# INTERNATIONAL STANDARD

# IEC 61788-6

First edition
2000-12



**Superconductivity –**

**Part 6:**
**Mechanical properties measurement –**
**Room temperature tensile test of Cu/Nb-Ti composite superconductors**

*Supraconductivité –*

*Partie 6:*
*Mesure des propriétés mécaniques –*
*Test de tension à température ambiante des composites supraconducteurs de Cu/Nb-Ti*

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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## FOREWORD

1) The IEC(International Electrotechnical Commission) is a world-wide organization for standardization comprising all national electrotechnical committee ( IEC National Committees). The object of the IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, the IEC publishes International Standards. Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International governmental and non-governmental organization liaising with the IEC also participate in this preparation. The IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.

2) The formal decisions or agreements of the IEC on technical matters, as nearly as possible, an international consensus of opinion on the relevant subjects since each technical committee has representation from all interested National Committee.

3) The documents produced have the form of recommendations for international use and are published in the form of standards, technical specifications, technical reports or guides and they are accepted by the National Committees in that sense.

4) In order to promote international unification, IEC National Committees undertake to apply IEC International Standards transparently to the maximum extent possible in their national and regional standards. Any divergence between the IEC Standards and the corresponding national or regional standard shall be clearly indicated in the latter.

5) The IEC provided no marking procedure to indicate its approval and cannot be rendered responsible for any equipment declared to be in conformity with one of its standards.

6) Attention is drawn to the possibility that some of the elements of this International Standard may be the subject of patent rights. The IEC shall not be held responsible for identifying any or all such patent rights.

International Standard IEC 61788-6 has been prepared by IEC technical committee 90: Superconductivity.

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

| FDIS | Report on voting |
|---|---|
| 90/82/FDIS | 90/88/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 3.

Annex A is for information only.

The committee has decided that the contents of this publication will remain unchanged until 2005. At this date, the publication will be

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

A bilingual version of this standard may be issued at a later date.

# INTRODUCTION

The Cu/Nb-Ti superconductive composite wires currently in use are multifilamentary composite material with a matrix that functions as a stabilizer and supporter, in which ultrafine superconductor filaments are embedded. An Nb-40~55 mass% Ti alloy is used as the superconductive material, while oxygen free copper and aluminum of high purity are employed as the matrix material. Commercial composite superconductors have a high current density and a small cross-sectional area. The major application of the composite superconductors is to build superconducting magnets. While the magnet is being manufactured, complicated stresses 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, of which the windings are made.

# SUPERCONDUCTIVITY –

## Part 6: Mechanical properties measurement – Room temperature tensile test of Cu/Nb-Ti composite superconductors

## 1 Scope

This part of IEC 61788 covers a test method detailing the tensile test procedures to be carried out on Cu/Nb-Ti superconductive composite wires at room temperature.

This test is used to measure modulus of elasticity, 0,2 % proof strength of the composite due to yielding of the copper component, and tensile strength.

The value for percentage elongation after fracture and the second type of 0,2 % proof strength due to yielding of the Nb-Ti component shall serve only as a reference (see clauses A.1 and A.2).

The sample covered by this test procedure should have a round or rectangular cross-section with an area of 0,15 mm$^2$ to 2 mm$^2$ and a copper to superconductor volume ratio of 1,0 to 8,0 without the insulating coating.

## 2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this part of IEC 61788. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this part of IEC 61788 are encouraged to investigate the possibility of applying the most recent edition of the normative document indicated below. For undated references, the latest edition of the normative document referred to applies. Members of IEC and ISO maintain registers of currently valid International Standards.

