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INTERNATIONAL STANDARD

NORME INTERNATIONALE

Superconductivity –
Part 18: Mechanical properties measurement – Room temperature tensile test of Ag- and/or Ag alloy-sheathed Bi-2223 and Bi-2212 composite superconductors

Supraconductivité –
Partie 18: Mesure des propriétés mécaniques – Essai de traction à température ambiante des supraconducteurs composites Bi-2223 et Bi-2212 avec gaine Ag et/ou en alliage d'Ag

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IEC Central Office
3, rue de Varembé
CH-1211 Geneva 20
Switzerland

Tel.: +41 22 919 02 11
Fax: +41 22 919 03 00
info@iec.ch
www.iec.ch

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The text of this standard is based on the following documents:

FDIS	Report on voting
90/326/FDIS	90/327/RVD

Full information on the voting for the approval of this standard can be found in the report on voting indicated in the above table.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

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- withdrawn,
- replaced by a revised edition, or
- amended.

INTRODUCTION

Several types of composite superconductors have now been commercialised. Especially, high temperature superconductors such as Ag- and/or Ag alloy-sheathed Bi-2223 (Ag/Bi-2223) and Ag- and/or Ag alloy-sheathed Bi-2212 (Ag/Bi-2212) wires are now manufactured in industrial scale. Commercial composite superconductors have a high current density and a small cross-sectional area. The major applications of composite superconductors are to build electrical power devices and superconducting magnets. While the magnet is being manufactured, complicated stresses/strains are applied to its windings and, while it is being energized, a large electromagnetic force is applied to the superconducting wires because of its high current density. It is therefore indispensable to determine the mechanical properties of the superconductive wires from which the windings are made.

The Ag/Bi-2223 and Ag/Bi-2212 superconductive composite wires fabricated by the powder-in -tube method are composed of a number of oxide filaments with silver and silver alloy as a stabilizer and supporter. In the case that the external reinforcement of Ag/Bi-2223 and Ag/Bi-2212 wires by using thin stainless or Cu alloy foils has been adopted in order to resist the large electromagnet force, this standard shall be also applied.

SUPERCONDUCTIVITY –

Part 18: Mechanical properties measurement – Room temperature tensile test of Ag- and/or Ag alloy-sheathed Bi-2223 and Bi-2212 composite superconductors

1 Scope

This International Standard specifies a test method detailing the tensile test procedures to be carried out on Ag/Bi-2223 and Ag/Bi-2212 superconductive composite wires at room temperature.

This test is used to measure the modulus of elasticity and to determine the 0,2 % proof strength.

When the 0,2 % proof strength could not be determined due to earlier failure, the stress level at apparent strains of 0,05 %, 0,1 %, 0,15 %, 0,2 %, 0,25 % with increment of 0,05 % is measured.

The values for elastic limit, fracture strength, percentage elongation after fracture and the fitted type of 0,2 % proof strength serve only as a reference (see Clauses A.4, A.5, A.6 and A.10).

The sample covered by this test procedure should have a round or rectangular cross-section with an area of 0,3 mm^2 to 2,0 mm^2 (corresponding to the tape-shaped wires with width of 2,0 mm to 5,0 mm and thickness of 0,16 mm to 0,4 mm).

2 Normative references

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

IEC 60050 (all parts), *International Electrotechnical Vocabulary* (available at <http://www.electropedia.org>)

ISO 376, *Metallic materials – Calibration of force-proving instruments used for the verification of uniaxial testing machines*

ISO 6892-1, *Metallic materials – Tensile testing – Part 1: Method of test at room temperature*

ISO 7500-1, *Metallic materials – Verification of static uniaxial testing machines – Part 1: Tension/compression testing machines – Verification and calibration of the force-measuring system*

ISO 9513, *Metallic materials – Calibration of extensometer systems used in uniaxial testing*

3 Terms and definitions

For the purposes of this document, terms and definitions given in IEC 60050-815 and ISO 6892-1, as well as the following terms and definitions apply.

