

Technical Report

ISO/TR 15263

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

Incertitudes de mesure dans les essais mécaniques sur matériaux métalliques — Évaluation des incertitudes pour les essais de traction **Document Preview**

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

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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 <u>Annex C</u> compared to the example given in <u>Annex B</u>.

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 $33^{[7]}$ and $35^{[8]}$. For a general introduction on the subject of uncertainty in measurement and testing refer to References [12] and [13].

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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 than a reasonable and since a since a

3.1 Terms and definitions Document Preview

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

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)

3.1.8

standard uncertainty

estimated standard deviation or estimated positive square root of the variance

3.1.9

expanded uncertainty

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

3.1.10

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
$a_{\rm o}$	mm	Original thickness of a flat test piece
$a_{\rm u}$	mm	Minimum thickness after fracture
$b_{\rm o}$	mm	Original width of the parallel length of a flat test piece
b_{u}	mm	Minimum width after fracture
d_{o}	mm	Original diameter of the parallel length of a circular test piece
d_{u}	mm	Minimum diameter of a circular test piece after fracture
$m_{ m E}$	MPa	Slope of the elastic part of the stress-extension curve
Ε	GPa ^a	Young's modulus (modulus of elasticity)
$egin{array}{c ccccccccccccccccccccccccccccccccccc$		
		$F_{ m eH}$
$F_{ m eL}$	N	Force at R _{eL}
$1 \text{ MPa} = 1 \text{ N/mm}^2 \cdot 1 \text{ GPa} = 1 \text{ kN/mm}^2$		

 $^{1 \}text{ MPa} = 1 \text{ N/mm}^2$; $1 \text{ GPa} = 1 \text{ kN/mm}^2$.

Depends on the property concerned.

Table 1 (continued)

