Manual of Codes of Practice for the Determination of Uncertainties in Mechanical Tests on Metallic Materials

Code of Practice No. 08

The Determination of Uncertainties in Compression Testing

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1. SCOPE

This procedure covers the evaluation of uncertainty in Young's modulus E and yield strength $R_{0.2}$ in compression testing on metallic materials, according to the following standard practices.

> ASTM E9-89a,*"Compression Testing on Metallic Materials at Room Temperature"*
> ASTM E111-82 (Reap. 88), *"Standard Test Method for Young's, Tangent and Chord Modulus"*

The procedure is restricted to tests performed continuously without interruptions under axial loading conditions, at room temperature with a digital acquisition of load and strain.

2. SYMBOLS AND DEFINITIONS

For a complete list of symbols and definitions of terms on uncertainties, see Reference 1, Section 2. The following are the symbols and definitions used in this procedure.

Symbol	Evaluated Quantity
A_0	Original cross-sectional area of the parallel length
c_i	Sensitivity coefficient associated with the uncertainty on measurement x_i
d	Minimum diameter during test
d_0	Original diameter of the parallel length of a cylindrical test-piece
d_v	Divisor associated with the assumed probability distribution
E	Young's Modulus of elasticity
E_t	Tangent modulus
k	Coverage factor used to calculate expanded uncertainty
K	number of (X,Y) datapairs
l_0	Original gauge length
L_0	Theoretical gauge length (distance between extensometer knives)
l_0'	Actual length with an extensometer angular mispositionning α
n	Number of repeated measurements
N	Number of measurands
p	Confidence Level
P	Load
$R_{p0.2}$	Proof strength, non-proportional elongation
U	Expanded uncertainty
$U(x_i)$	Standard uncertainty
u_A	Standard uncertainty on cross-sectional area
$u_c(y)$	Combined uncertainty on the mean result y of a measurand
$u_{CalClass}$	Standard uncertainty on diameter deduced from the caliper class

$u_{Caliper}$	Standard uncertainty on caliper data
u_{Cell}	Standard uncertainty on load cell data
$u_{CellClass}$	Standard uncertainty on load deduced from the load cell class
U_E	Expanded uncertainty on E
u_{Em}	Uncertainty on E due to the measures of ΔP, A_0, ΔL, l_0
$u_{ExtClass}$	Standard uncertainty on strain deduced from extensometer class
$u_{Extenso}$	Standard uncertainty on extensometer data
u_{El}	Lower bound of E's uncertainty interval
u_p	Standard uncertainty on load
$U_{Rp0.2}$	Expanded uncertainty on $Rp_{0.2}$
u_{Eu}	Upper bound of E's uncertainty interval
U_α	Uncertainty on the extensometer angular positioning
U_σ	Standard uncertainty on Stress
V	Value of a measurand
V_1	Graphical coefficient of variation
X	strain corresponding to Y
Y	Applied axial stress
y	Test (or measurement) mean value
ΔL	Elongation increment
ΔP	Load increment
α	Extensometer angular mispositioning
ε	Strain
σ	Stress

3. INTRODUCTION

It is good practice with any measurement to evaluate and report the uncertainty associated with the test results. A statement of uncertainty may be required by a customer who wishes to know the limits within which the reported result may be assumed to lie, or the test laboratory itself may wish to develop a better understanding of which particular aspects of the test procedure have the greatest effects on results so that this may be controlled more closely. This Code of Practice has been prepared within UNCERT, a project partially funded by the European Commission's Standards, Measurement and Testing program under reference SMT4-CT97-2165 to simplify the way in which uncertainties are evaluated. The aim is to produce a series of documents in a common format which is easily understood and accessible to customers, test laboratories and accessible to customers, test laboratories and accreditation authorities.

