IEC 61788-25

Edition 1.0 2018-08

INTERNATIONAL STANDARD

NORME INTERNATIONALE

colour inside

Superconductivity –
Part 25: Mechanical properties measurement – Room temperature tensile test on REBCO wires

Supraconductivité –
Partie 25: Mesure des propriétés mécaniques – Essai de traction à température ambiante des fils REBCO

IEC 61788-25:2018-08(en-fr)

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

COMMISSION ELECTROTECHNIQUE INTERNATIONALE

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FOREWORD

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The text of this International Standard is based on the following documents:

FDIS	Report on voting
90/404/FDIS	90/411/RVD

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

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

A list of all parts in the IEC 61788 series, published under the general title *Superconductivity*, can be found on the IEC website.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under "http://webstore.iec.ch" in the data related to the specific document. At this date, the document will be

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- withdrawn,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

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INTRODUCTION

Several types of composite superconductors have now been commercialized. The rare-earth-based oxide superconductor (SC) with chemical formula $REBa_2Cu_3O_7$ is used for practical SC wires, where the rare-earth element RE is typically Y, Dy, Gd, Nd, Ho or Sm, or a combination of two or more among them. This type of practical SC wire is usually called REBCO coated conductors. A typical architecture consists of a substrate of Ni-Cr-Mo based alloy, Ni-W alloy or stainless steel, a buffer layer consisting of a plurality of oxides, a SC layer and a protection layer of Ag. The substrate and buffer layer act as template to facilitate the well-oriented SC layer. In order to resist the large electromagnetic force, the wires are often externally reinforced by laminating thin stainless steel or Cu alloy foils. Commercial composite superconductors have a high current density and a small cross-sectional area. The major application of composite superconductors is to build electrical power devices and superconducting magnets. Complex stresses and strains are applied to the composite superconducting wires when devices are manufactured and energized. In the case of superconducting magnets, large electromagnetic forces are experienced by the windings due to the combination of high magnetic fields and high current density. It is therefore indispensable to determine the mechanical properties of the practical REBCO wires.

SUPERCONDUCTIVITY –

Part 25: Mechanical properties measurement – Room temperature tensile test on REBCO wires

1 Scope

This part of IEC 61788 specifies the test method and procedures for testing tensile mechanical properties of REBCO superconductive composite tapes at room temperature. This test is used to measure the modulus of elasticity and 0,2 % proof strength. The values for elastic limit, fracture strength and percentage elongation after fracture serve only as a reference. This document applies to samples having a rectangular cross-section with an area of 0,12 mm^2 to 6,0 mm^2 (corresponding to the tapes with width of 2,0 mm to 12,0 mm and thickness of 0,06 mm to 0,5 mm).

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

ISO 7500-1, *Metallic materials – Calibration and verification of static uniaxial testing machines – Part 1: Tension/compression testing machines – Calibration and verification 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, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp

3.1
tensile stress
R
tensile force divided by the original cross-sectional area of the test piece 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 tensile test

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

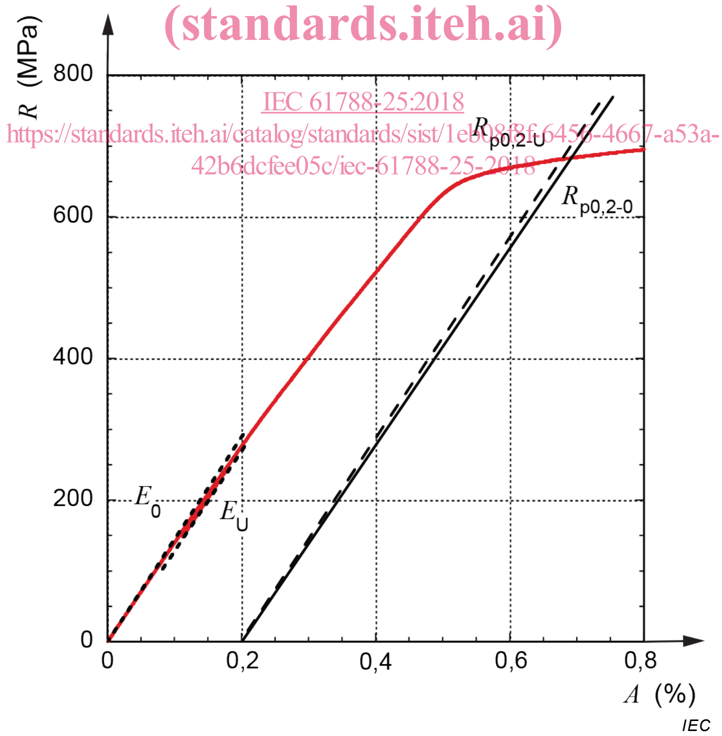
3.4
distance between grips
L_0
inward distance between grips that hold a test specimen in position before the test is started

