in the as-welded condition. Testing will be conducted with specimen suitable dimensions.

Direct visual testing shall be used. If required, mirrors and magnifying lenses are used to improve the angle of vision and to assist. The minimum light intensity at the surface is 1 000 lux (100 foot-candles). The written procedure or method shall include, at a minimum and either directly or by reference to applicable document(s), procedure identification number and date, revision number, identification of joints, complete testing requirements including lighting and method of testing, evaluation of indications, acceptance criteria, disposition of joints after evaluations.

4.2.6 Acceptance criteria

The requirements of ISO 17279-1:2018, Table 4, shall be met. Lack of bonding, lack of fusion, cracks and pin holes are not acceptable.

4.2.7 Test report

After the completion of the testing, the results shall be entered in the test report. A form of a test report is shown in [Annex A](#).

4.3 Four-point-probe testing

4.3.1 General

This subclause defines the method of four-point-probe testing of base materials and joints used in 2G HTS. Critical current (I_c), critical current density (J_c) and n -value can be measured from the test.

NOTE Typically, the resistance of the point of contact (contact resistance) is far smaller than the resistance of the test specimen, and can thus be ignored. However, for superconductors under cryogenic conditions, the contact resistance can dominate and completely obscure changes in the resistance of the test specimen itself. The effects of contact resistance are eliminated with the use of four-point-probe testing.

4.3.2 Qualification of test personnel

Testing shall be conducted by qualified personnel. Personnel qualification shall be done according to an appropriate quality management program.

4.3.3 Test equipment

Calibrated instruments shall be used for testing.

4.3.4 Surface condition and preparation

[Subclause 4.2.4](#) shall apply.

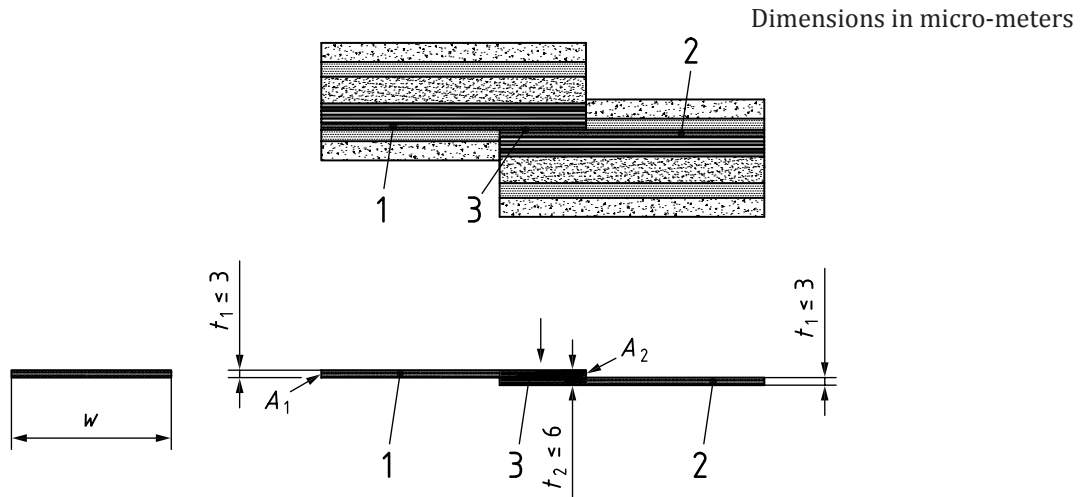
4.3.5 Testing

4.3.5.1 General

Testing shall be performed in accordance with a written test procedure or method applicable to the 2G HTS. The written test procedure or method shall include, at a minimum and either directly or by reference to applicable document(s), procedure identification number, date, revision number, identification of joints, complete testing requirements including method of testing, evaluation and reporting after evaluations.

