CMMT(MN)048

Room Temperature Tensile Testing: A Method for Estimating Uncertainty of Measurement

Abstract

Tensile testing, together with hardness and Charpy impact testing, is one of the most important quality control assessment methods used for product release certification of virtually all metallic materials. In addition tensile data are extensively used in design of products and are also sometimes used for component life assessment. A knowledge of the reliability and precision of the test method is important, and in addition there is now a requirement that measurement Standards include an assessment of the measurement uncertainty in accordance with the ISO TAG4 Standard ' Guide to the Expression of Uncertainty of Measurement'.

This document presents a proposed draft of an *informative* (ie non-mandatory) Annex for incorporation into EN 10002 Part 1 'Metallic Materials- Tensile Testing at Ambient Temperature'. It describes a method for estimating the measurement uncertainty in accordance with the ISO TAG 4 Guide, and in addition it summarises experimental **Reproducibility** data derived from Laboratory Inter-Comparison exercises which may be compared with estimates of measurement uncertainty.

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Note:

The document presented here contains the personal suggestions put forward by the author. The final Annex in the Standard may well have a different format since it will be subject to redrafting by an international committee of technical experts and also probably amended during the Standards voting process.

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1 Introduction

This Measurement Note provides guidance on how to estimate the uncertainty of measurement when undertaking Room Temperature Tensile Testing in accordance with the European Standard EN 10002 Part 1. It includes a suggested format for an 'Informative' (ie non-mandatory) annex for the Standard. In addition data obtained from Laboratory Inter-Comparisons of Tensile Testing are presented indicating the **Reproducibilty** obtained during such exercises. The proposed annex for the standard has been prepared at the request of the European Standards committee ECISS TC 1 SC1- Metallic Materials- Uniaxial Testing. It has been based upon an approach for estimating the uncertainty of measurement using an "error budget" concept using the tolerances specified in the testing and calibration standards which has been published elsewhere (Loveday, 1992) and which was subsequently expanded to form the basis of the informative annex for ISO 6892 (1995). The annex presented here has now been revised to follow more closely the approach for estimating the uncertainty of measurement outlined in the ISO TAG4 'Guide to the expression of uncertainty in measurement.' (1994). Outline details of how to prepare an Uncertainty Budget for Room Temperature Tensile Testing are show in the Annex, however further information on the estimation of uncertainty is now available in a 'Beginners Guide' (Bell, 1999).

The approach adopted here for the Tensile Uncertainty Budget is similar to that proposed for a creep testing uncertainty budget used in association with the Creep Certified Reference Material, CRM 425, (Loveday, 1996).

2 Discussion

It should be appreciated that it is not possible to calculate a single value for the measurement uncertainty for room temperature tensile testing for all materials since different materials exhibit different response characteristics to some of the specified control parameters, eg straining rate or stressing rate, and at present only limited systematic data are available over the testing parameters tolerances ranges specified in the Standard. Estimates of the measurement uncertainty for yield stress are given in the Annex for five materials, viz. two ferritic steels, an austenitic stainless steel and two nickel base alloys using material property data published elsewhere, (Loveday 1992). The 'Expanded Uncertainty' calculated at approximately the 95% confidence level are shown graphically in Figure 1, with a simple power law trend line plotted through the data. Thus it can be seen that the estimated measurement uncertainties range from ±2.3% up to ±4.6% at approximately the 95% confidence level. Thus two laboratories testing in accordance with EN10002 Part1, but controlling their machines at the extreme ends of the permitted tolerance ranges, may produce tensile results with differences up to 4.6 - 9.2% depending upon the material being tested. The estimated uncertainties do not take into account the inherent scatter attributable to material inhomogeneity.

Results from a number of laboratory inter-comparison exercises have been reported in the literature, and results from such exercises are presented here in graphical form as shown in Figure 2. The values for the 'Reproducibility' have been express as a percentage at the 95% confidence level so that they may be directly compared with the Estimated Measurement uncertainties. The Reproducibility has been calculated by multiplying the standard deviation of the scatter in the results by a factor of x2 to give values equivalent to the 95% confidence levels, dividing by the mean value the parameter being measured and expressing the result as a percentage. A simple trend line has been included on the graphs merely to indicate that there appears to be a general decrease in the reproducibility as the measured parameters increase in magnitude. It should be noted that in general during inter-comparison exercises all the laboratories aim to carry out the testing under similar conditions, i.e. the strain rate is at a specified value rather than anywhere in the range permitted in the Standard, and the material tested is usually selected from single bars or taken from adjacent pieces of plate so as to minimise the scatter attributable to material inhomogeneity. In the case of the Nimonic 75 which has been characterised as a Certified Reference Material, (CRM661), testpieces were tested from bars representing the extreme ends of the material property spectrum of the two hundred bars obtained from the one ton master melt. (Loveday & Ingelbrecht, 2000). If the inter-laboratory reproducibility for individual bars were considered, then the reproducibility for any parameter was typically a factor of 4 smaller than that for the entire bar stock, ie the Yield Strength reproducibility for a single bar was ~1% whereas for the entire bar stock it was ~4.0%.