numerical coefficient	Symbol	Unit	Designation
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 on numerical coefficient NOTE This is also used for other parameters e.g., number of samples in a bate (See 3.4.2). R MPa Stress R _{eth} MPa Upper yield strength R _m MPa Lower yield strength R _m MPa Proof strength, plastic extension (e.g., 0,2 %, R _{p0,2}) A % Percentage elongation after fracture S _o mm² Original cross-sectional area S _u mm² Smallest cross-sectional area after fracture Z % Percentage reduction of area after fracture Z % Percentage reduction of area after fracture u b Standard uncertainty (in general) u(x _i) b Standard uncertainty (in general) u(x _i) b Test (or measurement) mean result u(x _i) b Evaluated	$F_{\mathfrak{p}}$	N	Force at R _p
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 on unmerical coefficient NOTE This is also used for other parameters e.g., number of samples in a bate (See 3.4.2). R MPa Stress R _{eff} MPa Upper yield strength R _{eff} MPa Lower yield strength R _m MPa Tensile strength R _m MPa Proof strength, plastic extension (e.g., 0,2 %, R _{p0,2}) A % Percentage elongation after fracture S _o mm² Original cross-sectional area S _o mm² Smallest cross-sectional area after fracture Z % Percentage reduction of area after fracture Z % Percentage reduction of area after fracture U(x) b Standard uncertainty (in general) U(x) b Standard uncertainty (in general) U b Combined uncertainty (in general) V _e D Combined uncertainty	F_{m}	N	Maximum force
Lu mm Gauge length after fracture n - Number of readings or results or evaluated data pairs in the linear regression on numerical coefficient NOTE This is also used for other parameters e.g., number of samples in a batc (See 3.4.2). R MPa Stress Rell MPa Upper yield strength Rell MPa Lower yield strength R _m MPa Proof strength, plastic extension (e.g., 0,2 %, R _{p0,2}) A % Percentage elongation after fracture S ₀ mm² Original cross-sectional area S _u mm² Smallest cross-sectional area after fracture Z % Percentage reduction of area after fracture U(x) b Standard uncertainty (in general) U(x) b Standard uncertainty (in general) U(x) b Standard uncertainty (in general) U _c (y) b Combined uncertainty on measurement x _i U _c (y) b Evaluated value of the measurand d _v - Divisor associated with the assumed probability distribution c	i	mm	Original gauge length
Lu mm Gauge length after fracture n - Number of readings or results or evaluated data pairs in the linear regression on numerical coefficient NOTE This is also used for other parameters e.g., number of samples in a bate (See 3.4.2). R MPa Stress Rell MPa Upper yield strength Rm MPa Lower yield strength Rm MPa Proof strength, plastic extension (e.g., 0,2 %, Rp0.2) A % Percentage elongation after fracture So mm² Original cross-sectional area Su mm² Smallest cross-sectional area after fracture Z % Percentage reduction of area after fracture U(x) b Standard uncertainty (in general) U(x) b Standard uncertainty (in general) U(x) b Standard uncertainty (in general) y b Test (or measurement) mean result u_c b Combined uncertainty (in general) y b Evaluated value of the measurand d_v c Divisor associated with the	$L_{\rm e}$	mm	Extensometer gauge length
Number of readings or results or evaluated data pairs in the linear regression on numerical coefficient NOTE This is also used for other parameters e.g., number of samples in a bate (See 3.4.2). R		mm	Gauge length after fracture
$R_{\rm el.}$ MPa Upper yield strength $R_{\rm el.}$ MPa Lower yield strength $R_{\rm m}$ MPa Tensile strength $R_{\rm p}$ MPa Proof strength, plastic extension (e.g., 0,2 %, $R_{\rm p0,2}$) A % Percentage elongation after fracture $S_{\rm o}$ mm² Smallest cross-sectional area $S_{\rm u}$ mm² Smallest cross-sectional area after fracture Z % Percentage reduction of area after fracture Z % Desintage and an acceptance and secure and secure and secure and secure and probability destribution Z Z Desintage and acceptance a		-	NOTE This is also used for other parameters e.g., number of samples in a batch
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	R	MPa ^a	Stress
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	R_{oH}	MPa	Upper 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 ₀ mm² Original cross-sectional area S _u mm² 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 (in general) y b Combined uncertainty (in general) y b Combined uncertainty on the mean result of a measurement y b Combined uncertainty on the mean result of a measurement y c Combined uncertainty on the mean result of a measurement y b Evaluated value of the measurand dv - Divisor associated with the assumed probability distribution c b Sensitivity coefficient (in general) ci b Sensitivity coefficient associated with uncertainty on measurement x _i c _I b Individual value x _i		MPa	
R _p MPa Proof strength, plastic extension (e.g., 0,2 %, R _{p0,2}) A % Percentage elongation after fracture S _o mm² Original cross-sectional area S _u mm² 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 (in general) y b Combined uncertainty (in general) y b Combined uncertainty on the mean result of a measurement u _c (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 _i b Sensitivity coefficient associated with uncertainty on measurement x _i c _i b Individual value x _i b Individual value x _i b Arithmetic mean s b </td <td></td> <td></td> <td>-</td>			-