This Code of Practice is one of seventeen produced by the UNCERT consortium for the estimation of uncertainties associated with mechanical tests on metallic materials. Reference 1 is divided into 6 sections as follows, with all the individual CoPs included in Section 6 :

1. Introduction to the evaluation of uncertainty.
2. Glossary of definitions and symbols.
3. Typical sources of uncertainty in materials testing.
4. Guidelines for the estimation of uncertainty for a test series.
5. Guidelines for reporting uncertainty.
6. Individual Codes of Practice (of which this is one) for the estimation of uncertainties in mechanical tests on metallic materials.

This CoP can be used as a stand-alone document. For further background information on the measurement uncertainty and values of standard uncertainties of the equipment and instrumentation used commonly in material testing, the user may need to refer to Section 3 in Reference 1. The individual CoPs are kept as simple as possible by following the same structure:

- The main procedure.
- Quantifying the major contributions to the uncertainty for that test type (Appendix A)
- A worked example (Appendix B)

This CoP guides the user through the various steps to be carried in order to estimate the uncertainty in **Young's modulus and Proof Strength in compression testing.**

4. A PROCEDURE FOR THE ESTIMATING THE UNCERTAINTY IN COMPRESSION TESTING

Step 1. Identifying the Parameters for Which Uncertainty is to be Estimated

The first step is to list the quantities (measurands) for which uncertainties must be calculated. Table 1 shows the parameters that are usually reported in uni-axial compression testing. These measurands are not measured directly but are determined from other quantities (or measurements).

Table 1. Measurands, measurements, their units and symbols

Measurands	**Units**	**Symbol**
Proof strength, non-proportional elongation	MPa	$R_{p0.2}$
Modulus of elasticity	GPa	E
Measurements	**Units**	**Symbol**
Specimen original diameter	mm	d_0
Specimen original gauge length	mm	l_0
Load applied during test	kN	P
Strain		ε

Step 2. Identifying all sources of uncertainty in the test

In step 2, the user must identify all possible sources of uncertainty which may have an effect (either directly or indirectly) on the test. The list cannot be identified comprehensively beforehand as it is associated uniquely with the individual test procedure and the apparatus used. This means that a new list should be prepared each time a particular test parameter changes (for example when a plotter is replaced by a computer).

To help the user list all sources of uncertainty, 5 categories have been defined. The following table (Table 2) lists the 5 categories and gives some examples of sources of uncertainty in each category.

It is important to note that Table 2 is NOT exhaustive and is for GUIDANCE only - relative contributions may vary according to the material tested and the test conditions. Individual laboratories are encouraged to draft their own lists corresponding to their own test facilities and assess the associated significance of the contributions.

Table 2. Typical sources of uncertainty and their likely contribution to uncertainties on compression test measurand
[1 = major contribution, 2 = minor contribution]

Source	**Type**	**E**	$R_{p0.2}$
Test Instruments			
Load Cell		1	1
Extensometer		1	1
Caliper		1	influence through E
Tooling alignment		2	influence through E
Test Method			
Formula (decimals)		2	2
Sampling rate		2	2
Crosshead speed		2	2
Test Environment			
Temperature		2	2
Operator			
Choice of limits on graph		1	influence through E
Extensometer angular positioning		1	influence through E
Specimen			
Original Gauge Length		1	influence through E
Tolerance of shape		2	2
Parallelism		2	2
Cylindricity		2	2
Surface finish		2	2
Measurands			
E		-	1

Step 3. Classifying the Sources of Uncertainty According to Type A or B

In this third step, which is in accordance with Reference 2, *'Guide to the Expression of Uncertainties in Measurement'*, the sources of uncertainty are classified as Type A or B, depending on the way their influence is quantified. If the uncertainty is evaluated by statistical means (from a number of repeated observations), it is classified Type A. If it is evaluated by any other means it should be classified as Type B.

The values associated with Type B uncertainties can be obtained from a number of sources including a calibration certificate, manufacturer's information, an expert's estimation or any other mean of evaluation. For Type B sources, it is necessary for the user to estimate for each source the most appropriate probability distribution (further details are given in Section 2 of Reference 1).