IEC 60050-815:2000, *International Electrotechnical Vocabulary (IEV) – Part 815: Superconductivity*

ISO 6892:1998, *Metallic materials – Tensile testing at ambient temperature*

ISO 376:1999, *Metallic materials – Calibration of force-proving instruments used for the verification of uniaxial testing machines*

ISO 7500-1:1999, *Metallic materials – Verification of static uniaxial testing machines – Part 1: Tension/compression testing machines – Verification and calibration of the force-measuring system*

ISO 9513:1999, *Metallic materials – Calibration of extensometers used in uniaxial testing*

## 3 Terminology

For the purposes of this part of IEC 61788, the definitions given in IEC 60050-815 and ISO 6892, as well as the following, apply.

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

**3.2**
**tensile strength ($R_m$)**[2)]
tensile stress corresponding to the maximum testing force

**3.3**
**extensometer gauge length**
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 ($L_g$)**
length between grips that hold a test specimen in position before the test is started

**3.5**
**0,2 % proof strength ($R_{p0,2}$)**[3)] (see figure 1)
stress value where the copper component yields by 0,2 %. The designated stress, $R_{p0,2A}$ or $R_{p0,2B}$ corresponds to point A or B in figure 1, respectively. This strength is regarded as a representative 0,2 % proof strength of the composite. The second type of 0,2 % proof strength is defined as a 0,2 % proof strength of the composite where the Nb-Ti component yields by 0,2 %, of which value corresponds to the point C in figure 1 as described complementarily in the annex (see clause A.2).

**3.6**
**modulus of elasticity ($E$)**
gradient of the straight portion of the stress-strain curve in the elastic deformation region

## 4 Principle

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

## 5 Apparatus

The test machine and the extensometer 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.

### 5.1 Testing machine

A tensile machine control system that provides a constant strain rate shall be used. Grips shall have a structure and strength appropriate for the test specimen and shall be constructed to provide an effective 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 on them during testing. Gripping may be a screw type, or pneumatically or hydraulically actuated.

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2) The symbol $\sigma_{UTS}$ is commonly used instead of $R_m$.

3) The symbol $\sigma_{0.2}$ is commonly used instead of $R_{p0.2}$.

### 5.2 Extensometer

The weight of the extensometer shall be 30 g or less, so as not to affect the mechanical properties of the superconductive wire. Care shall also be taken to prevent bending moments from being applied to the test specimen (see clause A.3).

## 6 Specimen preparation

When a test specimen sampled from a bobbin needs to be straightened, a method shall be used that affects the material as little as possible.

### 6.1 Length of specimen

The length of the test specimen shall be the distance between grips plus the grip lengths. The distance between the grips shall be 100 mm or more, as requested for the installation of the extensometer.

### 6.2 Removing insulation

If the test specimen surface is coated with an insulating material, that coating shall be removed. Either a chemical or mechanical method shall be used with care taken not to damage the specimen surface (see clause A.4).

### 6.3 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 a round wire shall be calculated using the arithmetic mean of the two orthogonal diameters. The cross-sectional area of a rectangular wire 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.5).

## 7 Testing conditions

### 7.1 Specimen gripping

The test specimen shall be mounted on the grips of the tensile machine. At this time, the test specimen and tensile loading axis must be on a single 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.6).

### 7.2 Pre-loading and setting of extensometer

If there is any slack in the specimen when it is mounted, a force between one-tenth and one-third of the 0,2 % proof strength of the composite shall be applied to take up the slack before the extensometer is mounted. When mounting the extensometer, care shall be taken to prevent the test specimen from being deformed. The extensometer shall be mounted at the centre between the grips, aligning the measurement direction with the specimen axis direction. After installation, loading shall be zeroed.

### 7.3 Testing speed

The strain rate shall be $10^{-4}$/s to $10^{-3}$/s during the test using the extensometer. After removing the extensometer, the strain rate may be increased to a maximum of $10^{-3}$/s.

### 7.4 Test

The tensile machine shall be started after the testing speed has been set to the specified level. The signals from the extensometer and load cell shall be plotted on the abscissa and ordinate, respectively, as shown in figure 1. When the total strain has reached approximately 2 %, reduce the force by approximately 10 % and then remove the extensometer. The step of removing the extensometer can be omitted in the case where the extensometer is robust enough not to be damaged by the total strain and the fracture shock of this test. At this time, care shall be taken to prevent unnecessary force from being applied to the test specimen. Then, increase loading again to the previous level and continue testing until the test specimen fractures. Measurement shall be made again if a slip or fracture occurs on the gripped surfaces of the test specimen.

