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Measurement uncertainties in mechanical tests on metallic materials — The evaluation of uncertainties in tensile testing

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Foreword

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This document was prepared by Technical Committee ISO/TC 164, *Mechanical testing of metals*, Subcommittee SC 1, *Uniaxial testing*.

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.

Introduction

This document is based on a CEN Workshop Agreement which was issued in 2005 following a trilogy of documents concerned with measurement uncertainties in mechanical tests on metallic materials. The trilogy includes three documents, one concerned with the evaluation of uncertainties in low cycle fatigue testing, one with creep testing and this document focused on tensile testing.

For a meaningful estimate of uncertainty, all primary sources of uncertainty are to be included and their effects are to be properly quantified in the analyses. Reporting and interpreting the results of the calculations is also of utmost importance.

The calculations given in this document only capture the uncertainty associated with the uncertainty of the testing equipment's sensors over a short time scale. The uncertainty of a test result is dependent on much more than the uncertainty of the testing equipment's sensors.

Contributions to uncertainty due to misalignment, long-term environmental effects, and intermittent procedural errors, to name a few, are not included in these analyses. This is demonstrated by the results of the interlaboratory reproducibility in Annex C compared to the example given in Annex B.

A more realistic value of the uncertainty of the properties of material can be estimated using reproducibility data from laboratory intercomparisons involving several laboratories.

Results from reproducibility tests also include contributions to uncertainty from material inhomogeneity, different testing machines, controlling, and processing software together with the influence of different operators.

This document is based on CWA 15261-2[1)] and UNCERT CoP 07[1]. It describes a method for evaluating the uncertainty in tensile test results obtained from a series of tests that are performed in accordance with ISO 3534-3,[2] ISO 5725 series,[3] ISO 6892-1,[4] ISO 6892-2,[5] ISO 9513,[6] ISO Guides 33 and 35[7] and.[8] For a general introduction on the subject of uncertainty in measurement and testing refer to References [12] and [13].

1) Withdrawn

Measurement uncertainties in mechanical tests on metallic materials — The evaluation of uncertainties in tensile testing

1 Scope

This document describes how the evaluation of uncertainties in tensile tests can be obtained from tests at room temperature (ISO 6892-1) or elevated temperature (ISO 6892-2).

This document reports how it can be applied to tests performed at ambient and elevated temperatures under axial loading conditions with a digital acquisition of force and displacement.

NOTE 1 As CWA 15261-2[2)] and UNCERT CoP 07[1] reports, the tests are assumed to run continuously without interruptions on test pieces that have uniform gauge lengths.

NOTE 2 Annex C gives for information an indication of the typical scatter in tensile test results for a variety of materials that have been reported during laboratory inter-comparison exercises.

2 Normative references

There are no normative references in this document.

3 Terms, definitions and symbols

3.1 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminology 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/

3.1.1
coverage factor
number that, when multiplied by the combined standard uncertainty, produces the expanded uncertainty

Note 1 to entry: It is dependent on the confidence level (e.g., 95 % probability). It also depends on the effective degrees of freedom.

3.1.2
level of confidence
probability that the value of the measurand lies within the quoted range of uncertainty

3.1.3
measurand
specific quantity being reported as the measurement result

Note 1 to entry: A measurand can be a direct test reading or an estimate of a material property from other readings

2) Withdrawn

3.1.4
measurement
set of operations having the object of determining a value of the measurand

3.1.5
result
distinction is made between:

3.1.5.1
result of a measurement
value attributed to the measurand, obtained by measurement

3.1.6
standard deviation
positive square root of the variance

3.1.7.1
uncertainty of measurement
parameter, associated with the result of a measurement, that defines the range within which a specific fraction of the distribution of values that could reasonably be attributed to the measurand is estimated to fall (within a given confidence)

3.1.7.2
standard uncertainty
estimated standard deviation or estimated positive square root of the variance

3.1.7.3
expanded uncertainty
value obtained by multiplying the combined standard uncertainty by a coverage factor

3.1.8
variance
measure of the dispersion of a set of *n* measurement results. It is the sum of the squares of the deviations of the measurement results from the average, divided by *n-1*

3.2 Symbols

The symbols used in this document and corresponding designations are given in Table 1.