It should be noted that, in some cases, an uncertainty can be classified as either Type A or B depending on how it is estimated. Table 3 (see step 6) contains an example where, if the diameter of a cylindrical specimen is measured once, that uncertainty is considered Type B. If the mean value of two or more consecutive measurements is taken into account, then the influence is Type A.

Step 4. Estimating the standard uncertainty for each source of uncertainty

In this step the standard uncertainty, u, for each input source is estimated (see Appendix A). The standard uncertainty is defined as one standard deviation on a normal distribution and is derived from the uncertainty of the input quantity by dividing by the parameter d_v, associated with the assumed probability distribution. The divisors for the typical distributions most likely to be encountered are given in Section 2 of Reference 1.

In many cases the input quantity to the measurement may not be in the same units as the output quantity. For example, one contribution to $R_{p0.2}$ is the test temperature. In this case the input quantity is temperature, but the output quantity is stress. In such a case, a sensitivity coefficient (corresponding to the partial derivative of the $R_{p0.2}$/Test temperature relationship) is used to convert from temperature to stress (for more information, see Appendix A).

The significant sources of uncertainty and their influence on the evaluated quantities are summarized in Tables 3 and 4 (see step 6). These tables are structured in the following way:

Column 1: Sources of uncertainty
Column 2: Measurands affected by each source
Column 3: Value obtained in actual testing or nominal value
Column 4: Uncertainty in measurands. There are two types :
(1) Range allowed according to the test standard
(2) Maximum Range between measures made by several skilled operators

Column 5: Type of uncertainty
Column 6: Assumed probability distribution (Type A always Normal)
Column 7: Correction factor d_v for Type B sources
Column 8: Sensitivity coefficient c_i associated with the uncertainty on the measurement x_i
Column 9: Measurand standard uncertainty produced by the input quantity uncertainty. This figure is obtained by two different ways:

1. If the influence of the source on the measurand is directly proportional *(the numbers are the column numbers in Tables 3 and 4):*

$$9 = 3 \text{ x } 4 \text{ x } 7 \text{ x } 8$$

2. If the influence is not directly proportional:

$$9 = [u(X_{imax}) - u(X_{imin})] \text{ x } 7 \text{ x } 8$$

Step 5. Computing the Measurand's Combined Uncertainty u_c

Assuming that individual uncertainty sources are uncorrelated, the measurand's combined uncertainty, $u_c(y)$, can be computed using the root sum squares :

$$u_c(y) = \sqrt{\sum_{i=1}^{N} [c_i \cdot u(x_i)]^2} \qquad \textbf{(1a)}$$

$$\text{with} \quad c_i = \frac{\partial Y}{\partial x_i} \qquad \textbf{(1b)}$$

where c_i is the sensitivity coefficient associated with x_i. This uncertainty corresponds to plus or minus one standard deviation on the normal distribution law representing the studied quantity. The combined uncertainty has an associated confidence level of 68.27%.

Step 6. Computing the Expanded Uncertainty U

The expanded uncertainty U is defined in Reference 2 as "the interval about the result of a measurement that may be expected to encompass a large fraction of the distribution of values that could **reasonably** be attributed to the measurand". It is obtained by multiplying the combined uncertainty u_c by a coverage factor k that is selected on the basis of the level of confidence required. For a normal probability distribution, the most generally used coverage factor is 2 , which corresponds to a confidence interval of 95.4% (effectively 95% for most practical purposes). The expanded uncertainty U is, therefore, broader than the combined uncertainty u_c. Where a higher confidence level is demanded by the customer (such as for aerospace and electronics industries), a coverage factor k of 3 is often used so that the corresponding confidence level increases to 99.73%.

In cases where the probability distribution of u_c is not normal (or where the number of data points used in Type A analysis is small), the value of the coverage factor k should be calculated from the degrees of freedom given by the Welsh-Satterthwaite method (see Reference 1, Section 4 for more details).