## 8 Calculation of results

### 8.1 Tensile strength ($R_m$)

Tensile strength $R_m$ shall be the maximum force divided by the original cross-sectional area of the wire before loading.

### 8.2 0,2 % proof strength ($R_{p0,2A}$ and $R_{p0,2B}$)

The 0,2 % proof strength of the composite due to yielding of the copper component is determined in two ways from the loading and unloading stress-strain curves as shown in figure 1. The 0,2 % proof strength under loading $R_{p0,2A}$ shall be determined as follows: the initial linear portion under loading of the stress-strain curve is moved 0,2 % in the strain axis (0,2 % offset line under loading) and the point A at which this linear line intersects the stress-strain curve (point A) shall be defined as the 0,2 % proof strength under loading. The 0,2 % proof strength of the composite under unloading $R_{p0,2B}$ shall be determined as follows: the linear portion under unloading is to be 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. This measurement shall be discarded if the 0,2 % proof strength of the composite is less than three times the pre-load specified in 7.2.

Each 0,2 % proof strength shall be calculated using formula (1) given below:

$$R_{p0,2i} = F_i \, / \, S_o \qquad (1)$$

where

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

$F_i$ is the force (N) at each point;

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

Further, i = A and B.

### 8.3 Modulus of elasticity ($E_o$ and $E_a$)

Modulus of elasticity shall be calculated using the following formula and the straight portion, either of the initial loading curve or of the unloading one.

$$E = \Delta F \, (1 + \varepsilon_a)/(S_o \, \Delta\varepsilon) \qquad (2)$$

where

$E$ is the Modulus of elasticity (MPa);

$\Delta F$ is the increments (N) of the corresponding force;

$\Delta \varepsilon$ is the increment of strain corresponding to $\Delta F$;

$\varepsilon_a$ is the strain just after unloading as shown in figure 1.

$E$ is designated as $E_o$ when using the initial loading curve ($\varepsilon_a = 0$), and as $E_a$ when using the unloading curve ($\varepsilon_a \neq 0$).

## 9 Precision and accuracy

Unless otherwise specified, measurements shall be carried out in a temperature that can range from 10 °C to 35 °C. A force measuring cell with an accuracy within 1 % shall be used. The extensometer should have a strain accuracy within 1 %. The dimension-measuring apparatus shall have an accuracy within 1 %. The target precisions of this method are given by coefficient of variation (COV; standard deviation divided by the average). The COVs are less than 35 % and 8 % for moduli of elasticity $E_o$ and $E_a$, respectively, and 16 % and 6 % for 0,2 % proof strengths $R_{p0,2A}$ and $R_{p0,2B}$, respectively and 3 % for the tensile strength $R_m$ (see clause A.7).

## 10 Test report

### 10.1 Specimen

a) Name of the manufacturer of the specimen

b) Classification and/or symbol

c) Lot number

The following information shall be reported as necessary.

d) Raw materials and their chemical composition

e) Cross-sectional shape and dimension of the wire

f) Filament diameter

g) Number of filaments

h) Copper to superconductor ratio

### 10.2 Results

a) Tensile strength ($R_m$)

b) 0,2 % proof strengths ($R_{p0,2A}$ and $R_{p0,2B}$)

c) Modulus of elasticity ($E_o$ and $E_a$ with $\varepsilon_a$)

The following information shall be reported as necessary.

d) Second type of 0,2 % proof strength ($R_{p0,2C}$)

e) Percentage elongation after fracture ($A$)