A % Percentage elongation after fracture S _o mm² Original cross-sectional area S _u mm² Smallest cross-sectional area after fracture Z % Percentage reduction of area after fracture u b Standard uncertainty (in general) u _c 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 x _i b Individual value x _i b Arithmetic mean s b Sample standard deviation a, δ b Mid-point value between the upper and low	T T		
S _o mm² Original cross-sectional area S _u mm² Smallest cross-sectional area after fracture Z % Percentage reduction of area after fracture u b Standard uncertainty (in general) 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 Individual value the assumed probability distribution a, δ b Individual value deviation a, δ b Mid-p			
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$\begin{array}{c} u(x_i) & b \\ u(x_i) & b \\ u_c & b \\ & Combined uncertainty (in general) \\ y & b \\ & Test (or measurement) mean result \\ u_c(y) & b \\ & Combined uncertainty on the mean result of a measurement \\ Y & b \\ & Evaluated value of the measurand \\ d_v & - Divisor associated with the assumed probability distribution \\ c & b \\ & Sensitivity coefficient (in general) \\ & C_i & b \\ & Sensitivity coefficient associated with uncertainty on measurement x_i x_i & b \\ & Individual value \\ \hline x_i & b \\ & Individual value \\ \hline x_i & b \\ & Arithmetic mean \\ & S & b \\ & Sample standard deviation \\ & A, \delta & b \\ & Mid-point value between the upper and lower limits \\ & NOTE & Subscripts corresponding to the concerned property, e.g., \delta_{ao}. k, k_p - Coverage factor \\ U & b & Expanded uncertainty \\ \hline v_{eff} & - Effective degrees of freedom given by the Welsh-Satterthwaite method \\ f & - Degree of freedom (n-1) Y Y Y Y Y Y Y Y Y Y$			-
$\begin{array}{c} u_c \\ u_c \\ v \\ v \\ b \\ \end{array} \begin{array}{c} b \\ \end{array} \begin{array}{c} \text{Combined uncertainty (in general)} \\ y \\ u_c(y) \\ \end{array} \begin{array}{c} b \\ \end{array} \begin{array}{c} \text{Test (or measurement) mean result} \\ \end{array} \\ u_c(y) \\ \end{array} \begin{array}{c} b \\ \end{array} \begin{array}{c} \text{Combined uncertainty on the mean result of a measurement} \\ \end{array} \\ V \\ b \\ \end{array} \begin{array}{c} b \\ \end{array} \begin{array}{c} \text{Evaluated value of the measurand} \\ \end{array} \\ d_v \\ \end{array} \begin{array}{c} - \\ \end{array} \begin{array}{c} Divisor associated with the assumed probability distribution \\ \end{array} \\ c \\ c \\ \end{array} \begin{array}{c} b \\ \end{array} \begin{array}{c} \text{Sensitivity coefficient (in general)} \\ \end{array} \\ \end{array} \begin{array}{c} C_t \\ \end{array} \begin{array}{c} D_t \\ $			
$\begin{array}{c} x_{\rm c} \\ y \\ y \\ b \\ combined uncertainty (in general) \\ x_{\rm c}(y) \\ b \\ combined uncertainty on the mean result of a measurement \\ y \\ b \\ combined uncertainty on the mean result of a measurement \\ y \\ c \\ c$			
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	$u_{\rm c}$	(h	
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$\begin{array}{cccccccccccccccccccccccccccccccccccc$	+		
$ \begin{array}{c ccccccccccccccccccccccccccccccccccc$	Y	b	Evaluated value of the measurand
$ c_i \\ c_i$	$d_{ m v}$	-	Divisor associated with the assumed probability distribution
Temperature sensitivity coefficient x_i b Individual value Arithmetic mean a , δ 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 b Expanded uncertainty v_{eff} b Effective degrees of freedom given by the Welsh-Satterthwaite method f Degree of freedom $(n-1)$ Y b Evaluated value of the measurand f Coverage probability; confidence level f Factor of Student's distribution f Slope of the regression line or strain rate sensitivity NOTE Subscript corresponding to the concerned property, e.g., m_E .	С	b	Sensitivity coefficient (in general)
$\begin{array}{c ccccccccccccccccccccccccccccccccccc$	c_i	ds.iteh.a/catalog	Sensitivity coefficient associated with uncertainty on measurement $x_i^{20.5-20.2}$
$\begin{array}{c ccccccccccccccccccccccccccccccccccc$	c_{T}	b	Temperature sensitivity coefficient
$\begin{array}{c ccccccccccccccccccccccccccccccccccc$		b	Individual value
$\begin{array}{c ccccccccccccccccccccccccccccccccccc$	-	b	Arithmetic mean
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 v_{eff} - Effective degrees of freedom given by the Welsh-Satterthwaite method f - Degree of freedom $(n-1)$ Y v v v v v v v		b	Sample standard deviation
U b Expanded uncertainty v_{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 .		b	Mid-point value between the upper and lower limits
$\begin{array}{c ccccccccccccccccccccccccccccccccccc$	k, k _p	-	Coverage factor
For a Degree of freedom (n - 1) Y	U	b	Expanded uncertainty
For a Degree of freedom (n - 1) Y	$ u_{ m eff}$	-	Effective degrees of freedom given by the Welsh-Satterthwaite method
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 .		-	
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t - Factor of Student's distribution m - Slope of the regression line or strain rate sensitivity NOTE Subscript corresponding to the concerned property, e.g., m _E .		%	
m Slope of the regression line or strain rate sensitivity NOTE Subscript corresponding to the concerned property, e.g., $m_{\rm E}$.		-	
	-	b	Slope of the regression line or strain rate sensitivity
		l.	