Table 3a. Typical Worksheet for Uncertainty Budget Calculations For Estimating the Uncertainty in Young's Modulus E in Compression Testing

Column No. 1	2	3	4	5	6	7	8	9
Sources of uncertainty (xi)	**Measurand (Xi)**		**Uncertainties**					
	Measurand affected	**Nominal or average value**	**Uncertainty in measurement**	**Type**	**Probability Distribution**	**Divisor dv**	**Ci**	**u(Xi)**
Apparatus								
Load Cell	P	(KN)		B	Rectangular	sqrt(3)	$\frac{l_0}{A_0 \Delta L}$	u(Cell)
Extensometer	ε	(mm)		B	Rectangular	sqrt(3)	$\frac{\Delta P l_0}{A_0 \Delta L^2}$	u(ext)
Calliper	do	(mm)		B	Rectangular	sqrt(3)	$-8\frac{\Delta P l_0}{p d_0^3 \Delta L}$	u(cal)
Operator								
Manual choice of regression limits on graph	P	(KN)		A	Normal	1	1	u(reg)
Manual extensometer angular positionning	ε	(mm)		A	Normal	1	1	u(ang)
Specimen								
Original gauge length	lo	(mm)		A	Normal	1	1	u(gl)
Combined Standard Uncertainty					Normal			uc
Expanded Uncertainty					Normal			UE

Table 3b. Typical Worksheet for Uncertainty Budget Calculations For Estimating the Uncertainty in Proof Strength in Compression Testing

Column No. 1	2	3	4	5	6	7	8	9
Sources of uncertainty (xi)	**Measurand (Xi)**		**Uncertainties**					
	Measurand affected	**Nominal or average value**	**Uncertainty in measurement**	**Type**	**Probability Distribution**	**Divisor dv**	**Ci**	**u(Xi)**
Apparatus								
Load Cell	P	(KN)		B	Rectangular	sqrt(3)	1	u(Cell)
Extensometer	ε	(mm)		B	Rectangular	sqrt(3)	1	u(ext)
Young's Modulus E	Rp0,2	(Mpa)		B	Normal	1	1	u(mod)
Combined Standard Uncertainty					Normal			uc
Expanded Uncertainty					Normal			URp0,2

Tables 3a and 3b show the recommended format of the calculation worksheet for estimating the uncertainty in Young's Modulus E and Proof Strength $R_{p0.2}$ for a cylindrical test piece (the most common geometry). Appendix A presents the mathematical formulae for calculating uncertainty contributions and Appendix B gives a worked example.

Step 7. Reporting of Results

Once the expanded uncertainty has been estimated, the results should be reported in the following way:

$$V = y \pm U$$

> *The reported expanded uncertainty is based on a standard uncertainty multiplied by a coverage factor, k = 2, which for a normal distribution corresponds to a coverage probability p of approximately 95%. The uncertainty evaluation was carried out in accordance with UNCERT CoP 08: 2000.*

where V is the estimated value of the measurand
y is the test (or measurement) mean result
U is the expanded uncertainty associated with y
p is the confidence level

5. REFERENCES

1. *Manual of Codes of Practice for the determination of uncertainties in mechanical tests on metallic materials*. Project UNCERT, EU Contract SMT4-CT97-2165, Standards Measurement & Testing Programme, ISBN 0-946754-41-1, Issue 1, September 2000.

2. BIPM, IEC, IFCC, ISO, IUPAC, OIML, *"Guide to the Expression of Uncertainty in Measurement"*, International Standardization Organization, Geneva, Switzerland, ISBN 92-67-10188-9, First Edition, 1993. [This Guide is often referred to as the GUM or the ISO TAG4 document].

3. ASTM E9-89a (Reapproved 1995): *"Standard Test Methods of Compression Testing of Metallic Materials at Room Temperature"*, American Society for Testing and Materials, May 1989.