### 10.3 Test conditions

a) Strain rate

b) Distance between grips

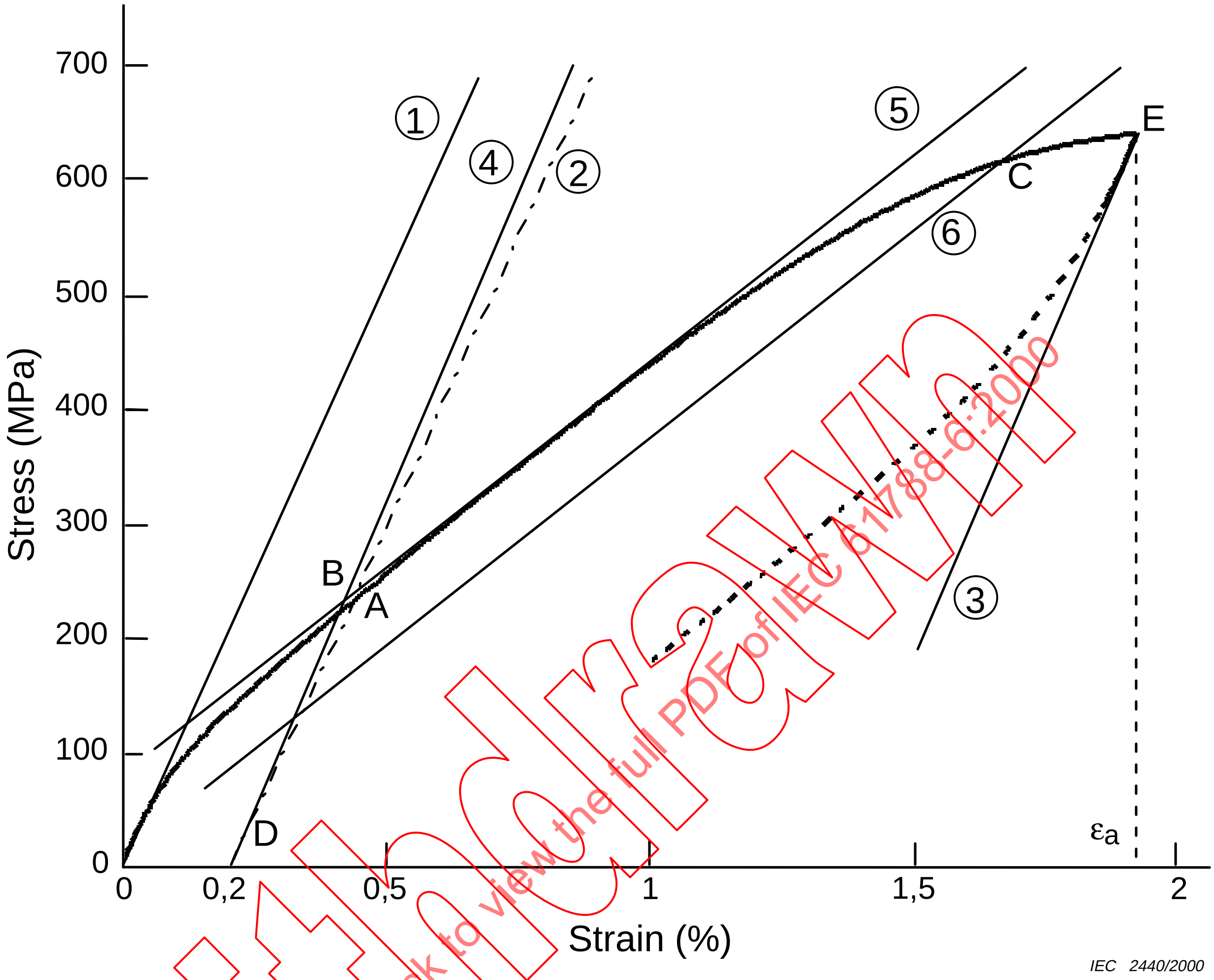
c) Temperature

The following information shall be reported as necessary.

d) Manufacturer and model of testing machine

e) Manufacturer and model of extensometer

f) Gripping method






**Key**

① Initial loading line

② 0,2 % offset line for initial loading line

③ Unloading line

④ 0,2 % offset line for unloading line

⑤ Second linear part for loading line

⑥ 0,2 % offset line for second linear part

NOTE 1 When the total strain has reached ~2 % (point E), the load is reduced by 10 % and the extensometer is removed, if necessary. Then, the load is increased again.