The testing area shall include the joint and the accessible adjacent HAZ of base material for some distance from the joint edge. The total length of specimen shall be at least 60 mm including 20 mm joint. The test shall be done after joining and final heat-treated condition (oxygenation annealing), or otherwise required, and is carried out at the LN2 cryogenic environment or other temperature determined by the manufacturer. The test shall be done at weld reinforced condition with commercially available materials considering thermal shrinkage coefficient so as not for joints to be damaged during the test.

Schematic of two superconducting layers with lap-joint in 2G HTS is shown in [Figure 4](#). When current passes through a superconducting layer (1 μm to 3 μm thick) of 2G HTS from superconducting layer 1 to joint to superconducting layer 2, the current generates a voltage difference between superconducting layer 1 and superconducting layer 2. 2G HTS without joint and HAZ is resistance-free in cryogenic environment, thus the most voltage difference comes from joint and HAZ.



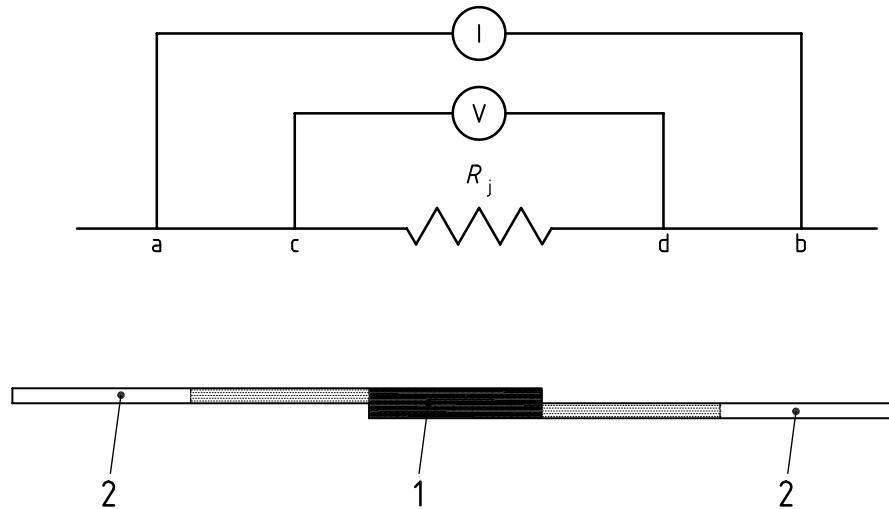
Key

- 1 upper superconducting layer
- 2 bottom superconducting layer
- 3 joining area
- w width of superconducting layer
- t_1 thickness of superconducting layer (1 $\mu\text{m} \sim 3 \mu\text{m}$)
- t_2 almost $2 t_1$ or slightly less than $2 t_1$, depending on pressure during joining
- A_1 cross-sectional area of superconducting layers 1 and 2 ($A_1 = t_1 \times w$)
- A_2 cross-sectional area of lap-joined two superconducting layers ($A_2 = t_2 \times w$)

Figure 4 — Typical 2G HTS multi-layers, and the constituents and thicknesses of each layer

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Figure 5 is a schematic of four-point-probe testing in lap-joined 2G HTS. Four probes are attached to the test specimen as shown in the figure. A current is made to flow the length of the test specimen through probes labelled a and b in the Figure 5. This can be done using a current source or a power supply having current output readout. If the test specimen has any resistance to the flow of electrical current, then there is a drop of potential (or voltage) as the current flows along the test specimen, for example between the two probes labelled c and d in the figure. The voltage drop between probes c and d can be measured by a digital voltmeter. The resistance of the test specimen between probes c and d is the ratio of the voltage registering on the digital voltmeter to the value of the output current of the power supply. The high impedance of the digital voltmeter minimizes the current flow through the portion of the circuit comprising the voltmeter. Thus, since there is no potential drop across the contact resistance associated with probes c and d, only the resistance associated with the joint and associated HAZ of superconductor between probes c and d is measured as a function of current. 2 HAZ lengths adjacent to the joint are about twice of joint length. However, the HAZ is dependent on the heat input and dwell time during joining. Manufacturer may determine the HAZ length by four-point-probe testing.