Appendix A

Aspects and Mathematical Formulae for Calculating Uncertainties in Compression Testing at room temperature

Young's Modulus E

ASTM E111 states: "For most loading systems and test specimens, effects of backlash, specimen curvature, initial grip alignment, etc., introduce significant errors in the extensometer output when applying a small load to the test specimen. Measurements should therefore be made from a preload, known to be high enough to minimize these effects, to some higher load, still within either the proportional limit or elastic limit of the material."

The value for Young's modulus may be obtained by determining the slope of the line of the load extension plot below the proportional limit. Young's modulus is calculated from the load increment and corresponding extension increment, between two points on the line as far apart as possible, by use of the following equation:

$$E = \left(\frac{\Delta P}{A_0}\right) \Big/ \left(\frac{\Delta L}{l_0}\right) \quad (1)$$

where :
ΔP = load increment on the segment considered
A_0 = original cross-section
ΔL = extension increment on the segment considered
l_0 = original gauge length

Uncertainty in Young's Modulus due to the measurement of ΔP, A_0, ΔL, l_0

$$u_{E_m} = \sqrt{\left(\frac{\partial E}{\partial \Delta P}\right)^2 u_{\Delta P}{}^2 + \left(\frac{\partial E}{\partial l_0}\right)^2 u_{l_0}{}^2 + \left(\frac{\partial E}{\partial \Delta L}\right)^2 u_{\Delta L}{}^2 + \left(\frac{\partial E}{\partial A_o}\right)^2 u_{A_0}{}^2} \quad (2)$$

$$u_{E_m} = \sqrt{\left(\frac{l_0}{A_0 \Delta L}\right)^2 u_{\Delta P}{}^2 + \left(\frac{\Delta P}{A_0 \Delta L}\right)^2 u_{l_0}{}^2 + \left(\frac{\Delta P l_0}{A_0 \Delta L^2}\right)^2 u_{\Delta L}{}^2 + \left(\frac{\Delta P l_0}{A_0^2 \Delta L}\right)^2 u_{A_0}{}^2} \quad (3)$$

Uncertainty in Young's Modulus due to stress variation

$$s = P/A \quad (4)$$

leads to :

$$u_s = \sqrt{u_P^2 + u_A^2} = \sqrt{u_{Cell}^2 + u_{Caliper}^2} \quad (5)$$

for a cylindrical specimen where only one caliper measurement is made (diameter of the calibrated length),

or

$$u_s = \sqrt{u_P^2 + u_A^2} = \sqrt{u_{Cell}^2 + 2u_{Caliper}^2} \quad \mathbf{(6)}$$

for a rectangular specimen where two measures are made (width and thickness of the calibrated length), with

$$u_{Cell} = \sqrt{u_{CellClass}^2} \quad \mathbf{(7)}$$

and

$$u_{Caliper} = \sqrt{u_{CalClass}^2} \quad \mathbf{(8)}$$

Other major contributions to the uncertainty. (see Table 2)

Load Cell:

u_{Cell} (see calculation above)

Extensometer:

$$u_{Extenso} = \sqrt{u_{ExtensoClass}^2} \quad \mathbf{(9)}$$

Caliper:

$u_{Caliper}$ (see calculation above)

Extensometer angular positioning: the length l_0' measured with and angular mispositioning α is $l_0' = L_0(1-\cos\alpha)$. The error due to that mispositioning is $(1-\cos\alpha)$. The uncertainty u_{ExPos} is directly linked to α : $u_{ExPos} = \sin\alpha \approx \alpha$ when α is small (in radians) and considered within a rectangular distribution.

Choice of limits (software or manual): If the load/extension data is obtained in numerical form, the errors that may be introduced by plotting the data and fitting a straight line graphically to the experimental points can be reduced by calculating the Young's modulus from the slope of the straight line fitted to the appropriate data by the method of least squares.