NOTE 2 The slope of the initial loading line is usually smaller than that of the unloading line. Then, two lines can be drawn from the 0,2 % offset point on the abscissa to obtain 0,2 % proof strength of the composite due to yielding of the copper component. Point A is obtained from the initial loading line, and Point B is obtained from the unloading line. Point C is the second type of 0,2 % proof strength of the composite where the Nb-Ti component yields.

**Figure 1 – Stress-strain curve and definition of modulus of elasticity and 0,2 % proof strengths**

# Annex A
(informative)

## Additional information relating to clauses 1 to 10

This annex gives reference information on the variable factors that can seriously affect the tensile test methods, together with some precautions to be observed when using the standard.

### A.1 Percentage elongation after fracture (*A*)

In Cu/NbTi superconductive wires there is a difference in strength between the copper and NbTi, and the wire is often deformed in waves by the shock of fracture. In such a case, it is difficult to find the elongation accurately after fracture using the butt method. Hence, the measurement of elongation after fracture shall serve only as a reference. The movement of the cross-head may be used to find the approximate value for elongation after fracture, instead of using the butt method, as shown below. To use this method, the cross-head position at fracture must be recorded. Use the following formula to obtain the elongation after fracture, given in percentage.

$$A = 100\ (L_u - L_c)\ /\ L_c \tag{A.1}$$

where

$A$ is the percentage elongation after fracture;

$L_c$ is the initial distance between cross-heads;

$L_u$ is the distance between cross-heads after fracture.

### A.2 Second type of 0,2 % proof strength ($R_{p0,2C}$)

The second type of 0,2 % proof strength, at which the Nb-Ti component yields, is defined reasonably on the basis of the rule-of-mixture for the bimetallic composite including continuous filaments. As indicated in figure 1, it shall be the stress $R_{p0,2C}$ corresponding to point C, at which the straight portion of the loading curve after the point A is moved by 0,2 % along the strain axis intersects the stress-strain curve. The relevant straight portion is usually observed for the commercial Cu/Nb-Ti superconductive wires, because the copper component deforms plastically in a linear behaviour. Often the stress-strain curve does not show any straight line, but is rounded off for some wires, when they have high copper/non-copper ratio and are highly cold worked. It has been empirically made clear that the rounded-off appearance is observed when the following *k*-factor is less than 0,4:

$$k = (R_m - R_{p0,2A})\ /R_{p0,2A} \tag{A.2}$$

The $R_{p0,2C}$ is one of important parameters describing the mechanical property of the composite material in the scientific viewpoint, but its use is not always demanded in the engineering sense.

### A.3 Extensometer

When using a special type of extensometer, which is attached with an unremovable spacer for determining the gauge length, it may introduce a problem during the unloading of the wire to zero force. To avoid a compressive force on the spacer, the actual gauge length must be adjusted during installation with sufficient clearance. If the clearance after unloading is not negligible, it must be included in calculating the strain values.

If the test specimen is thin and the extensometer is relatively heavy, any bending moment caused by the weight of the extensometer can stress the specimen, eventually resulting in the specimen yielding. To avoid this, the light extensometer with balance weight is to be carefully attached. Alternatively, a sufficiently light extensometer without a balance weight is also acceptable to use. Figure A.1 shows an extensometer made with a Ti alloy, weighing about 3 g. It is so light that even single use without a balance weight could provide enough precision according to the procedure of the present standard. Figure A.2 shows one of the lightest extensometers commercially available, with a total weight of 31 g together with a balance weight. Using it, a round robin test (RRT) was conducted in Japan and good results were obtained. The results were used to establish the present international standard.