3.1
tensile stress
R
tensile force divided by the original cross-sectional area at any moment during the test

3.2
tensile strain
A
displacement increment divided by initial gauge length of extensometers at any moment during the test

3.3
extensometer gauge length
L_G
length of the parallel portion of the test piece used for the measurement of displacement by means of an extensometer

3.4
distance between grips
L_o
length between grips that hold a test specimen in position before the test is started

3.5
modulus of elasticity
E
gradient of the straight portion of the stress-strain curve in the elastic deformation region

SEE: Figure 1.

Note 1 to entry: It can be determined differently depending upon the adopted procedures:

a) one from the initial loading curve by zero offset line expressed as E_0,

b) the other one given by the slope of line during the elastic unloading, expressed as E_U.

3.6
0,2 % proof strength
$R_{p0,2}$
stress value when the superconductive composite wire yields by 0,2 %

SEE: Figure 1.

Note 1 to entry: The designated stress, $R_{p0,2\text{-}0}$ or $R_{p0,2\text{-}U}$ corresponds to point A or B obtained from the initial loading or unloading curves in Figure 1, respectively. This strength is regarded as a representative 0,2 % proof strength of the composite.

3.7
tensile stress at specified strains
R_A
tensile stress corresponding to different specified strain (*A*)

3.8
fracture strength
R_f
tensile stress at the fracture

Note 1 to entry: In most cases, the fracture strength is defined as tensile stress corresponding to the maximum testing force

3.9
tensile stress at elastic limit
R_{el}
tensile stress at elastic limit corresponding to transition instant from elastic to plastic deformation

3.10
tensile strain at elastic limit
A_{el}
strain at elastic limit

Note 1 to entry: The stress R_{el} and the corresponding strain A_{el} refer to point G in Figure A.5, respectively and are regarded as the transition point from elastic to plastic deformation.

4 Principle

The test consists of straining a test piece by a tensile force, generally to fracture, in principle for the purpose of determining the mechanical properties defined in Clause 3.

Depending on the employed strain measuring method, however, the quantities determined by the present test should be limited. When using the conventional single extensometer system, the determination of E_U and $R_{p0,2-U}$ is recommended. On the other hand, all quantities described here can be determined by using double extensometer system, because of its capability to compensate the bending effects of the specimen thereby guaranteeing a proper determination of the modulus of elasticity.

5 Apparatus

5.1 General

The test machine and the extensometers shall conform to ISO 7500-1 and ISO 9513, respectively. The calibration shall obey ISO 376. The special requirements of this standard are presented here.

5.2 Testing machine

A tensile machine control system that provides a constant crosshead speed shall be used. Grips shall have a structure and strength appropriate for the test specimen and shall be constructed to provide a firm connection with the tensile machine. The faces of the grips shall be filed or knurled, or otherwise roughened, so that the test specimen will not slip during the test. Gripping may be a screw type, or pneumatically or hydraulically actuated.

5.3 Extensometer

The mass of the extensometer shall be 30 g or less, so as not to affect the mechanical properties of superconductive composite wires. The mass of the extensometers shall be balanced symmetrically around the wire to avoid any non-alignment force. Care shall be taken to prevent bending moments from being applied to the test specimen (see Clauses A.2 and A.3).

6 Specimen preparation

6.1 General

When a test specimen sampled from a bobbin needs to be straightened, a method that affects the material as little as possible shall be used. Care shall be taken to prevent bending or pre-loading when the specimen is handled manually.

6.2 Length of specimen

The length of the test specimen shall be the sum of the inward distance between grips and both grip lengths. The inward distance between the grips shall be 60 mm or more, as requested for the installation of the extensometer.

6.3 Removing insulation

If the test specimen surface is coated with an insulating material, the coatings shall be removed. Either a chemical or mechanical method shall be used with care taken in removing the coating so as not to damage the specimen surface (see Clause A.7).