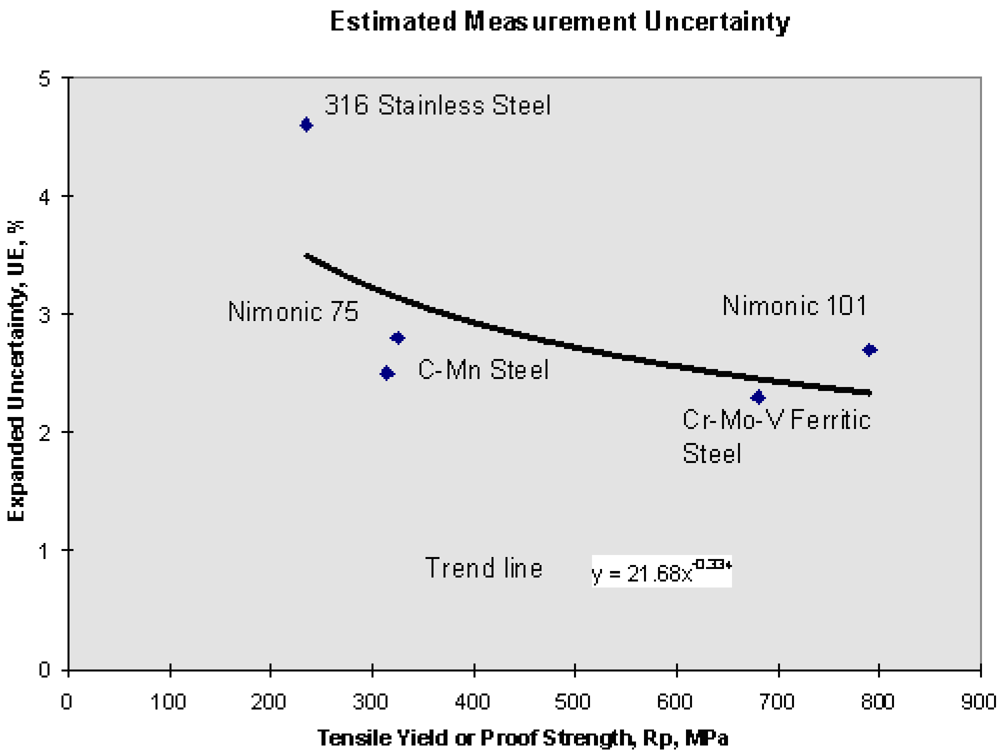

Figure 1. Expanded Measurement Uncertainties at the 95% confidence level for Proof or Yield Strengths selected materials tested in accordance with EN 10002 Part 1

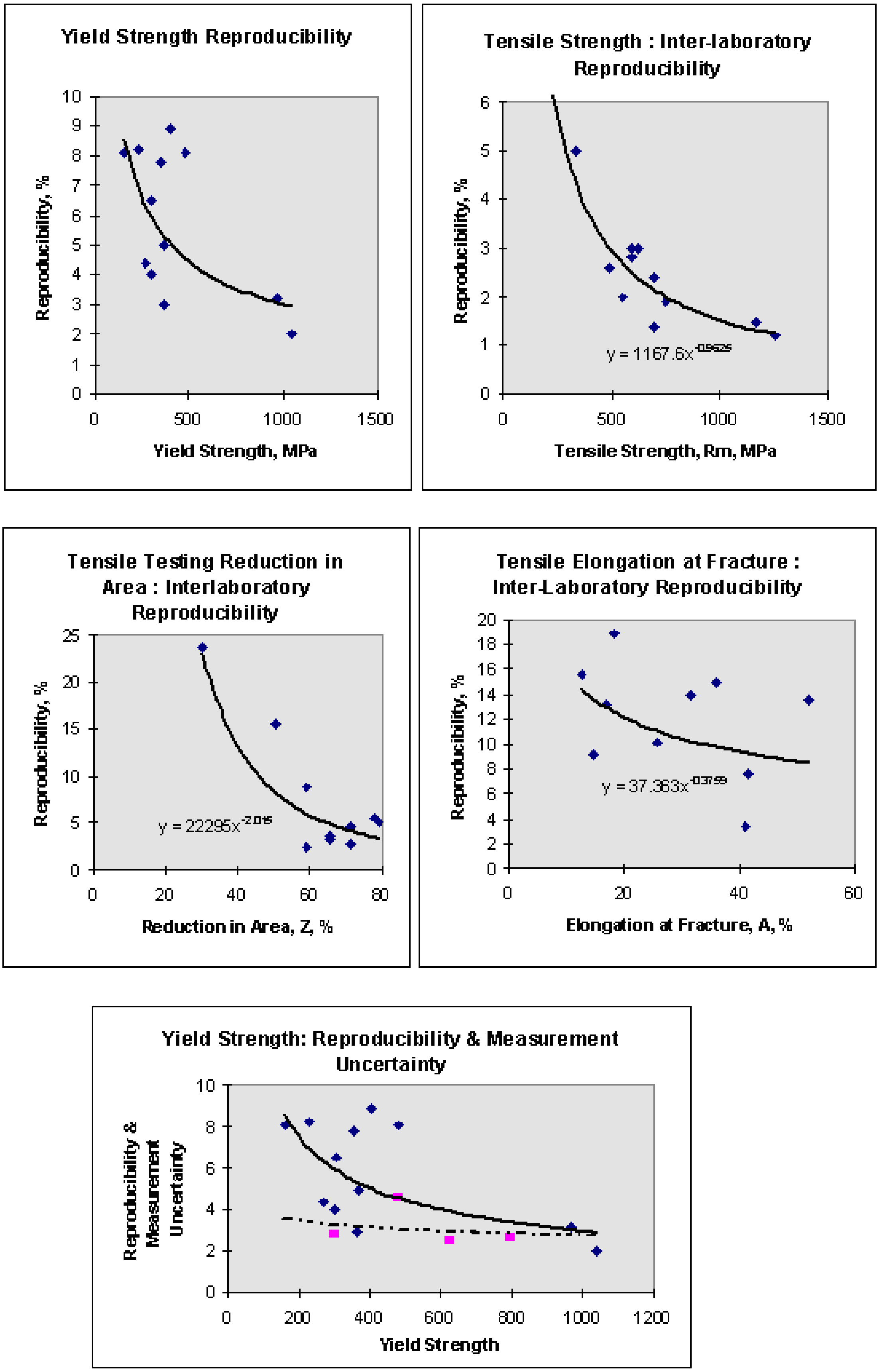

Figure 2. Values of Reproducibility from Laboratory Inter-Comparison Exercises

3 Recommendations

Using the procedures outlined in this Note and the attached Annex it should be possible to estimate measurement uncertainty associated with room temperature tensile testing. If the material's response to variations in strain rate over the range specified in the testing Standard is not known, then an estimate of the Reproducibility of tensile properties may be obtained by comparison with data from laboratory inter-comparison exercises.