Since the superconductive composite wire is covered with a soft copper, a scratch in the surface of the specimen made as it is mounted can be a starting point of fracture. Care should therefore be taken when handling the specimen.

## A.4 Insulating coating

The coating on the surface of the test specimen should be removed using an appropriate organic solvent that would not damage the specimen. If the coating material is not dissolved by the organic solvent, a mechanical method should be used with care to prevent the copper from being damaged. If the coating is not removed, it affects the strength to only a small extent. For example, tensile strength decreases by less than 3 % for a low-strength wire which has a high copper ratio of 7. The coating is not designed as a structural component. An analysis of measurement as a three-component composite, i.e. copper, Nb-Ti and insulating coating, is too complicated to conduct. Therefore this test method covers the bare wire in order to maintain accuracy.

## A.5 Cross-sectional area

Where even greater accuracy is required, the cross-sectional area may be obtained by correcting the radius of the corner of the rectangular wire finished by dies, using the value given on the manufacturing specifications. For rolling or Turk's-head finish, the radius of the corner is not controlled and a correction is made using a microphotograph of the cross-section.

## A.6 Gripping force

A weak gripping force results in slippage and a strong gripping force can break the gripped surface. Care should therefore be used when adjusting the gripping force.

## A.7 Precision

The magnitude of COV for the experimental data mentioned in clause 9 is based on the guideline proposed by the Japanese National Committee of IEC TC 90. JNC fulfilled the domestic round robin test (RRT) in 1996 by contributions from eight research organizations[1]. Comparing the result with a variety of experimental conditions, a realistic level of precision according to the present test method has been determined[2].



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[1] M. Shimada, M. Hojo, H. Moriai and K. Osamura; Jpn. Cryogenic Eng., 33(1998) 665.

[2] K. Osamura, A. Nyilas, M. Shimada, H. Moriai, M. Hojo, T. Fuse and M. Sugano; Adv. Superconductivity XI (1999) 1515.

The modulus of elasticity $E_o$ determined under the loading curve has been found to be always smaller than the modulus $E_a$ under unloading. The precision to $E_o$ is fairly low as shown by a COV of 35 %. The reason why the $E_o$ is so small and scattered compared with the $E_a$, is attributed to the following handling issues: the bending of the wire specimen, the misalignment of sample gripping with respect to the load axis and a week grip, and so on. Also, it is pointed out that the copper component is in a plastic state at room temperature before the test, depending on a degree of thermal contraction during cooling from the heat treating temperature. As a whole, the initial loading curve with non-linearity causes the result of $E_o < E_a$.

The German National Committee reported that the modulus of elasticity could be determined with a COV of 4 % by adopting a initial linear loading at zero-offset. This low COV was achieved by using two light extensometers (Figure A.1) which enabled the cancelling of the possible initial bending effects and ensured a high degree of linearity for the zero-offset loading line.

Care must be taken while handling specimens in order not to induce strain to the copper component. Otherwise, the 0,2 % proof strength of the composite due to yielding of the copper component would increase due to work hardening. Allowable pre-loading limit should be taken into consideration in this line. According to the result of RRT, it is made clear that $R_{p0,2A} > R_{p0,2B}$ holds together with the COV for $R_{p0,2A}$ > the COV for $R_{p0,2B}$. As mentioned in the above paragraph, the result of $E_o < E_a$ is in accordance with $R_{p0,2A} > R_{p0,2B}$.

The second type of 0,2 % proof strength $R_{p0,2C}$ is the quantity determined with high precision, that shall serve only as reference. Its COV has been reported to be 3 %. Care must, however, be taken to ensure an existence of straight portion in the stress-strain curve after the point A in figure 1.

As mentioned in A.1, the percentage elongation after fracture determined by the crosshead method is assessed only as a reference value because a COV of 36 % for elongation has been reported and this variability is too high.