**Key**

- 1 joining area
- 2 heat-affected zone (HAZ)
- R_j electrical resistance of the joint
- a Current lead 1.
- b Current lead 2.
- c Voltage tap 1.
- d Voltage tap 2.

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Figure 5 — Schematic of four-point-probe testing in lap-joined 2G HTS CC

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The test procedure is as follows.

- a) Attach c and d (joint fusion line each) probes to the test specimen and connect to a digital voltmeter and attach a and b (5 mm from the c and d each) probes to an ammeter and a power supply. A strip chart recorder may be connected between probes c and d.
- b) Set the thermocouple reader to read the K thermocouple and read the symbol of the thermocouple attached to the thermocouple. Do not bend the thermocouple.
- c) Place the container, test specimen with attached probes, and thermocouple. Pour liquid nitrogen or other cryogen into the container. Read the potential across the thermocouple.
- d) When the container is completely cooled and the temperature drops to about 70 K or whatever decided, turn the power supply on. When the resistance of the superconductor changes with variable current, the voltage output changes. Read the potential difference on the voltmeter. The ratio of the voltage to the current flowing through the test specimen is the resistance of the superconductor between the two voltage probes (c and d).

In [Figure 5](#), current (I) passes through the two end probes (a and b) and voltage (V) is measured between the two centre probes (c and d) which is for joint and HAZ. The average resistance, R , between the two centre probes (c and d) is calculated from [Formula \(1\)](#).

$$I = V / R \quad (1)$$

where

V is the voltage difference;

I is the current flow between the two centre probes (c and d).

R is also given by [Formula \(2\)](#) because most voltage difference comes from joint and HAZ.

$$R_j = \rho_j \times l_j / A_2 \text{ or } R_{HAZ} = \rho_{HAZ} \times l_{HAZ} / A_1 \quad (2)$$

where is

ρ_j is the resistivity of the joint in Ω -cm;

ρ_{HAZ} is the resistivity of the HAZ in Ω -cm;

l_j is the length of the joint measured in cm;

l_{HAZ} is the length of the HAZ measured in cm;

A_1 and A_2 is the cross-sectional areas of superconducting layer and lap-joined two superconducting layers in cm^2 , respectively.

Thus, total resistance of the test specimen with lap-joint is as [Formula \(3\)](#).

