Measurement Uncertainty in Material Testing: Differences and Similarities Between ISO, CEN and ASTM Approaches

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There are requirements for all CEN standards to include statements on measurement uncertainty. ASTM also requires that all test methods include statements of precision and bias. This note discusses the main differences and commonalities in current standards polices and their potential implications in the mechanical testing area.

INTRODUCTION

Measurement uncertainty has had a long history in the standards community [1]. According to the 'Guide to the expression of uncertainty in measurement' (GUM) [2], uncertainty of a measurement result is a parameter that characterises the spread of values that could *reasonably* be attributed to the 'measurand' [3] (i.e. the quantity being measured). It defines the range of values within which the measurand is estimated to lie within a stated level of confidence. It also reflects the limitations of controlling the parameters that influence the measurement.

In 1999, ISO 17025 [4] was widely adopted. One of its requirements was that testing laboratories provide uncertainty estimates.

There is currently no universal policy for measurement uncertainty within either ISO Technical Committee 164 on 'Mechanical Testing of Metals' or the corresponding committees in CEN and ASTM. There are no mandatory requirements for test standards to include procedures for estimating the uncertainty in the test results.

UNCERTAINTY - WHY EVALUATE IT?

An increasing proportion of standards users realise the great benefits of utilising measurement uncertainty to optimise design codes, improve process control and the quality and performance of their products. Meaningful uncertainty statements can reduce costs.

A significant proportion of standards users and test laboratories are, however, not concerned about this issue or are reluctant to address it. This primarily is due to lack of education, or lack of knowledge on how to do it or the perceived high financial costs associated with the evaluation process.

It is a requirement for all accredited calibration laboratories that results reported in a calibration certificate are accompanied by a statement describing the uncertainty associated with these results. It is also a requirement for test laboratories under the following circumstances:

(a) where it is required by the client,
(b) where it is required by the specification calling up the test, and
(c) where the uncertainty affects compliance to a specification or limit.

Uncertainty evaluation is also recommended for the test laboratory to understand which aspects of the test procedure have the greatest effects on the results so that such aspects may be closely controlled or monitored.

DIFFERENCES AND COMMONALITIES BETWEEN ISO, CEN AND ASTM APPROACHES TO MEASUREMENT UNCERTAINTY IN TESTING

CEN policy is based on CEN/BT WG 122 recommendations [5] that: “Every new or revised European Standard including a measurement method or a test method providing quantitative results must address measurement uncertainty. A process for uncertainty evaluation or, if not possible, values of precision (i.e. repeatability and reproducibility) should normally be included.” CEN technical committees have the responsibility for implementing these recommendations. CEN recognises GUM and ISO 5725 [6] as the primary reference documents for uncertainty evaluation. It also recognises the ‘International vocabulary of basic and general terms in metrology’ (VIM) [3], and ISO 3534 [7] as the primary reference documents for terminology.

The ASTM approach [8] requires that every test method has a precision and bias section. These are mandatory parts of the test standard and are normally derived from an inter-laboratory study conducted during the development of the standard and in accordance with E691 [9]. ASTM E177 [10] defines precision as “the closeness of agreement between independent test results obtained under stipulated conditions”. Precision is computed as a standard deviation of the test results – less precision is reflected by a larger standard deviation. It is calculated for repeatability and reproducibility. Bias is the difference between the mean of a large number of test results and an accepted reference value. Bias is therefore a measure of systematic errors influencing the measurement. In mechanical testing there are usually no accepted reference values. The bias, therefore, cannot be established. Hardness and Young’s modulus measurements are the only exceptions.

ASTM E456 [11] defines uncertainty as “an indication of the variability associated with a measured value that takes into account two major components of error: (1) bias, and (2) the random error attributed to the imprecision of the measurement process”.

For a testing laboratory to develop an estimate of uncertainty to be reported with their test results, the ASTM definition of uncertainty is not consistent with GUM. According to the ASTM definition only random error effects, i.e. Type A uncertainties are considered. The GUM methodology takes into account all sources of uncertainty and utilises additional sources of information.

A question was raised of whether the precision data in ASTM test methods could be used to satisfy a laboratory’s estimate of uncertainty if the test method was properly followed [1]. Clause A22.2 of the Form and Style for ASTM Standards [8] says: "It is neither appropriate for, nor the responsibility of, the test method to provide explicit values that a user would quote as their estimate of uncertainty. Uncertainty values must be based on data generated by a laboratory reporting results using the test method."

Precision and bias values such as those included in ASTM standards are likely to vary considerably if the material or the test conditions are different from those used in the study that produced them [12]. They can also change if the number of participating laboratories or the number of tests conducted is not sufficiently large.

In essence, the CEN/GUM approach qualifies the test result. The ASTM approach qualifies the test method.