4 Acknowledgements

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Appendix: Precision of Tensile Testing and Estimation of Uncertainty of Measurement

EN 10002 Part1 : Metallic Materials - Tensile Testing at Ambient Temperature

Annex J (Informative)

Precision of Tensile Testing and Estimation of the Uncertainty of Measurement

K1 Introduction

This annex gives guidance of how to estimate the uncertainty of the measurements undertaken in accordance with this standard using a material with known tensile properties. It should be noted that it is not possible to give an absolute statement of uncertainty for this test method because there are both **material dependent** and **material independent** contributions to the uncertainty statement. Hence it is necessary to have a prior knowledge of a material's tensile response to straining or stressing rate before being able to calculate the measurement uncertainty.

An approach for estimating the uncertainty of measurement using the "error budget" concept based upon the tolerances specified in the testing and calibration standards has been presented elsewhere (Loveday, 1992) and was subsequently expanded to form the basis of the informative annex for ISO 6892 (1995). This annex has now been revised to follow more closely the approach for estimating the uncertainty of measurement outlined in the ISO TAG 4 'Guide to the expression of uncertainty in measurement.' (1994).

The precision of the test results from a tensile test is dependent upon factors related to the material being tested, the test piece geometry and machining, the testing machine, the test procedure and the methods used to calculate the specified material properties. Ideally all the following factors should be considered:

- measurement of the testpiece dimensions, gauge-length marking, extensometer gauge-length
- measurement of force and extension
- test temperature and loading rates in the successive stages of the test,
- the method of gripping the testpiece and the axiality of the application of the force
- the testing machine characteristics (stiffness, drive, control and method of operation)
- human and software errors associated with the determination of the tensile properties
- the material inhomogeneity which exists even within a single processed batch obtained from a single melt of material.

In practice the requirements and tolerances of the present standard do not allow all the effects to be quantified, but interlaboratory tests may be used to determine the overall uncertainty of results under conditions close to those used at industrial laboratories. However such tests do not separate effects related to the material inhomogeneity from those attributable to the testing method.

It should be appreciated that it is not possible to calculate a single value for the measurement uncertainty for all materials since different materials exhibit different response characteristics to some of the specified control parameters, eg straining rate or stressing rate (Loveday 1992). The uncertainty budget presented here could be regarded as an upper bound to the measurement uncertainty for a laboratory undertaking testing in compliance with EN 10002 Pt1 since it is possible that a laboratory could actually control some of the testing parameters to a better level of precision than that demanded by the standard, eg the force might be measured to ± 0.5% (ie, a Class 0.5 machine) whereas the testing standard EN 10002 Pt1 only requires that the force shall be measured to better than ± 1%. Alternatively, the actual value of the Uncertainty of the Force Measurement system, determined during the verification of the machine in accordance Annex D of ISO 7500 Pt1, could be used in the uncertainty budget.

It should be noted that when evaluating the total scatter in experimental results the uncertainty in measurement should be considered in addition to the inherent scatter due to material inhomogeneity. A statistical approach to the analysis of intercomparison exercises ('Round Robin' experiments) does not separate out the two contributing causes of the scatter, but never the less gives a useful indication of the likely range of tensile results measured by different laboratories using similar material. Typical results from various inter-comparision exercises are given in Section K5.

K2 An Overview of Uncertainty Estimation Based Upon the GUM

The: **"Guide to the expression of uncertainty in measurement",** was published jointly by several authoritative standards bodies, namely BIPM, IEC, IFCC, ISO, IUPAC, IUPAP and OIML which will be referred to hereafter as GUM (Guide to Uncertainty in Measurement). It is a comprehensive document of over 90 pages based upon rigorous statistical methods for the summation of uncertainties from various sources. Its complexity has provided the driving force for a number of organisations to produce simplified versions of the GUM, eg the National Institute of Science and Technology (NIST) in the USA (Taylor and Kuyatt), the National Measurement Accreditation Service (NAMAS) in the UK (NIS 80 and NIS 3003). These various documents all give guidance of how to estimate uncertainty of measurement based upon an "uncertainty budget" concept.

The total uncertainty of a measurement is determined by summing all the contributing components in an appropriate manner. It is necessary to quantify all the contributions, and at the preliminary evaluation stage to decide whether some contributions are negligible and therefore not worth including in the subsequent calculations. For most practical measurements, in the materials field the definition of negligible may be taken as a component smaller than one-fifth of the largest component. The GUM categorises two ways of evaluating uncertainties, A and B. Type A determinations is by repeat observations and provided sufficient readings are available, say greater than 9, then conventional statistical analysis can be used to determine the standard deviation $s(q_k)$.