6.4 Determination of cross-sectional area (S_0)

A micrometer or other dimension-measuring apparatus shall be used to obtain the cross-sectional area of the specimen after the insulation coating has been removed. The cross-sectional area of tape-shaped wires shall be obtained from the product of its thickness and width. Corrections to be made for the corners of the cross-sectional area shall be determined through consultation among the parties concerned (see Clause A.8). In addition, in the cases of lens-shaped wires, measurement of width and thickness by photograph may also be done. Mean value of middle and edge thickness shall be used for wires with varying thickness along its width to minimize mismatch effect on its cross-sectional area. The cross-sectional area of a round wire shall be calculated using the arithmetic mean of the two orthogonal diameters.

7 Testing conditions

7.1 Specimen gripping

When the test specimen is going to be mounted on the grips of the tensile machine, the test specimen and tensile loading axis shall be aligned to be in a straight line. Sand paper may be inserted as a cushioning material to prevent the gripped surfaces of the specimen from slipping and fracturing (see Clause A.9). During mounting of the sample, bending or deformation shall be prevented.

7.2 Setting of extensometer

When mounting the extensometer, care shall be taken to prevent the test specimen from being deformed like in the case of indentation due to extensometers' sharp edges which might cause an earlier fracture of the specimen. The extensometer shall be mounted at the centre between the grips, aligning the measurement direction with the specimen axis direction.

During mounting care should be taken not to pre-load the specimen. After installation, loading shall be physically set to zero.

In the case where a double extensometer system is used, it shall be mounted symmetrically around the cross-section to allow averaging of the strain to compensate the bending effects.

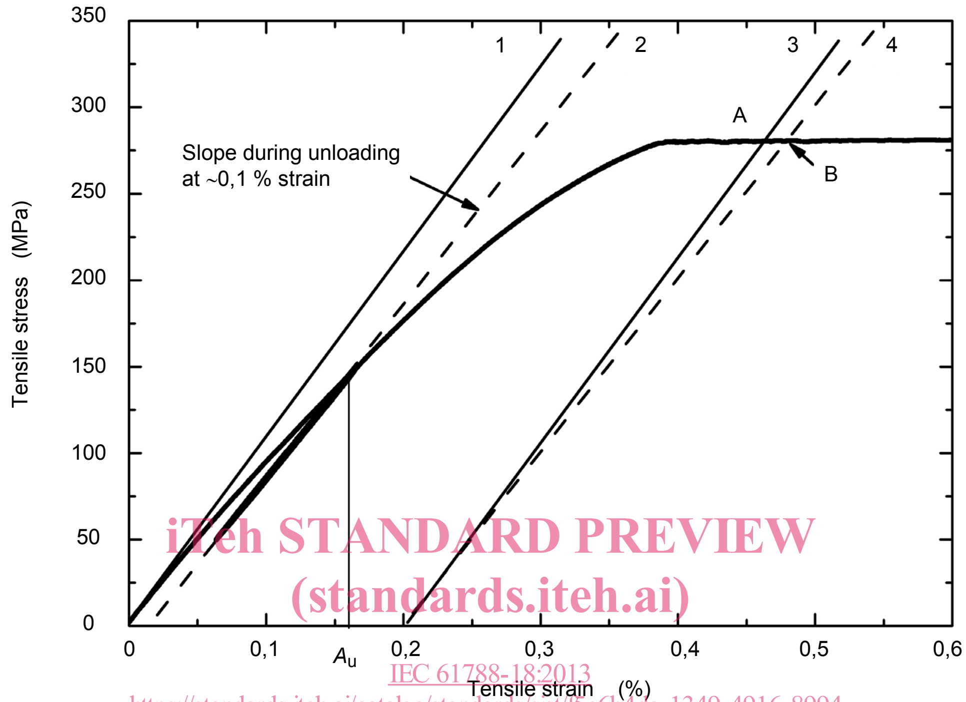
7.3 Testing speed

The tensile tests shall be performed with displacement control. The machine crosshead speed is recommended to be set between 0,1 mm/min and 0,5 mm/min.