3.5
modulus of elasticity
E
slope of the straight portion of the stress–strain curve in the elastic deformation region

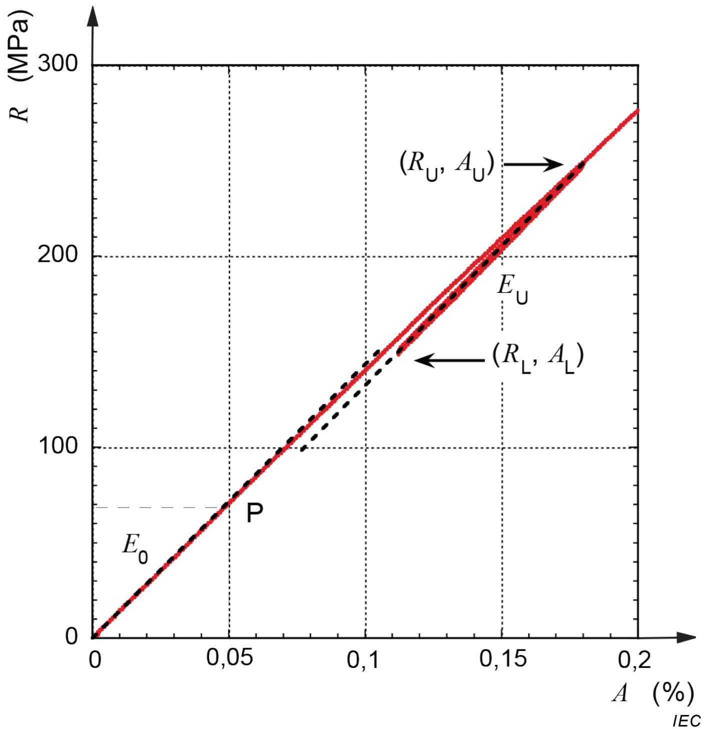
SEE: Figure 1

Note 1 to entry: The straight portion of the initial stress–strain curve is very narrow as indicated in Figure 1. To measure this quantity with a small standard uncertainty, the use of double extensometer systems will be an appropriate technique. In this sense, the quantity of E_U should be a representative data for the present text, while E_0 should be reported only when the measure is performed by means of double extensometer system.

Note 2 to entry: In the case of composite superconductor, however, it can be determined differently depending upon the adopted procedures; one from the initial loading curve by the zero offset line expressed as E_0, the other one given by the slope of line during unloading, expressed as E_U. The dotted straight lines drawn along the initial loading curve and the unloading one in Figure 1 b) are only a guide to the eye for determining the slope.



a)



b)

The red curves are the observed data and the black continuous and black dotted straight lines are additional lines to indicate how to determine the moduli of elasticity and 0,2 % proof strengths.

Figure 1 – Typical stress–strain curve and definition of moduli of elasticity and 0,2 % proof strengths

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

SEE: Figure 1

3.7
fracture strength
R_f
tensile stress at the fracture

3.8
tensile stress at elastic limit
R_{el}
tensile force divided by the original cross-sectional area at the elastic limit corresponding to the transition from elastic to plastic deformation indicated by point P in Figure 1 b)

3.9
tensile strain at elastic limit
A_{el}
strain at the elastic limit corresponding to the transition from elastic to plastic deformation indicated by point P in Figure 1 b)

4 Principle

The test consists of straining a test piece by a tensile force, generally to fracture, for the purpose of determining the modulus of elasticity and 0,2 % proof strength described in Clause 1.

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 $R_{\mathrm{p0,2\text{-}U}}$ is recommended. On the other hand, all E_0, E_{U}, $R_{\mathrm{p0,2\text{-}0}}$ and $R_{\mathrm{p0,2\text{-}U}}$ can be determined by using double extensometer system, because of its capability to compensate the bending effects of the specimen and to guarantee a proper determination of the modulus of elasticity.

Additional information relating to Clauses 1 to 10 is given in Annex A.

5 Apparatus

5.1 General

The test machine and the extensometer shall conform to ISO 7500-1 and ISO 9513, respectively. The calibration shall obey ISO 376. The special requirement for this document is presented in 5.2 and 5.3.

5.2 Testing machine

A tensile machine control system that provides a constant cross head 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 testing. 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 around the wire to avoid any non-alignment force. The generation of bending moments due to the non-alignment force shall be prevented (see Clause A.2).

6 Specimen preparation

6.1 General

Bending and/or pre-loading shall be prevented 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 the grip lengths. The minimum specimen length (L_{sm}) shall be calculated as,

$$L_{\mathrm{sm}} = 2 \times L_{\mathrm{g}} + L_{\mathrm{G}} + 2 \times L_{\mathrm{x}} \quad (1)$$

where L_{g} is the grip length, L_{G} is the gauge length of extensometer. L_{x} is the free gap distance between grip and extensometer and shall meet the condition,

$$L_{\mathrm{x}} \geq 0{,}7 \times L_{\mathrm{G}} \quad (2)$$

6.3 Determination of cross-sectional area (S_o)

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.