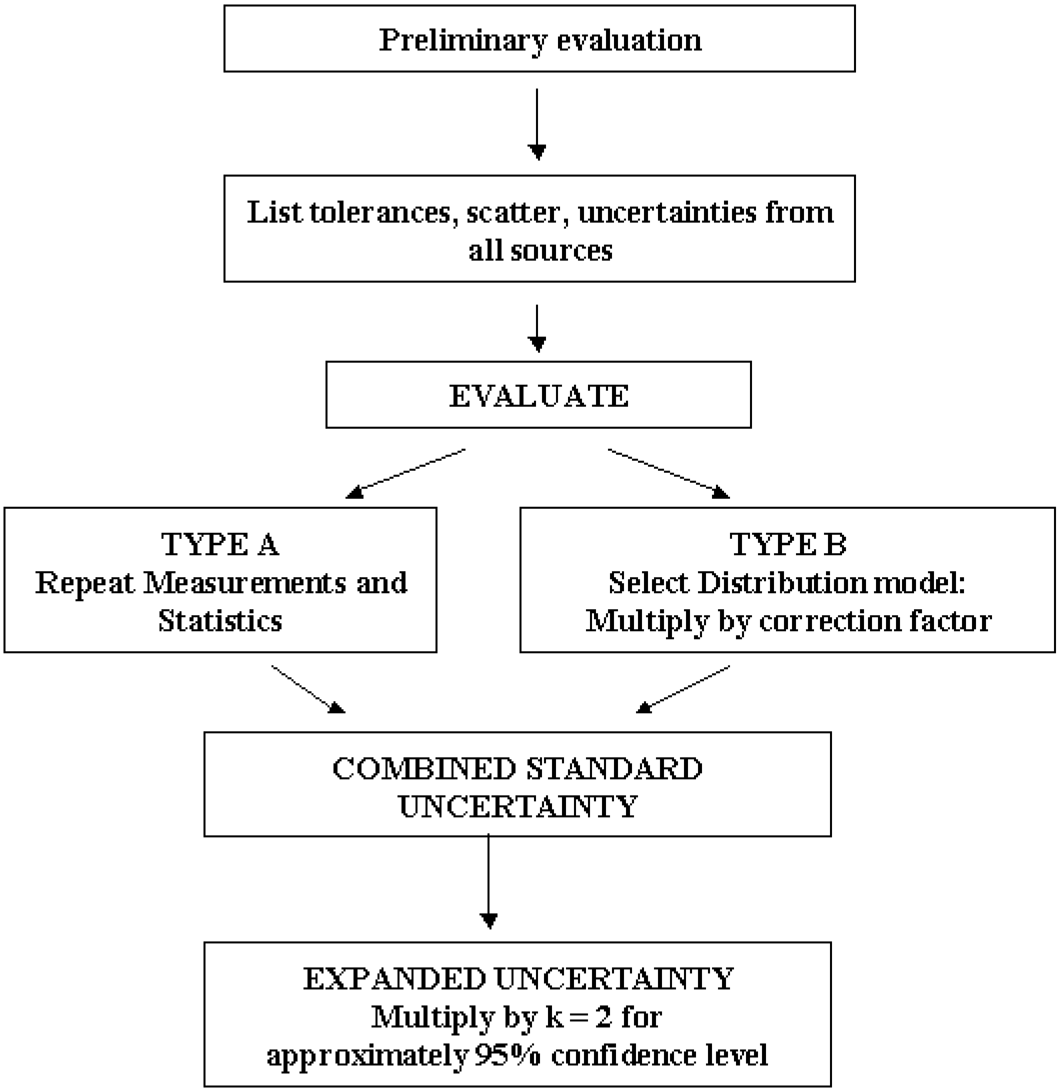

Table K1. GUM: Outline of Procedure for Estimation of Uncertainty

Type B evaluation is by means other than Type A and makes use of, for example, tolerances specified in standards, measured data, manufacturers specifications, calibration certificates and in most cases a knowledge of a simple model of the relationship between the various components, and of the likely distribution model of the components. If for example the tolerance specified in a Standard is ± a, then in absence of any other knowledge, it may be appropriate to assume a rectangular distribution model in which case, the uncertainty becomes

$u_s = \frac{a}{\sqrt{3}}$ [1].

If better knowledge is available it may be that a triangular distribution would be more appropriate, then $u_s = \frac{a}{\sqrt{2}}$ [2], (see GUM), where us denotes a **Standard Uncertainty** obtained by multiplying U by an appropriate factor. The next step is to determine the **Combined Standard Uncertainty, u_c** by summing the standard uncertainties, usually by using the root sum square method. The **Expanded Uncertainty U_E**, is then obtained by multiplying u_c by a coverage factor, k, where k = 2 for approximately 95% confidence level, thus, $U_E = 2u_c$; this procedure is shown schematically in Table K2.