Table 1 — Symbols and corresponding designations

Symbol	Unit	Designation
a_o	mm	Original thickness of a flat test piece
a_u	mm	Minimum thickness after fracture
b_o	mm	Original width of the parallel length of a flat test piece
b_u	mm	Minimum width after fracture
d_o	mm	Diameter of the parallel length of a circular test piece
d_u	mm	Minimum diameter of a circular test piece after fracture
m_E	MPa	Slope of the elastic part of the stress-extension curve
E	GPa [a]	Young's modulus (modulus of elasticity)
F	N	Force
ΔF	N	Force increment
F_{eH}	N	Force at R_{eH}
F_{eL}	N	Force at R_{eL}

[a] 1 MPa = 1 N/mm²; 1 GPa = 1 kN/mm².

[b] Depends on the property concerned.

Table 1 *(continued)*

Symbol	Unit	Designation
F_p	N	Force at R_p
F_m	N	Maximum force
L_o	mm	Original gauge length
L_e	mm	Extensometer gauge length
L_u	mm	Gauge length after fracture
n	-	Number of readings or results or evaluated data pairs in the linear regression or numerical coefficient NOTE This is also used for other parameters e.g., number of samples in a batch. (See 3.4.2).
R	MPa [a]	Stress
R_{eH}	MPa	Upper yield strength
R_{eL}	MPa	Lower yield strength
R_m	MPa	Tensile strength
R_p	MPa	Proof strength, plastic extension (e.g., 0,2 %, $R_{p0,2}$)
A	%	Percentage elongation after fracture
S_o	mm^2	Original cross-sectional area
S_u	mm^2	Smallest cross-sectional area after fracture
Z	%	Percentage reduction of area after fracture
u	[b]	Standard uncertainty (in general)
$u(x_i)$	[b]	Standard uncertainty on measurement x_i
u_c	[b]	Combined uncertainty (in general)
y	[b]	Test (or measurement) mean result
$u_c(y)$	[b]	Combined uncertainty on the mean result of a measurement
Y	[b]	Evaluated value of the measurand
d_v	-	Divisor associated with the assumed probability distribution
c	[b]	Sensitivity coefficient (in general)
c_i	[b]	Sensitivity coefficient associated with uncertainty on measurement x_i
c_T	[b]	Temperature sensitivity coefficient
x_i	[b]	Individual value
$\overline{x}$	[b]	Arithmetic mean
s	[b]	Sample standard deviation
a , δ	[b]	Mid-point value between the upper and lower limits NOTE Subscripts corresponding to the concerned property, e.g., δ_{ao}.
k, k_p	-	Coverage factor
U	[b]	Expanded uncertainty
ν_{eff}	-	Effective degrees of freedom given by the Welsh-Satterthwaite method
f	-	Degree of freedom (n – 1)
Y	[b]	Evaluated value of the measurand
p	%	Coverage probability; confidence level
t	-	Factor of Student's distribution
m	[b]	Slope of the regression line or strain rate sensitivity NOTE Subscript corresponding to the concerned property, e.g., m_E.

[a] 1 MPa = 1 N/mm^2; 1 GPa = 1 kN/mm^2.

[b] Depends on the property concerned.

Table 1 *(continued)*

Symbol	Unit	Designation
b	[b]	Intercept in the regression line
S_{xy}	[b]	Empirical covariance in the linear regression
S_x	[b]	Standard deviation of x-values in the linear regression
S_y	[b]	Standard deviation of y-values in the linear regression
r	-	Correlation coefficient in the linear regression
S_m	[b]	Standard deviation of the slope of the regression line
S_b	[b]	Standard deviation of the intercept of the regression line
$S_{m(\mathrm{rel})}$	-	Bound regarding the upper and the lower proportional limit for the determination of Young's modulus in the linear regression
ΔL	mm	Displacement increment based on initial gauge length
ΔL_{pl}	mm	Plastic displacement
ΔL_{z}	mm	Calculated zero-point
ΔL_{el}	mm	Elastic displacement
$A_{(a)}$	%	Elongation automatically given by an extensometer
$A_{(m)}$	%	Elongation determined manually
e	-	Strain / extension
$\dot{e}$	s^{-1}	Strain rate
e_{pl}	-	Plastic strain
$e_{(\mathrm{rupt})}$	-	Strain at fracture
$R_{(\mathrm{rupt})}$	MPa	Stress at fracture
$C_{A(m)}$	%	Correction in comparison with the percentage elongation value measured manually
σ	MPa	True stress
ε	-	True plastic strain
$\dot{\varepsilon}$	s^{-1}	True plastic strain rate
m'		Strain rate sensitivity
K'	MPa	Material flow stress at a true strain rate of unity
T	°C	Ambient temperature during testing
n', σ_{yo}, T_1, C_{o}	[b]	Numerical coefficients

[a] 1 MPa = 1 N/mm²; 1 GPa = 1 kN/mm².