7 Testing conditions

7.1 Specimen gripping

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

7.2 Setting of extensometer

When mounting the extensometer, deformation of the test specimen shall be prevented like the indentation due to extensometer's sharp edges which might cause an early 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, pre-loading the specimen shall be prevented. After installation, loading shall be physically zeroed.

7.3 Testing speed

The initial strain rate shall be slower than 10^{-4} s^{-1} during the test using the extensometer (see B.3.1).

7.4 Test

The tensile machine shall be started after the testing speed has been set to the specified level. The stress and strain calculated from the output signals of load cell and extensometer, respectively, shall be plotted on the ordinate and abscissa of the diagram as shown in Figure 1 a) and b). When the strain has reached a value between 0,1 % and 0,2 % as indicated A_U, the stress shall be reduced by approximately 30 % to 40 % of R_U to R_L. Then, the stress shall be increased again and the test should be continued to the point where the specimen is fractured.

Prior to the start of any material test programme, the test equipment shall be checked completely using similar size wires of known elastic properties (see Clause A.9).

8 Calculation of results

8.1 Modulus of elasticity (E)

Modulus of elasticity shall be calculated in general using the following formula and the straight portion of the initial loading curve and of the unloading one as shown in Figure 1 b). Appropriate software for data evaluation, with the function of enlargement of the stress–strain diagram especially around the region where the deviation from linearity is expected, should be used for post analyses of the plotted data.

$$E = \Delta F/(S_o \Delta A) \quad (3)$$

where

E is the modulus of elasticity (GPa);

ΔF is the increment of the force (N);

ΔA is the increment of strain corresponding to ΔF;

S_o is the original cross-sectional area of the test specimen (mm^2).

Since the unloading process is carried out at the strain indicated by the point A_U in Figure 1, the same Formula (3) 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 % to 0,2 %.

After the test, the results shall be examined using the ratio E_0/E_U. The ratio shall satisfy the condition as given in Formula (4) in which Δ = 0,2 [Osamura et al., 2008 and 2014].

$$1 - \Delta < \frac{E_0}{E_U} < 1 + \Delta \tag{4}$$

When it does not satisfy the condition, 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.

8.2 0,2 % proof strength ($R_{p0,2\text{-}0}$ and $R_{p0,2\text{-}U}$)

The 0,2 % proof strength of the composite is 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 to 0,2 % along the strain axis (0,2 % offset line under loading) and the point at which this linear line intersects the stress–strain curve shall be defined as the 0,2 % proof strength under loading.

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

Each 0,2 % proof strength shall be calculated using Formula (5):

$$R_{p0,2\text{-}i} = F_i \,/\, S_o \tag{5}$$

where

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

F_i is the force at each point (N);

S_o is the original cross-sectional area of the test specimen (mm^2);

i indicates 0 or U.

9 Uncertainty of measurement

Unless otherwise specified, measurements shall be carried out in a temperature that can range from 285 K to 305 K. A force measuring cell with the relative standard uncertainty less than 0,1 %, valid between zero and the maximum force value shall be used. The extensometers should have the relative standard uncertainty of strain less than 0,5 %. The displacement measuring transducer (e.g. LVDT [linear variable differential transformer]) used for the calibration should have the relative standard uncertainty less than 0,1 %.

The value of relative standard uncertainty corresponding to the number of specimens tested of measured moduli of elasticity E_0 and E_U, proof strength $R_{p0,2\text{-}0}$ and $R_{p0,2\text{-}U}$ shall be calculated using Formula (6):

$$X_{RSU}(N) = X_{<COV>} / \sqrt{N} \qquad (6)$$

where

$X_{RSU}(N)$ is the value of relative standard uncertainty;

N is the number of specimens tested;

$X_{<COV>}$ is the value of averaged coefficient of variation for all data tested.

According to the international round robin test (RRT, see Clause A.7), the parameter $X_{<COV>}$ has been evaluated as follows: 7,0 %, 4,6 %, 4,3 % and 4,1 % for E_0, E_U, $R_{p0,2\text{-}0}$ and $R_{p0,2\text{-}U}$, respectively.

Evaluation of combined standard uncertainty for the modulus of elasticity is given in Annex B.

10 Test report

10.1 Specimen

a) Name of the manufacturer of the specimen

b) Classification and/or symbol

c) Lot number

d) Cross-sectional shape and dimension of the wire

e) Materials comprising the substrate and stabilizer

10.2 Results

Results of the following mechanical properties shall be reported:

a) Modulus of elasticity (E_0 and E_U)

b) 0,2 % proof strengths ($R_{p0,2\text{-}0}$ and $R_{p0,2\text{-}U}$)