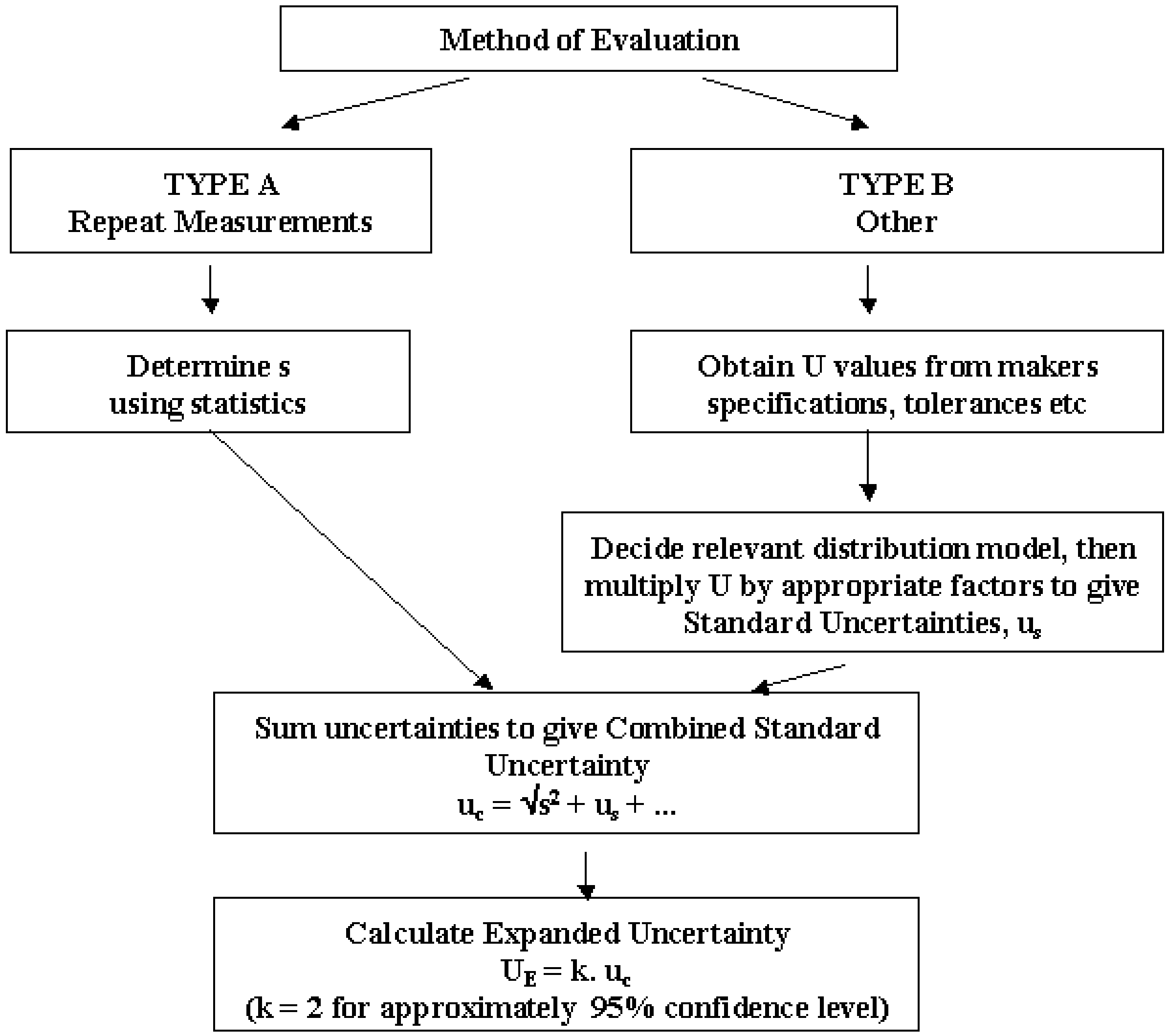

Table K2 Procedure for estimating uncertainty in accordance with the GUM

K3 Tensile Testing : Uncertainty Estimation

K3.3 Material Independent Parameters

The tolerances for the various testing parameters for tensile properties specified in EN 10002 Pt1. are given in Table K3. Because of the shape of the stress-strain curve, some of the tensile properties in principle can be determined with a higher degree of precision than others, eg, the upper yield stress, R_{eh} is only dependent on the tolerances for measurement of force and cross sectional area, whilst proof stress, R_p, is dependent on force, strain (displacement), gauge length and cross-sectional area. In the case of reduction in area, Z, the measurement tolerance for cross sectional area both before and after fracture need to be considered.

	Tensile Properties, % Error					
Parameter	**R_{eh}**	**R_{eL}**	**R_m**	**R_p**	**A**	**Z**
Force	1	1	1	1	-	-
Strain * (Displacement)	-	-	-	1	1	-
Gauge * Length, Lo	-	-	-	1	1	-
So	1	1	1	1	-	1

Su	-	-	-	-	-	2
* Assuming a Class 1 extensometer calibrated in accordance with EN 10002 Part 4.						

Table K3. Measurement uncertainty for tensile testing based upon material independent parameters, using tolerances specified in EN 10002 Part 1.

In the GUM two types of uncertainty are categorised. Type A and B. A type A evaluation of uncertainty may be based on any valid statistical method for treating data. A type B evaluation is based on some other means thus the use of tolerances specified in a standard comes under the type B category. The tolerances shown above for tensile testing represent maximum bound values, ie all the values must lie within the specified tolerance viz, a = ± 1%, and thus the model distribution corresponds to a rectangular probability distribution specified in the GUM, hence the standard uncertainty values for the individual parameters are given by $a/\sqrt{3}$ [3]. To fully comply with the assessment of uncertainty it would be necessary to consider all the possible sources of uncertainty contributing to the measurements including those due to uncertainties in the devices used in the calibration chain, ie the force proving devices and the extensometer calibrators. In practice, such sources of error are second order effects and for the purposes of this paper a simplified approach will be adopted using the concepts outlined in the GUM. This the combined uncertainty of the material independent parameters for R_{eh}, R_{eL}, R_m and A is $\sqrt{0.33 + 0.33} = \pm\ 0.81\%$ [4], and for R_p is $\sqrt{0.33 + 0.33 + 0.33 + 0.33} = \pm\ 1.15\%$ [5]; using a root mean-squares summation approach.

K3.2 Material Dependent Parameters

For room temperature tensile testing the only tensile properties significantly dependent upon the materials response to the straining-rate (or stressing-rate) control parameters are R_{eh}, R_{eL} and R_p. Tensile strength, R_m, can also be strain rate dependent, however in practice it is usually determined at a much higher straining-rate than R_p and is generally relatively insensitive to variations in the rapid strain-rates.

In principle it will be necessary to determine any materials strain rate response before the total error budget can be calculated. Some limited data is available and the following examples may be used to estimate uncertainty for some classes of materials.

A typical example of data set used to determine materials response over the strain rate range specified in EN10002 Pt1 is shown in Figure K1 and a summary of materials response for proof stress for a number of materials measured under strain rate control is given in Table K4. Earlier data on a variety of steels measured under a set stressing rate are given in the seminal paper by Johnson and Murray (1966).