[b] Depends on the property concerned.

4 Steps for the evaluation of uncertainty

4.1 General

Figure 1 shows the different steps for the evaluation of uncertainty.

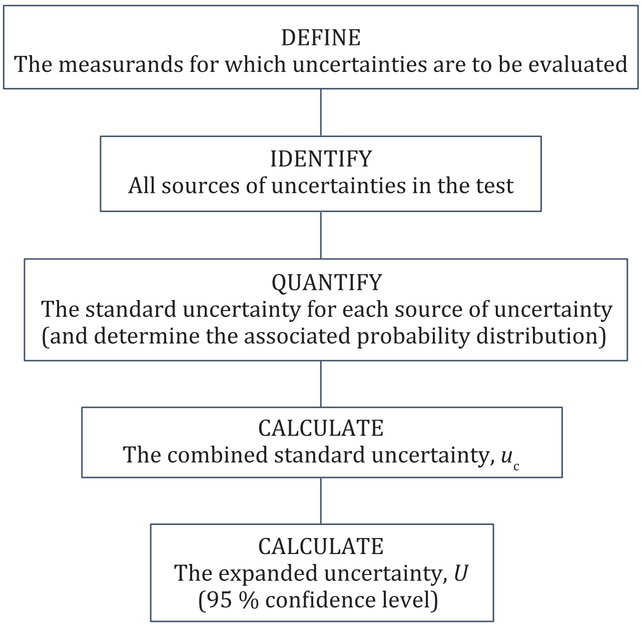

Figure 1 — Steps for the evaluation of uncertainty

4.2 Step 1 — Defining the measurands for which uncertainty is to be evaluated

The measurands (quantities) for which the uncertainties are to be calculated are listed.

Table 2 shows the measurands that can be reported in tensile testing. These measurands are measured directly or are not measured directly and are determined from other quantities (or measurements).

Table 2 — Measurands, measurements and their units and symbols

Measurand	Unit	Symbol
Original cross-sectional area	mm^2	S_o
Slope of the elastic part of the stress-extension curve	MPa	m_E
Proof strength at 0,2 % plastic extension	MPa	$R_{p0,2}$
Upper yield strength	MPa	R_{eH}
Lower yield strength	MPa	R_{eL}
Tensile strength	MPa	R_m
Percentage elongation after fracture	%	A
Percentage reduction of area	%	Z
Test piece original thickness (rectangular test piece)	mm	a_o
Test piece original width (rectangular test piece)	mm	b_o
Test piece original diameter (circular test piece)	mm	d_o
Original gauge length	mm	L_o
Force applied during test	N	F
Axial displacement during the test	mm	ΔL
Final gauge length	mm	L_u
Minimum diameter of a circular test piece after fracture	mm	d_u

[a] The Young's-modulus is not usually reported in tensile testing (only if ISO 6892-1:2019, Annex G is applied).

The measurands not measured are calculated with Formulae (1) to (9):

for rectangular test piece see Formula (1):

$$S_o = a_o \cdot b_o \tag{1}$$

for circular test piece see Formula (2):

$$S_o = d_o^2 \cdot \pi/4 \tag{2}$$

for slope of beginning of stress-extension curve see Formula (3):

$$m_E = \Delta R/\Delta e = (\Delta F \cdot L_o)/(\Delta L \cdot So) \tag{3}$$

for proof strength see Formula (4):

$$R_p = F_p/S_o \tag{4}$$

for upper yield strength see Formula (5):

$$R_{eH} = F_{eH}/S_o \tag{5}$$

for lower yield strength see Formula (6):

$$R_{eL} = F_{eL}/S_o \tag{6}$$

for tensile strength see Formula (7):

$$R_m = F_m/S_o \tag{7}$$

for percentage elongation after fracture see Formula (8):

$$A = (L_u - L_o) \cdot 100/L_o \tag{8}$$

for percentage reduction of area see Formula (9):

$$Z = (S_o - S_u) \cdot 100/S_o \tag{9}$$

4.3 Step 2 — Identifying all sources of uncertainty in the test

All possible sources of uncertainty that can have an effect (either directly or indirectly) on the test are identified.

The list cannot be identified comprehensively beforehand as it is associated uniquely with the individual test procedure and apparatus used. A new list can be prepared each time a particular test parameter changes. To help the user list all sources, four categories have been defined. Table 3 lists these categories and gives some examples of the sources of uncertainty in each category.