In this case, the equation for Young's modulus fitted by the method of least squares (all data pairs having equal weight) is:

$$E = \left(\Sigma(XY) - K\overline{X}\overline{Y}\right) / \left(\Sigma X^2 - K\overline{X}^2\right) \quad \mathbf{(10)}$$

Where:
Y = applied axial stress
X = corresponding strain
K = number of (X, Y) data pairs

Σ = sum from 1 to K.

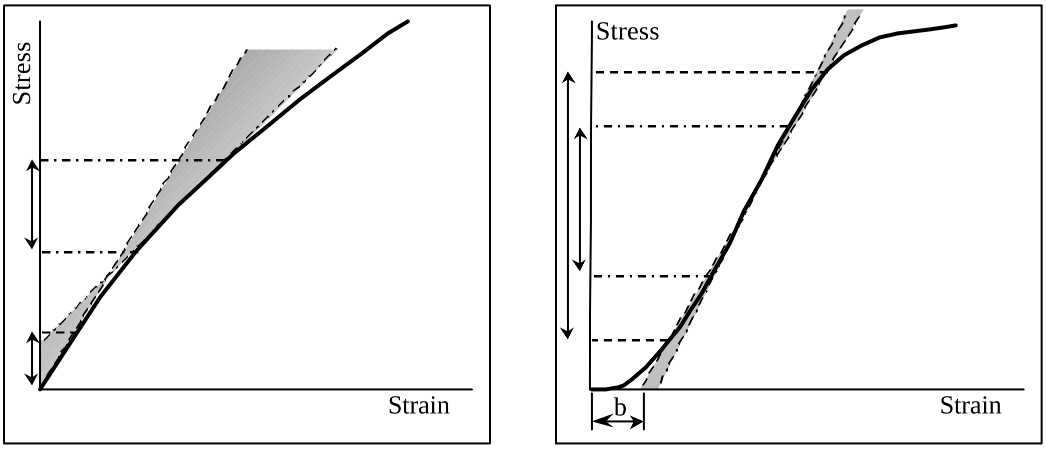
$$X = \frac{\Delta L}{l_0} \tag{11}$$

$$Y = \frac{\Delta L}{A_0} \tag{12}$$

$$\overline{X} = \frac{\Sigma X}{K} = \text{average of X values} \tag{13}$$

$$\overline{Y} = \frac{\Sigma Y}{K} = \text{average of Y values} \tag{14}$$

The Young's modulus calculated in this way depends on the quality of the data used in the fitting, especially when the curve has no linear segment, or if the foot of the curve is non-linear (see following figures). The value for Young's modulus is thus directly linked to the algorithm (software) determining the linear segment from which the calculation is made.



Non-linear curve :
E depends on the segment considered

Non-linear foot of the curve :
E depends on the segment considered

Fig. 1 How E depends on the segment of the stress strain curve considered.

The coefficient of determination r^2 indicates the closeness of the fit and is defined as follows:

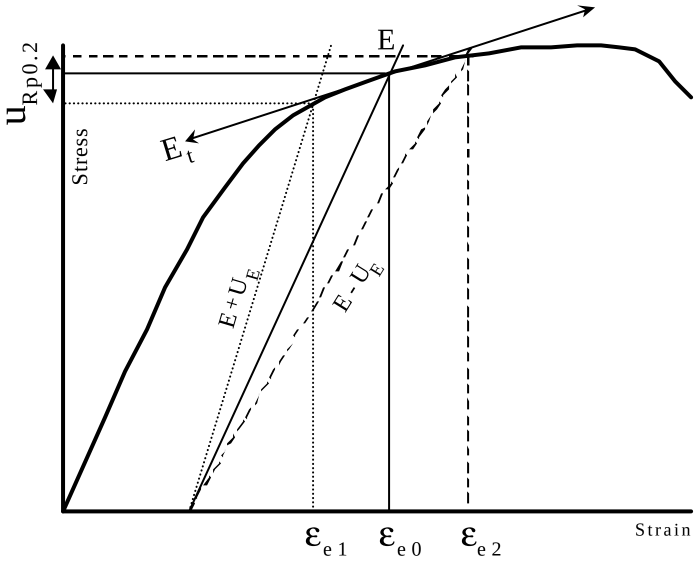
$$r^2 = \left(\left[\Sigma XY - \frac{\Sigma X \; \Sigma Y}{K} \right]^2 \right) \Bigg/ \left(\left[\Sigma X^2 - \frac{(\Sigma X)^2}{K} \right] \left[\Sigma Y^2 - \frac{(\Sigma Y)^2}{K} \right] \right) \tag{15}$$