Table 1 (continued)

Symbol	Unit	Designation
S_{xy}	b	Empirical covariance in the linear regression
S_{x}	b	Standard deviation of x-values in the linear regression
S_{ν}	b	Standard deviation of <i>y</i> -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
$S_{m(rel)}$	-	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
$\Delta L_{ m pl}$	mm	Plastic displacement
$\Delta L_{ m z}$	mm	Calculated zero-point
$\Delta L_{ m el}$	mm	Elastic displacement
$A_{(a)}$	%	Elongation automatically given by an extensometer
$A_{(m)}$	%	Elongation determined manually
е	-	Strain / extension
ė	s ⁻¹	Strain rate
$e_{ m pl}$	-	Plastic strain
$e_{ m (rupt)}$	-	Strain at fracture
R _(rupt)	MPa	Stress at fracture Standards
$C_{A(m)}$	%	Correction in comparison with the percentage elongation value measured manually
σ	MPa	True stress
ε	-	True plastic strain and Provide
Ė	s-1	True plastic strain rate
m′		Strain rate sensitivity
K'	MPa	Material flow stress at a true strain rate of unity
	°C	Ambient temperature during testing
n' , σ_{yo} , T_1 , C_o	b	Numerical coefficients
a 1 MPa = 1 N/r	mm ² ; 1 GPa = 1 kN	/mm ² .

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.

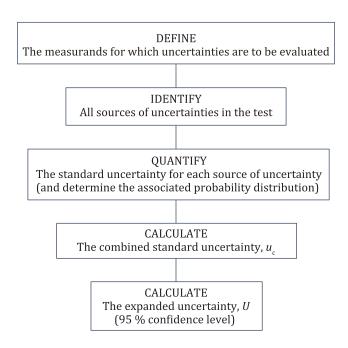


Figure 1 — Steps for the evaluation of uncertainty

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

IInit Symbol Measurand

Measurand	Unit	Symbol
Original cross-sectional area	mm ²	So
Slope of the elastic part of the stress-extension curve 7/4-000c-40	MPa MPa MPa	so-tr-15263-2024 m _E
Proof strength at 0,2 % plastic extension	MPa	$R_{p0,2}$
Upper yield strength	MPa	$R_{ m eH}$
Lower yield strength	MPa	$R_{ m eL}$
Tensile strength	MPa	R _m
Percentage elongation after fracture	%	A
Percentage reduction of area	%	Z
Test piece original thickness (rectangular test piece)	mm	$a_{\rm o}$
Test piece original width (rectangular test piece)	mm	$b_{\rm o}$
Test piece original diameter (circular test piece)	mm	d_{o}
Original gauge length	mm	$L_{\rm o}$
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 ap	plied).

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

for rectangular test piece see Formula (1):

$$S_0 = a_0 \cdot b_0 \tag{1}$$

for circular test piece see Formula (2):

$$S_0 = d_0^2 \cdot \pi/4 \tag{2}$$

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

$$m_{\rm E} = \Delta R/\Delta e = (\Delta F \cdot L_{\rm o})/(\Delta L \cdot S_{\rm o}) \tag{3}$$

for proof strength see Formula (4):

$$R_{\rm p} = F_{\rm p}/S_{\rm o} \tag{4}$$

for upper yield strength see Formula (5):

$$R_{\rm eH} = F_{\rm eH}/S_{\rm o} \tag{5}$$

for lower yield strength see <a>Formula (6):

$$R_{\rm eL} = F_{\rm eL}/S_{\rm o} \tag{6}$$

for tensile strength see Formula (7): / standards.iteh.ai)

$$R_{\rm m} = F_{\rm m}/S_{\rm o} \tag{7}$$

for percentage elongation after fracture see Formula (8):

$$A = (L_{\rm u} - L_{\rm o}) \cdot 100/L_{\rm o}$$
(8)

for percentage reduction of area see Formula (9):

$$Z = (S_0 - S_u) \cdot 100/S_0 \tag{9}$$

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. <u>Table 3</u> lists these categories and gives some examples of the sources of uncertainty in each category.