7.4 Test

Following this procedure, the tensile machine shall be started after the crosshead speed has been set to the specified level. The strain and stress calculated from the output signals of the extensometer and the load cell respectively shall be plotted on the abscissa and ordinate of the diagram as shown in Figure 1 and Figure 2. When the total strain has reached a value of approximately 0,1 % (point A_u), the tensile stress shall be reduced by 30 % to 40 %. Then, the load shall be increased again to the previous level and the test shall be continued to the point where the specimen is fractured.

Prior to the start of any material test program it is advisable to check the complete test equipment using similar size wires of known elastic properties (see Clause A.13).



1 Straight line drawn from the initial loading curve (zero offset line)

2 Straight line drawn from the unloading curve

3 0,2 % offset line drawn from the initial loading curve by parallel shifting

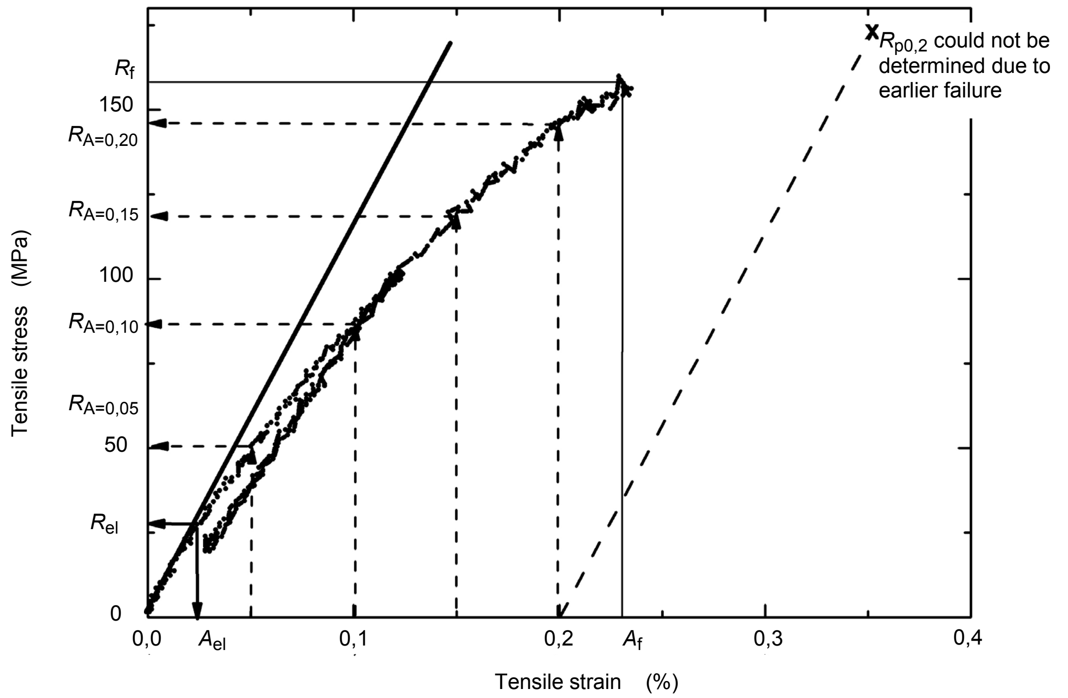
4 0,2 % offset line drawn from the unloading curve by parallel shifting

A 0,2% proof strength obtained by the offset line 3

B 0,2% proof strength obtained by the offset line 4

NOTE The slope of the initial loading curve decreases usually with increasing strain. Then, two straight lines can be drawn from the 0,2 % offset point on the abscissa to obtain 0,2 % proof strength of the composite. Point A is obtained from the initial loading curve, and Point B is obtained from the unloading curve.