and values close to 1.00 are desirable.

A coefficient of variation V_1 can be assigned to the slope as follows:

$$V_1 = 100 \times \sqrt{\frac{\frac{1}{r^2} - 1}{K - 2}} \tag{16}$$

V_1 can be considered as a Type A standard uncertainty for Young's modulus.



Estimation of the uncertainty on $R_{p0.2}$ by the tangent modulus

Fig. 2 Estimation of uncertainty using the tangent modulus

Combined Uncertainty on Young's Modulus

$$u_c(E) = \sqrt{u_{E_m}^2 + u_{Extenso}^2 + u_{Caliper}^2 + u_a^2 + V_1^2} \quad \textbf{(17)}$$

Expanded Uncertainty U_E on Young's Modulus

$U_E = k.u_c(E)$ with k depending on the desired level of confidence (k=2 for 95% confidence)

Uncertainty on Proof Stress $Rp_{0.2}$

The uncertainty on $Rp_{0.2}$ depends on the uncertainty on the Young's modulus in the following way.

The tangent modulus E_t is calculated from a reasonable number of data pairs depending on the acquisition rate.

The distribution of $R_{p0.2}$ depending on Young's modulus and must be calculated in two steps:

Upper limit u_{Eu}

$$u_{Eu} = \frac{(e_{e2} - e_{e0})E_t}{R_{p0.2}} \times 100 \quad \textbf{(18)}$$

$$u_{Eu} = \frac{\left(\frac{R_{0.2}}{E - U_{Ee}} - \frac{R_{0.2}}{E}\right)E_t}{R_{p0.2}} \times 100 \qquad (19)$$

Lower limit u_{El}

$$u_{El} = \frac{(e_{e0} - e_{e1})E_t}{R_{p0.2}} \times 100 \qquad (20)$$

$$u_{El} = \frac{\left(\frac{R_{p0.2}}{E - U_E} - \frac{R_{p0.2}}{E}\right)E_t}{R_{p0.2}} \times 100 \qquad (21)$$

Uncertainties linked to the sources considered of major contribution in Table 2.

The considered sources of uncertainty are: U_{Cell} and $U_{extenso}$

Combined uncertainty $u_{C(Rp0,2)}$ on Proof Stress

$$u_C\left(Rp_{0,2}\right) = \sqrt{\left(\frac{u_{Eu} + u_{El}}{2}\right)^2 + u_{Extenso}^2 + u_{Cell}^2} \qquad (22)$$

Expanded Uncertainty $U_{Rp0.2}$ on Proof Strength

$U_{Rp0.2} = k.u_C\left(Rp_{0,2}\right)$ with k depending on the desired level of confidence (k=2 for 95% confidence)

Appendix B

A Worked Example for Calculating Uncertainties in Compression Testing

B1. Introduction

A customer asked the testing laboratory to carry out a compression test on a 7000 series aluminum specimen, using a 25mm long 30mm diameter cylindrical test pieces according to the ASTM E9-89 Standard. The laboratory has considered the sources of uncertainty in its test facility and has found that the sources of uncertainty in the compression tests are identical to those described in Table 2 of the Main Procedure.

