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

Code of Practice No. 12

The Determination of Uncertainties in Double Shear Testing

L Legendre G. Brigodiot and F Tronel

EADS Centre Commun de Recherche
12, rue Pasteur BP76
92152 - Suresnes Cedex
FRANCE

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1. SCOPE

This Code of Practice (CoP) covers the evaluation of uncertainty in Shear Strength S and Ultimate Load P_{max} in double shear testing on metallic materials, according to ASTM B769 - 87.

ASTM B769 - 87 - *"Standard Method for Shear Testing of Aluminum Alloys"*

The Code of Practice is restricted to tests performed continuously without interruptions under axial loading conditions, at room temperature with 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 Code of Practice.

A_0	original cross-sectional area of the rod
d_0	original diameter of the cylindrical rod
d_b	diameter of the blade
d_f	diameter of the fork
l_0	original blade position
l	blade position during test
P	applied load
P_{max}	maximum applied load
S	shear strength
t	time
ε	strain
$\Delta\varepsilon$	strain rate
ΔP	load rate
σ	stress

Original cross-sectional area of the rod	$A_0 = d_0^2 . \pi / 4$
Stress	$\sigma = P / 2A_0$
Strain	$\varepsilon = \Delta l / l_0 = (l - l_o) / l_0$
Strain rate	$\Delta\varepsilon = \varepsilon / t$

3. Introduction

It is good practice in 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 to simplify the way in which uncertainties are evaluated. It has been funded by the European Commission's Standards, Measurement and Testing programme under reference SMT4-CT97-2165. The aim is to produce a series of documents in a common format which is easily understood 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 measurement uncertainty and values of standard uncertainties for 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 shear strength and ultimate load in double shear testing.

4. A PROCEDURE FOR THE ESTIMATION OF UNCERTAINTY IN DOUBLE SHEAR 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 mono-axial double shear testing.

Table 1 Measurands, their units and symbols

Measurands	**Units**	**Symbol**
Shear Strength	MPa	S
Ultimate Load	N	P_{max}
Measurements	**Units**	**Symbol**
Applied Load	N	P
Original diameter of rod	mm	d_0

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 (e.g. when a plotter is replaced by a computer). To help the user list all sources of uncertainty, five categories have been defined. The following table (Table 2) lists the five 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 double shear test measurands

[1 = major contribution, 2 = minor contribution]

Source	**Shear Strength S**	**Ultimate load P_{max}**
Testing Means		
Load Cell	1	1
Micrometer	1	1
Tooling stiffness	2	2
Center die geometry	2	2
Outer die geometry	2	2
Test Method		
Formula (decimals)	2	2
Sampling rate	2	2
Pre-load	2	2
Load rate	2	2
Strain rate	2	2
Test Environment		
Temperature	2	2
Operator		
-		-
Specimen		
Cylindricity	2	2

Step 3. Classification of 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 means of evaluation. For *Type B* sources, it is necessary for the user to estimate the most appropriate probability distribution for each source (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 2 contains an example where, if the diameter of a 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 and is derived from the uncertainty of the input quantity by dividing by the parameter d_v, which is 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 P_{max} is the test temperature. In this case the input quantity is temperature, but the output quantity is load. In such a case, a sensitivity coefficient c_T (corresponding to the partial derivative of the P_{max}/test temperature relationship) is used to convert from temperature to load (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 to the measure *(the numbers are the column numbers in tables 3 and 4):*

$$9 = 3 \times 4 \times 7 \times 8$$

2. If the influence is not directly proportional to the measure:

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

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 :

$$u_c(y) = \sqrt{\sum_{i=1}^{N} [c_i u(x_i)]^2} \quad \text{with} \quad c_i = \frac{\partial Y}{\partial x_i} \tag{1}$$

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 which 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 industry, electronics), 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 3 Typical Worksheet for Uncertainty Budget Calculations For Estimating the Uncertainty in Shear Strength in Double Shear 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	(N)		B	Rectangular	sqrt(3)	$\frac{2}{p\ d_0^2}$	u(Cell)
Micrometer	do	(mm)		B	Rectangular	sqrt(3)	$-4\frac{P_{max}}{p\,d_0^3}$	u(Mic)
Combined Standard Uncertainty					Normal			uc
Expanded Uncertainty					Normal			UE

Table 4 Typical Worksheet for Uncertainty Budget Calculations For Estimating the Uncertainty in Ultimate Load in Double Shear 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	(N)		B	Rectangular	sqrt(3)	1	u(Cell)
Combined Standard Uncertainty					Normal			uc
Expanded Uncertainty					Normal			URp0,2

Tables 3 and 4 show the recommended format for the calculation worksheet for estimating the uncertainty in shear strength S and ultimate load P_{max} for a cylindrical test piece. 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 12: 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.