Since the equivalent tolerances, a, are based on measured data, using a simple least mean squares fit to the data, it is necessary to decide what distribution model of the uncertainties is appropriate in accordance with the GUM. If it is assumed that the model is a normal distribution with upper and lower limits +a and -a, such that the best estimate of the quantity is $(a_+ + a_-)/2$ and that there is a 2 out of 3 chance (ie a 67% probability) that the value of the quantity lies in the interval a_- to a_+, then the uncertainty U = a. [Note: if it was assumed that the probability was 50%, then u =1.48a] (See Taylor and Kuyatt, 1993).

Material	Nominal Composition	$R_{P0.2}$ MPa	Proof Stress/ Strain-Rate Variation %	Equivalent Tolerance ± %
Ferritic Steel				
Pipe steel	Cr-Mo-V-Fe(bal)	680	0.1	0.05
Plate steel (BS 4360 Grade 43E)	C-Mn-Fe (bal)	315	1.8	0.9
Austenitic Steel				
316 Stainless	17 Cr; 11 Ni-Fe (bal)	235	6.8	3.4

Nickel Base Alloys				
Nimonic 75	18 Cr, 5 Fe, 2 Co-Ni (bal)	325	2.8	1.4
Nimonic 101	24 Cr, 20 Co, 3 Ti, 1.5 Mo, 1.5 Al-Ni (bal).	790	1.9	0.95

Table K4. Variation in room temperature proof stress over the strain rate range permitted in EN10002 Pt1.

K3.3 Combined standard measured uncertainty

The material dependent response of proof stress over the permitted strain rate range specified in the standard given in Table K4 may be combined with the standard uncertainties derived from material independent parameters specified in Table K3 to give the Combined Uncertainty, u_C for the various materials indicated, as shown in Table K5.

For the purpose of this analysis the total value of the variation in proof stress over the strain-rate range permitted in the standard has been halved and expressed as an equivalent tolerance, ie for 316 stainless steel, the proof stress can vary by 6.8% over the permitted strain-rate range so it is equivalent to a tolerance of ± 3.4%, which should be divided by √3, ie 1.963 and then added to the combined uncertainty of the material independent parameters using the root mean square method.. Therefore for 316 stainless steel the combined standard uncertainty is given by:

$$\pm \sqrt{1.15^2 + 1.96^2} = \pm \sqrt{5.17} = \pm 2.3\%$$ [6] (2)

Material	Standard uncertainty from material independent parameters ± %	Material Dependent Standard Uncertainty ± %	Combined Standard Uncertainty ± %	Expanded Uncertainties at 95% Confidence ±%
Ferritic Steel				
Pipe steel	1.15	0.03	$\sqrt{1.33} = 1.15$ [7]	2.3
Plate steel	1.15	0.52	$\sqrt{1.59} = 1.26$ [8]	2.5
Austenitic Steel				
316 Stainless	1.15	1.96	$\sqrt{5.17} = 2.3$ [9]	4.6
Nickel Base Alloys				
Nimonic 75	1.15	0.81	$\sqrt{1.98} = 1.41$ [10]	2.8
Nimonic 101	1.15	0.55	$\sqrt{1.63} = 1.28$ [11]	2.7

Table K5. Combined standard measurement uncertainty for room temperature proof stress determined in accordance with En 10002 Pt1.

K3.4 Expanded Uncertainity

In accordance with the ISO TAG 4 Guide, the total Expanded Uncertainties are obtained by multiplying the Combined Standard Uncertainties by a coverage function, k. For approximately 95% level of confidence, k = 2 and the corresponding Expanded Uncertainties are also listed in Table K5.

K4 Discussion

A method of calculating the measurement uncertainty for room temperature tensile testing using an "Uncertainty Budget" concept has been outlined and examples given for a few materials where the material response to the testing parameters is known. It should be noted that the Expanded Uncertainties have been calculated using a simplified approach based on the GUM. In addition there are other factors that can affect the measurement of tensile properties such as testpiece bending, methods of gripping the testpiece, or the testing machine control mode, ie. extensometer control or load/crosshead control which may affect the measured tensile properties, (Gray and Sharp, 1988), however since there is insufficient quantitative data available it is not possible to include their effects in error budgets at present. It should also be recognised that this uncertainty budget approach only gives an estimate of the uncertainty due to the measurement technique and does not make an allowance for the inherent scatter in experimental results attributable to material inhomogeneity.

An indication of the scatter in experimental results attributable to inhomogeneity in material ie **material scatter** may be determined by undertaking repeat testing on the same testing machine, under the identical testing conditions, ie same operator, same strain-rate etc., thereby determining the **repeatability.** An example of such data for Nimonic 75, which is now available as a Certified Reference Material for Room Temperature Tensile Testing, CRM661*, is given in Table K6 where it can be seen that the repeatability for the 0.2% room temperature proof stress is ± 2.5% with approximately 95% confidence limit. The standard deviation+ is ± 1.25% and this may be added to the combined measurement uncertainty (± 3.6%, see Table K3) using the least mean squares approach and multiplying by K = 2 to give the total Expanded Uncertainty at approximately the 95% confidence level, i.e.

Total Expanded Uncertainty = $2\sqrt{[(3.6)^2 + (1.25)^2]}$ = ± 3.8% [12].

This implies that differences of up to 7.6% between two laboratories measuring the proof stress of Nimonic 75, should not be regarded as being statistically significant at the 95% confidence level, assuming that both laboratories are able to demonstrate repeatability of ± 2.5%, and both are undertaking the measurements within the tolerances specified in the testing standard.