B2. Estimation of Input Quantities to the Uncertainty Analysis

1 All tests were carried out according to the laboratory's own written procedure using appropriately calibrated compression test facility and ancillary measurement instruments. The test facility was located in a temperature-controlled environment (21±2^{o}C).

2 The diameter of each specimen was measured using a calibrated digital micrometer with an accuracy of ± 0.002 mm and a resolution of ±0.001 mm. Five readings were taken, including three at 120 degrees intervals at the center of the specimen and two readings at locations near the ends of its parallel length.

3 The tests were carried out on a Class 1.0 machine.

4 The axial strain was measured using a calibrated Class 0.5 single-sided extensometer with a nominal gauge length of 12.0 mm.

5 The error in the extensometer gauge length (due to resetting of extensometer reading at the beginning of each test) was estimated to be ± 0.030 mm (equivalent to ± 0.25% strain).

B3. Example for Uncertainty Calculations and Reporting of Results

Table B1 lists the input quantities used to produce Table B2, the uncertainty budget for estimating the uncertainty in E and in $R_{p0.2}$.

Table B1. Input Quantities Used for Producing Tables B2 and B3

Quantity	Symbol	Values	Mean	standard deviation
Applied Load	P	± 1%		
Strain	ε	± 0,5%		
Specimen original diameter	d_0	± 0.02mm		
Specimen original gauge length	l_0	± 0.03mm		
Angle(Specimen/Extenso)	α	± 1°		
Load range used for E	ΔP	± 1%		
Elongation range used for E	ΔL	± 0.5%		

Table B2. Uncertainty Budget For Estimating the Uncertainty in Young's Modulus E in compression testing at room temperature

Column No. 1	2	3	4	5	6	7	8	9
Sources of uncertainty (xi)	Measurment (Xi)		Uncertainties					
	Measurment affected	Nominal or average value	Uncertainty in measurement	Type	Probability Distribution	Divisor dv	Ci	u(Xi)
Apparatus								
Load Cell	P	(KN)	1%	B	Rectangular	$\sqrt{3}$	4.091	0.07%
Extensometer	ε	(mm)	0.50%	B	Rectangular	$\sqrt{3}$	404.66	3.50%
Calliper	do	(mm)	negl	B	Rectangular	$\sqrt{3}$	0.219	negl
Operator								
Manual choice of regression limits on graph	P	(KN)	4%	A	Normal	1	1	4%
Manual extensometer angular positionning	ε	(mm)	1deg	A	Normal	1	1	1%
Specimen								
Original gauge length	lo	(mm)	0,03mm	A	Normal	1	1	0.03%
Combined Standard Uncertainty					Normal			5.41%
Expanded Uncertainty (with k=2)					Normal			10.82%

Table B3. Uncertainty Budget For Estimating the Uncertainty in Proof Strength, $R_{p0.2}$ in compression testing at room temperature

Column No. 1	2	3	4	5	6	7	8	9
Sources of uncertainty (xi)	**Measurment (Xi)**		**Uncertainties**					
	Measurement affected	**Nominal or average value**	**Uncertainty in measurement**	**Type**	**Probability Distribution**	**Divisor dv**	**Ci**	**u(Xi)**
Apparatus								
Load Cell	P	(KN)	1%	B	Rectangular	$\sqrt{3}$	1	1.73%
Extensometer	ε	(mm)	0.50%	B	Rectangular	$\sqrt{3}$	1	0.71%
Young's Modulus E	Rp0,2	(MPa)	5.41%	B	Normal	1	1	5.41%
Combined Standard Uncertainty					Normal			5.72%
Expanded Uncertainty (with k=2)					Normal			11.44%

B4. Reported Results

E = 71205 GPa ± 10.82%
and
$\mathbf{R_{p0.2}}$= 456 MPa ± 11.44%

The above reported expanded uncertainties are based on standard uncertainties multiplied by a coverage factor k=2, providing a level of confidence of approximately 95%. The uncertainty evaluation was carried out in accordance with UNCERT recommendations.