There has been a lot of emphasis on reducing the within-laboratory variability (i.e. improving the repeatability precision) as if it is the only goal. Reducing the within-laboratory variability does not necessarily mean 'better' (in terms of quality) results. Figure 1 shows an example of not uncommon variability of fatigue life data from an inter-laboratory study where each laboratory conducted at least 3 repeat tests [12]. Despite the relatively small number of tests conducted the data indicates that in this case the between-laboratories variability is far more serious than the within-laboratory variability.

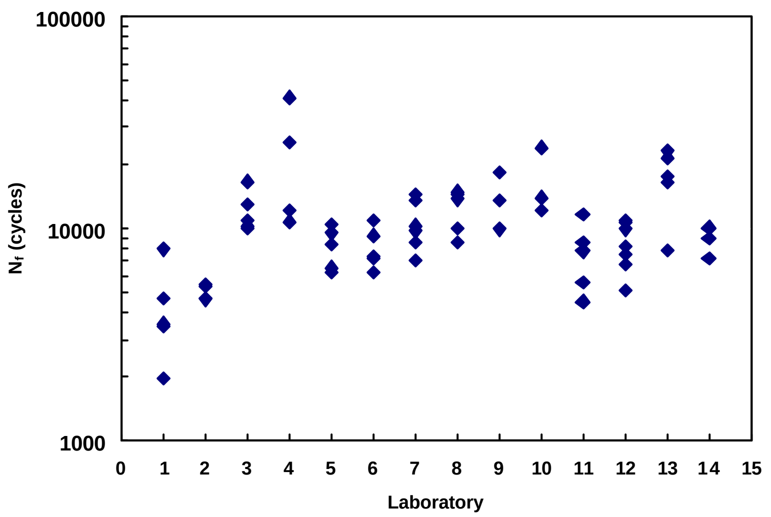

Figure 1 Fatigue life data (inter-laboratory tests, 9Cr1Mo steel, axial strain-control, total strain range = 0.6%, 525°C) [12]

According to the GUM, uncertainty of measurement comprises, in general terms, many components. Some may be evaluated from the statistical distribution of the results of a series of measurements and can be characterised by experimental standard deviations - these are called 'Type A'. The other components, which can also be characterised by standard deviations, are evaluated from assumed probability distributions based on other information, such as calibration certificates, manufacturer's statements or previous experience - these are called 'Type B'. All the components are combined to produce an expanded uncertainty with an associated confidence level of, normally, 95%.

Methodologies based on GUM have been developed within Europe including a project called UNCERT and, more recently, CEN Worksop 11 to address specific needs in the mechanical testing of metallic materials.

UNCERT [13] was a collaborative project, partly funded by the EC's Standards, Measurement and Testing programme. The project produced a manual that has, for the first time, enabled industry to evaluate the uncertainty in any of 17 specified mechanical tests (including tension, compression, creep, fatigue, fatigue crack growth, K_{1C}, CTOD, impact and hardness).

Three of the UNCERT procedures (namely for LCF, tension and creep testing) have been developed further by CEN Workshop 11 on "Measurement Uncertainty in Mechanical Testing" and published in 2005 [14]. Figure 2 shows a flowchart of the calculation procedure used in these procedures, which, as with UNCERT, are also based on the GUM methodology.

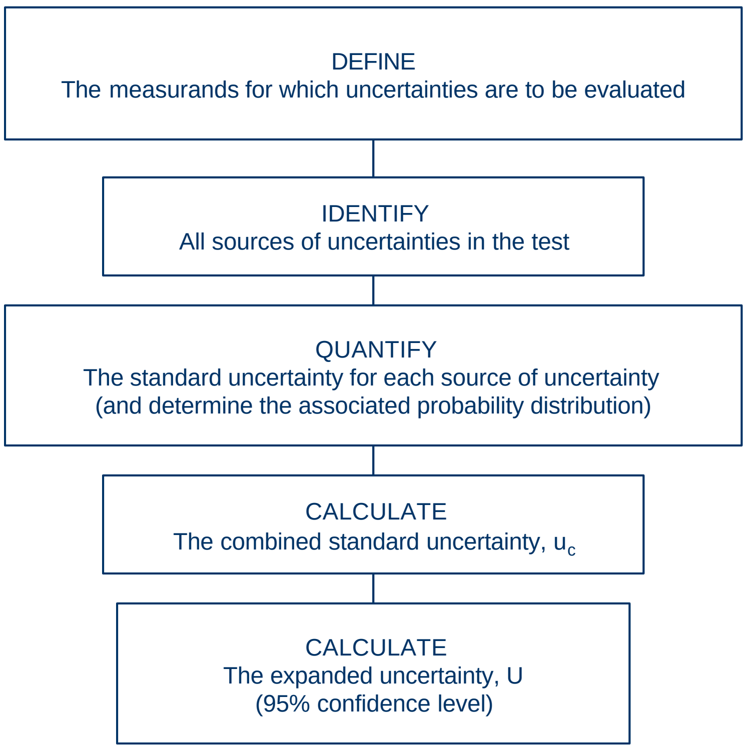

Figure 2 Steps for the uncertainty evaluation procedure used in UNCERT codes of practice and CEN Workshop 11 documents