Testpiece number	**$R_{P0.2}$ MPa**
GAN 96	315.3
97	313.9
99	313.1
100	316.1
122	304.3
124	310.0
127	315.0
128	319.3
129	311.7
142	318.5
143	314.4
150	316.0
n = 12	$\bar{q}$ =314.0

	s = 4.0

Repeatability = $\frac{2s}{\bar{q}} \times 100 = \frac{8}{314} \times 100 = \pm\ 2.5\%$ [13]

(95% Confidence)

Table K6. Room temperature 0.2% Proof stress data, $R_{P0.2}$, for Nimonic 75 measured at a strain rate of 2×10^{-3} min^{-1}.

K5 Interlaboratory Scatter

An indication of the typical scatter in tensile test results for a variety of materials that have been observed during laboratory intercomparison exercises, which include both material scatter and measurement uncertainty are shown in Tables K7a-d. The results for the **Reproducibility** are expressed in % calculated by multiplying the standard deviation by 2 and dividing the result by the mean, thereby giving values which represent the 95% confidence level, in accordance with the recommendations given in the GUM, and which may be directly compared with the Expanded Uncertainty values given above.

Material	**Code**	**Yield Strength MPa**	**Reproducibility +/- U_E, %**	**Reference**
Aluminium	EC-H 19	158.4	8.1	ASTM Report, 1994
	2024-T 351	362.9	3.0	ASTM Report, 1994
Steel				
Low Carbon, Plate. AISI 105. Bar. High Strength. Austenitic stainless. Austenitic stainless. AISI 316.	HR3 C22 Fe510C X2Cr13 30NiCrMo16 X2CrNi18-10 X2CrNiMo18-10 X5CrNiMo17-12-2	228.6 402.4 367.4 967.5 1039.9 303.8 353.3 480.1	8.2 8.9 5.0 3.2 2.0 6.5 7.8 8.1	Roesch et al, 1993. ASTM Report, 1994. Roesch et al, 1993. ASTM Report, 1994. Roesch et al, 1993. Roesch et al, 1993. Roesch et al, 1993. ASTM Report, 1994.
Nickel Alloys				
INCONEL 600	NiCr15Fe8 Nimonic 75, (CRM661)	268.3 298.1	4.4 4.0	ASTM Report, 1994. Loveday,1999.

Table K7a: Yield Strengths (0.2% Proof Strengths or Upper Yield Strengths): Reproducibility from laboratory Intercomparison exercises.

Material	**Code**	**Tensile Strength MPa**	**Reproducibility +/- U_E, %**	**Reference**
Aluminium	EC-H 19	176.9	not reported	ASTM Report, 1994
	2024-T 351	491.3	2.6	ASTM Report, 1994

Steel				
Low Carbon, Plate. AISI 105. Bar. High Strength. Austenitic stainless. Austenitic stainless. AISI 316.	HR3 C22 Fe510C X2Cr13 30NiCrMo16 X2CrNi18-10 X2CrNiMo18-10 X5CrNiMo17-12-2	335.2 596.9 552.4 1253 1167.8 594.0 622.5 694.6	5.0 2.8 2.0 1.2 1.5 3.0 3.0 2.4	Roesch et al, 1993. ASTM Report, 1994. Roesch et al, 1993. ASTM Report, 1994. Roesch et al, 1993. Roesch et al, 1993. Roesch et al, 1993. ASTM Report, 1994.
Nickel Alloys				
INCONEL 600.	NiCr15Fe8 Nimonic 75, (CRM661)	695.9 749.6	1.4 1.9	ASTM Report, 1994. Loveday, 1999.

Table K7b: Tensile Strengths, R_m: Reproducibility from laboratory Intercomparison exercises.

Material	**Code**	**Reduction in Area, Z %**	**Reproducibility +/- U_E, %**	**Reference**
Aluminium	EC-H 19	79.1	5.1	ASTM Report, 1994.
	2024-T 351	30.3	23.7	ASTM Report, 1994.
Steel				
	C22 Fe510C X2Cr13 30NiCrMo16 X2CrNiMo18-10 X5CrNiMo17-12-2	65.6 71.4 50,5 65.6 77.9 71.5	3.6 2.7 15.6 3.2 5.6 4.5	ASTM Report, 1994. Roesch et al, 1993. ASTM Report, 1994. Roesch et al, 1993. Roesch et al, 1993. ASTM Report, 1994.
Nickel Alloys	NiCr15Fe8 Nimonic 75, (CRM661)	59.3 59.0	2.4 8.8	ASTM Report, 1994 Loveday, 1999

Table K7c: Reduction in Area: Reproducibility from laboratory Intercomparison exercises.

Material	**Code**	**Elongation at fracture, A %**	**Reproducibility +/- U_E, %**	**Reference**
Aluminium	EC-H 19	14.6	9.1	ASTM Report, 1994.
	2024-T 351	18.0	18.9	ASTM Report, 1994.

Steel				
	C22	25.6	10.1	ASTM Report, 1994.
	Fe510C	31.4	14	Roesch et al, 1993.
	X2Cr13	12.4	15.5	ASTM Report, 1994.
	30NiCrMo16	16.7	13.2	Roesch et al, 1993.
	X2CrNiMo18-10	51.9	13.6	Roesch et al, 1993.
	X5CrNiMo17-12-2	35.9	14.9	ASTM Report, 1994.
Nickel Alloys	NiCr15Fe8	41.6	7.7	ASTM Report, 1994
	Nimonic 75, (CRM661)	41.0	3.3	Loveday, 1999

Table K7d: Elongation after fracture: Reproducibility from laboratory Intercomparison exercises.