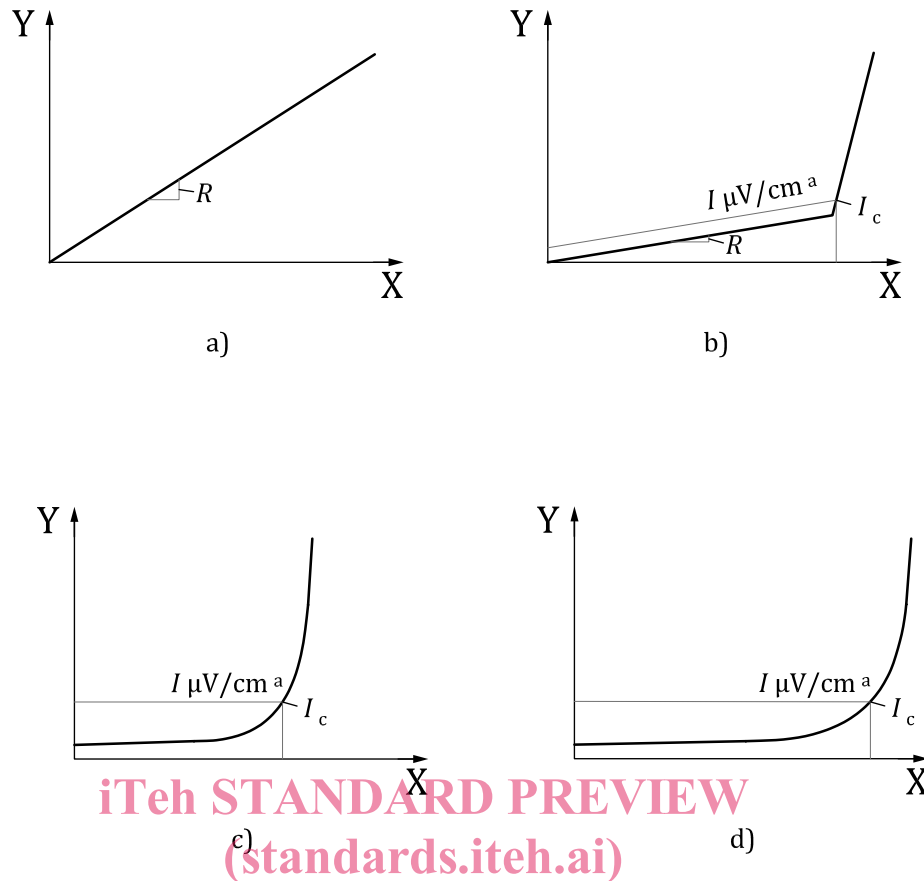
$$I = V / (R_j + R_{HAZ}) \quad (3)$$

4.3.5.2 Self-field critical current (I_c)

Critical current value of joint ($I_{c,j}$) is extremely important to confirm joint integrity. The self-field critical current (I_c) values of the joined superconductor shall be measured using a standard four-point-probe testing and in a bath of liquid nitrogen (LN_2) or other pre-determined cryogenic environment. Although this method is not an ultimate method, it is quite effective in the first-round evaluation. If the current is plotted versus the voltage reading in 2G HTS, the result is similar to that shown in [Figure 6](#). The V - I curve is obtained from a commercially available data acquisition system (DAS) and LabVIEW¹⁾. The DAS and LabVIEW shall be calibrated.

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1) LabVIEW is the trademark of a product. This information is given for the convenience of users of this document and does not constitute an endorsement by ISO of the product named. Equivalent products may be used if they can be shown to lead to the same results.

**Key**

X current in A

Y voltage in V

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Figure 6 — Examples of V - I curve measured in joint of 2G HTS CC

Figure 6 a) and b) show resistance and are not superconducting joints. However, Figure 6 c) and d) shows perfect superconducting joint, of which the slope of V - I curve is zero (zero voltage and resistance) till around its critical current (I_c). Figure 6 c) is lower than the virgin (heat-unaffected base metal) and Figure 6 d) is same of the virgin, respectively. The self-field I_c values of the 2G HTS joint shall be measured using a $1 \mu\text{V}/\text{cm}$ criterion from the V - I curve obtained by four-point-probe testing. When the distance between voltage taps [Figure 6 c) and d)] is 8 cm, the current value at $8 \mu\text{V}$ is critical current (I_c).

4.3.5.3 Critical current density (J_c)

J_c characterizes the maximum electrical transport current per cross-sectional unit area that the superconductor is able to maintain without resistance and is expressed in terms of I_c divided by joined cross-sectional area. The cross-sectional areas of virgin (base metal) and joint in Figure 4 are A_1 and A_2 respectively and expressed as Formula (4).

$$J_{c,v} = I_{c,v} / A_1 \text{ or } J_{c,j} = I_{c,j} / A_2 \quad (4)$$

For example, when the thickness and width of superconducting layer in 2G HTS are $1 \mu\text{m}$ and $4 \mu\text{m}$, respectively, and I_c of 84 A in Figure 6 d) is applied, A_1 and A_2 are $4 \mu\text{m}^2$ and $8 \mu\text{m}^2$. Then, $J_{c,v}$ and $J_{c,j}$ can be calculated as $21 \text{ A}/\mu\text{m}^2$ and $10,5 \text{ A}/\mu\text{m}^2$, respectively, which are extremely high due to 2G HTS.