RECOMMENDATIONS

Based on the above, the following is recommended:

1. Every new or revised test or measurement standard should address measurement uncertainty and give indicative values of precision of the results (in terms of the standard deviation values for repeatability and reproducibility). Wherever applicable, these precision values should be obtained from an inter-laboratory study as part of the validation phase in the development of the standard.

2. In addition, guidelines or, preferably, a detailed process for uncertainty evaluation for the test results should be included either in the test standard itself or as a stand-alone document. The methodology of calculating uncertainty should be consistent with GUM and the terminology used should be in accordance with VIM and/or other relevant ISO standards. If a complete uncertainty analysis is not possible, the test laboratory should at least attempt to identify all the components of uncertainty and make a reasonable estimation. The form of reporting the result should never give a wrong impression of the uncertainty. If no fit-for-purpose, relevant and justifiable information is available, it is better that no statement is given. No statement is better than a misleading one.

3. Inter-comparison tests and measurements – even between only two independent laboratories – are essential in highlighting insidious systematic errors in the test systems involved. Test laboratories should be encouraged to seek such activities.

4. Standard developers should address and strive continually to reduce systematic variability of test results between laboratories.

Some of the above recommendations are already included, in part, in CEN and ASTM policy documents.

Current activities within ISO/JCGM, ASTM Committee E11 and elsewhere aim to address some of the above-mentioned issues as well as provide solutions to some critical aspects relevant to uncertainty evaluation for tests such as those in the mechanical testing field.

REFERENCES

1. Ullman, N. R., 'Addressing measurement uncertainty in ASTM International's test methods' ASTM Standardization News, Oct 2005, 42-45.

2. 'Guide to the expression of uncertainty in measurement' (GUM) International Organisation for Standardization, Geneva, Switzerland, ISBN 92-67-10188-9, First Edition, 1993. Published by CEN as ENV 13005:1999.

3. ‘International vocabulary of basic and general terms in metrology’ (VIM) International Organisation for Standardization, Geneva, Switzerland, ISBN 92-67-01075-1, Second edition, 1993.

4. ISO 17025, ‘General requirements for accreditation of laboratories’

5. ‘Implementation of the concept of measurement uncertainty in European Standards’ CEN/BT/WG 122 ‘Uncertainty of measurement’, June 2002

6. ISO 5725, ‘Accuracy (trueness and precision) of measurement methods and results’

7. ISO 3534, ‘Statistics, vocabulary and symbols’

8. ‘Form and style for ASTM standards’, The “Blue Book”, ASTM International.

9. ASTM E691 ‘Conducting an interlaboratory study to determine the precision of a test method’ Annual Book of ASTM Standards, Vol. 14.02, ASTM International.

10. ASTM E177 ‘Use of the terms precision and bias in ASTM test methods’, Annual Book of ASTM Standards, Vol. 14.02, ASTM International.

11. ASTM E456 ‘Standard terminology relating to quality and statistics’, Annual Book of ASTM Standards, Vol. 14.02, ASTM International.

12. Kandil, F. A. and Dyson, B.F., ‘The influence of load-misalignment during uniaxial low-cycle fatigue testing – II: Applications’ Fatigue & Fracture of Engineering Materials & Structures, Vol. 16, No. 5, 1993, 529-537.

13. ‘UNCERT Manual of codes of practice for the determination of uncertainties in mechanical tests on metallic materials’ EU Contract SMT4-CT97-2165, Standards Measurement and Testing Programme, Edited by F A Kandil et al, Published by the National Physical Laboratory, UK, ISBN 0-946754-41-1, Issue 1, September 2000.

14. ‘Measurement uncertainties in mechanical tests on metallic materials’ — ‘Part 1: The evaluation of uncertainties in low-cycle fatigue testing’ CWA 15261-1: 2005 — ‘Part 2: The evaluation of uncertainties in tensile testing’ CWA 15261-2: 2005— ‘Part 3: The evaluation of uncertainties in creep testing’ CWA 15261-3: 2005.

Fathy Kandil is chairman of VAMAS TWA13, chairman of CEN Workshop 11 on ‘Measurement Uncertainty in Mechanical Testing’ and was co-ordinator of project UNCERT and member of CEN BT WG122 on ‘Measurement Uncertainty’. He is convenor or member of a number of other standards committees in ISO, BSI and ASTM.