Appendix A

Methods and Mathematical Formulae for Calculating Uncertainties in Double Shear Testing at room temperature

A1. Shear Strength

$$S = \frac{P_{\max}}{2\left(\frac{pD^2}{4}\right)} = \frac{2P_{\max}}{pD^2}$$

$$\frac{\partial S}{\partial D} = \frac{-4P_{\max}}{pD^3}$$

$$\frac{\partial S}{\partial P} = \frac{2}{pD^2}$$

$$u_S = \sqrt{\left(\frac{\partial S}{\partial D}\right)^2 u_D^2 + \left(\frac{\partial S}{\partial P}\right)^2 u_P^2}$$

where u_D is the uncertainty on the diameter measurement (from the micrometer)
u_P is the uncertainty on the load measurement (from the load cell)

A2. Ultimate load P_{max}

$$\mathrm{S} = \frac{\mathrm{P_{max}}}{2\left(\frac{\pi \mathrm{D}^2}{4}\right)} = \frac{2\mathrm{P_{max}}}{\pi \mathrm{D}^2}$$

$$\mathrm{P_{max}} = \frac{\mathrm{S}\pi\mathrm{D}^2}{2}$$

$$\frac{\partial P_{\max}}{\partial D} = SpD$$

$$\frac{\partial P_{\max}}{\partial S} = \frac{pD^2}{2}$$

$$u_{P\max} = \sqrt{\left(\frac{\partial P_{\max}}{\partial D}\right)^2 u_D^2 + \left(\frac{\partial P_{\max}}{\partial S}\right)^2 u_S^2}$$

where u_D is the uncertainty on the diameter measurement (from the micrometer)
u_S is the uncertainty on the stress (see above : 4.1 Shear Strength)

Appendix B

A Worked Example for Calculating Uncertainties in Double Shear Testing

B1. Introduction

A customer asked the testing laboratory to carry out double shear on a 7000 series aluminum cylindrical rod according to Standard ASTM B769-87. The laboratory has considered the sources of uncertainty in its test facility and has found that the sources of uncertainty in fatigue life test results 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 an appropriately calibrated compression test facility and ancillary measurement instruments. The test facility was located in a temperature-controlled environment (21±2°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. Three readings were taken at 120 degree intervals at the center of the specimen.

3 The tests were carried out on a servo-electric test facility under total strain controlled conditions. The machine was calibrated to Class 1.0.

B3. Example for Uncertainty Calculations and Reporting of Results

Table B1 lists the input quantities used to produce Tables B2 and B3, the uncertainty budgets for estimating the uncertainty in shear strength and ultimate load.

Table B1 Input Quantities Used for Producing Tables B2 and B3

Quantity	Symbol	Values	Mean	Standard deviation
Specimen original diameter	d_0	6.332 6.328 6.329	6.33	0.001
Applied Load	P	-	-	-
Ultimate load displayed	P_{max}	20 000 N	-	-

Table B2 Uncertainty Budget For Estimating the Uncertainty in Shear Strength in Double Shear 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	(N)	1%	B	Rectangular	sqrt(3)	0.0159	0.03%
Micrometer	do	(mm)	0.001mm	A	-	-	100.415	0.1%
Combined Standard Uncertainty					Normal			0.1%
Expanded Uncertainty (k=2)					Normal			0.2%

Table B3 Uncertainty Budget For Estimating the Uncertainty in Ultimate Load in Double Shear 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	(N)	1%	B	Rectangular	sqrt(3)	1	1%
Combined Standard Uncertainty					Normal			1%
Expanded Uncertainty (k=2)					Normal			2%

B4. Reported Results

$$\mathbf{S} = 318 \text{ MPa} \pm 0.2\ \%$$

and

$$\mathbf{P_{max}} = 20\,000 \text{ N} \pm 2\ \%$$

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 CoP12 recommendations.