Figure 1 – Typical stress-strain curve and definition of modulus of elasticity and 0,2 % proof strengths of an Ag/Bi-2223 wire externally laminated by brass foil



IEC 2165/13

NOTE In cases where the 0,2 % offset proof strength could not be determined due to earlier failure of the wires, the tensile stresses at specified strains such as 0,05 %, 0,10 %, 0,15 %, and 0,20 % with an increment of 0,05 % are measured. In addition, the fracture strength, R_f and the percentage elongation to fracture A_f were derived from the stress-strain curve.

Figure 2 – Typical stress-strain curve of an Ag/Bi-2223 wire where the 0,2 % proof strengths could not be determined and definition of tensile stresses at specified strains

8 Calculation of results

8.1 Modulus of elasticity (*E*)

Modulus of elasticity shall be calculated in general using the following equation and the straight portion of the initial loading curve and of the unloading one. Appropriate software for data evaluation, with the function of enlargement of the stress strain graph especially around the region where the deviation from linearity is expected, should be used for post analyses of the plotted data (see Clause A.12).

$$E = \Delta F/(S_0\ \Delta A) \tag{1}$$

where

E is the modulus of elasticity;

ΔF is the increment of the corresponding force;

ΔA is the increment of strain corresponding to ΔF;

S_0 is the original cross – sectional area of the test specimen.

Since the unloading process is carried out at the strain indicated by the point A_U in Figure 1, the same equation (1) is used for both the unloading modulus (E_U) and the initial loading one (E_0).

It is recommended to measure the unloading curve at the starting point A_U, where A_U is recommended to be approximately 0,1 %.

After the test, the results shall be examined using the ratio E_0 / E_U. The ratio shall satisfy the condition as given in condition (2) in which Δ = 0,3 (see Clause A.11).

$$1 - \Delta < \frac{E_0}{E_U} < 1 + \Delta \qquad (2)$$

If it does not satisfy the condition (2), the test is judged not to be valid. Then the test shall be repeated after checking the experimental procedure according to the present test method.

It is recommended to achieve the unloading – reloading procedure as follows: When the loading curve reaches the strain of A_U = 0,10 %, the stress is reduced by 30 % to 40 % and then the wire is reloaded.

The slope of the unloading curves shall be obtained in the linear portion between the stress where the unloading started and the stress which is generally 90 % referring to the onset of the unloading stress.

8.2 0,2 % proof strength ($R_{p\ 0,2}$)

The 0,2 % proof strength of the composite shall be determined in two ways, from the initial loading part and the unloading/reloading part of the stress-strain curve as shown in Figure 1.

The 0,2 % proof strength under loading $R_{p0,2\text{-}0}$ shall be determined as follows: the initial linear portion of the loading line of the stress-strain curve is moved parallel to 0,2 % along the strain axis (0,2 % offset line under loading) and the point A at which this linear line intersects the stress-strain curve shall be defined as the 0,2 % proof strength under initial loading.

The 0,2 % proof strength under unloading $R_{p0,2\text{-}U}$ shall be determined as follows: the linear portion of the unloading line is moved parallel to the 0,2 % offset strain point. The intersection of this line with the stress-strain curve determines the point B that shall be defined as the 0,2 % proof strength under unloading. Depending on the unloading line (4 in Figure 1) 0,2 % proof strength ($R_{p0,2\text{-}U}$) is determined.

Each 0,2 % proof strength shall be calculated using equation (3) given below:

$$R_{p0,2\text{-}i} = F_i \,/\, S_0 \qquad (3)$$

where

$R_{p0,2\text{-}i}$ is the 0,2 % proof strength (MPa) at each point;

F_i is the force (N) at each point;

S_0 is the original cross-sectional area (in square millimetres) of the test specimen;

further, i = 0 at 0 % and i = U at 0,1 %.

8.3 Tensile stress at specified strains (R_A)

On the other hand, when the 0,2 % proof strength could not be determined due to earlier failure, then the stress level at strains of 0,05 %, 0,1 %, 0,15 %, 0,2 %, 0,25 % with increment of 0,05 % strength is measured (see Figure 2).