K6 References

Standards

ISO (TAG4)(1993) 'Guide to the expression of uncertainty in measurement.' BIMP/IEC/IFCC/ISO/ IIUPAC/IUPAP/OIML

ISO 5725:Accuracy (trueness and precision) of measurement methods and results. Part 1 General principle and definitions.

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Measurement Results. NIST Technical Note 1297.

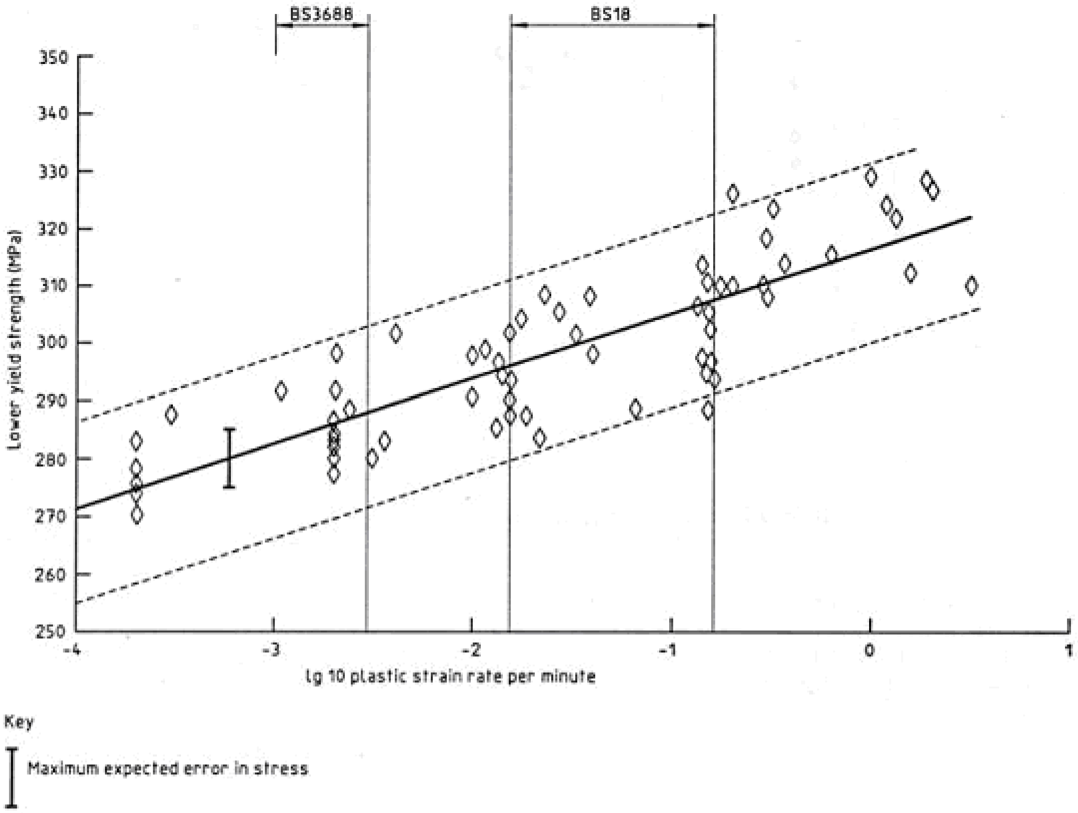

Figure J.1 - Variation of lower yield strength (R_{eL}) at room temperature as a function of strain rate, for plate steel [6]

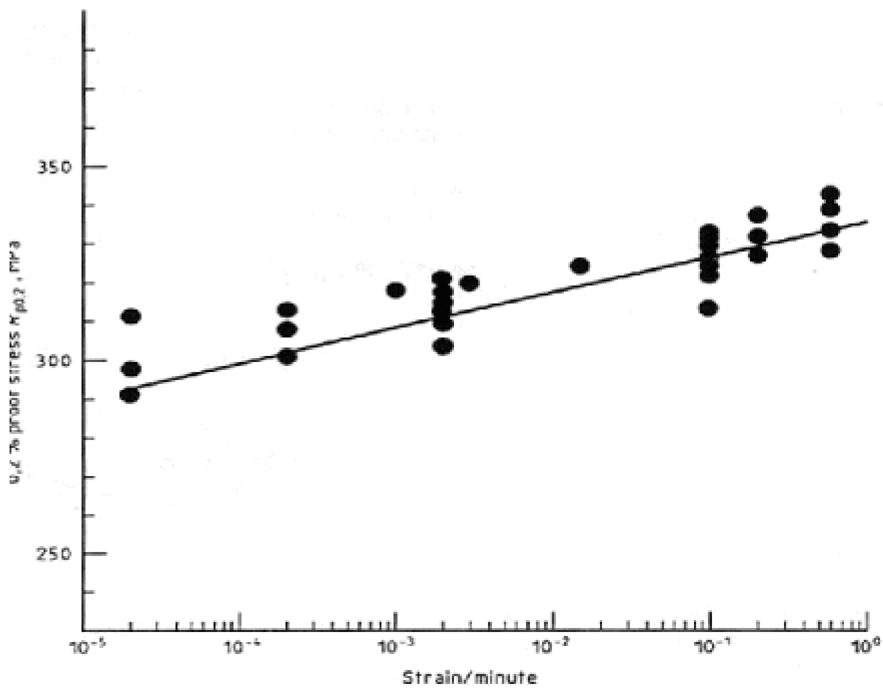

Figure J.2 - Tensile test data at 22°C for Ni Cr 20 Ti

Footnotes

* Available from the Institute for Reference Materials and Measurements, (IRMM), Joint Research Centre, Retieseweg, B 2440, Geel, Belgium.

+ Note: The full value of the standard deviation is used since in the case of a destructive test as performed on a tensile testpiece, n = 1, hence the standard deviation of the mean is given by $s/\sqrt{n}$.

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