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

SECTION 4

Guidelines for the estimation of uncertainty for a series of tests

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4.1 Laboratories' needs for uncertainty calculation

Testing laboratories are increasingly interested in the use of a unique calculation method of uncertainty for two reasons. The credibility of a laboratory is often increasingly linked to obtaining certification from an accredited organisation, and an indispensable criterion for the certification is the ability to provide uncertainties associated with each result of a test, which have been determined following a prescribed and established method. Therefore laboratories develop internal procedures aiming to satisfy the demands of certification organisations. The lack of agreement in individual test procedures leads laboratories to repeat tests already undertaken by clients or suppliers. These redundant tests require time, cost and resources. An agreed overall method and straightforward calculation routine for uncertainty is therefore needed urgently to harmonise results and to reduce the costs to the mechanical test laboratories. The viability of the testing regimes relies more on mastering measurement methods than on increasing the volume of tests carried out.

4.2 Past approach to estimating the uncertainty in multiple tests

The estimated testing uncertainty has relied until now on the determination of an estimate of the measurand y and the standard deviation s of a number n of individual measurements y_i:

$$y = \frac{\sum y_i}{n} \pm \sigma$$

The expression of measurement uncertainty relies heavily on the statistical magnitudes characterizing a series of n measurements. In this case the standard deviation s is not appropriate and is often not what the client demands. The UNCERT approach, which is based on ISO TAG4 document, has therefore concentrated on the development of a method of calculation that effectively only quantifies the uncertainties associated with the testing methods. The COPs are based on rigorous statistical methods but are complex, taking into account a lot of sources of error.

The UNCERT method has the advantage of allowing each laboratory to consider its own test configuration and integrating this into the uncertainty calculation. The calculation reflects the uncertainty in each individual test according to a defined configuration (equipment and method of test) but does not consider the nature or properties of the material being tested. The uncertainty associated with the inhomogeneity of the material is not part of the results and the problem addressed here is solely the quantification of testing uncertainty on a unique test sample. The calculation establishes the uncertainty linked to a particular test in a defined configuration, and does not take into account the statistical advantages of a series of tests. Thus, all tests appear to have the same uncertainty, which can lead to extreme cases (points exceptionally included whose interval of uncertainty would not cover the true value: see Figure 1 below). It does not include therefore the fact that multiple tests can reduce the uncertainty.

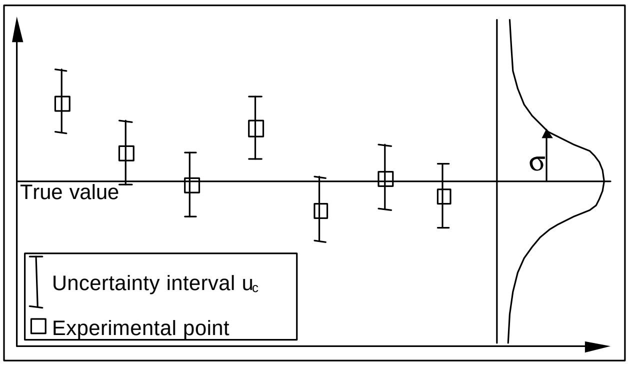

Figure 1 - Comparison between s and u_c on a chronological series.

4.3 How to repeat a series of tests

In most material studies, the mechanical material characterization is not based on a single (unique) test value. Laboratories perform a series of tests (according to their clients' demands) that clearly show a certain dispersion of results, giving rise to a standard deviation calculation. The dispersion originates from both experimental variation and testing material inhomogeneity.

This dispersion allows the laboratory to evaluate the interval in which the true value of the characteristic is likely to be found. For a series of n tests, the average value $\overline{q}$ of a characteristic q is obtained by:

$$\overline{q} = \frac{\sum q_i}{n}$$

And the uncertainty in this material characteristic is:

$$U = k\sqrt{\frac{u_c^2}{n} + \sigma^2}$$

where k is the level of confidence required by the client and u_c is the combined uncertainty linked to the method of test according to the COP. Two types of figure then appear according to the value of this combined uncertainty u_c:

If $u_c > s$, then a certain number $n = f(D/u_c)$ of tests should be carried out to increase the confidence in the average value M for the material. It is therefore necessary to repeat tests so that the effect of s becomes greater than u_c / n, and only the inherent effects of the material remains.

If $u_c < s$, the calculation needs a supplementary number n of iterations to be made to reduce s to an acceptable level D. The number of tests can be determined using the method of experimental design [1], which has the general expression:

$$n = 2\left(s \; \frac{U_{1-a/2} + U_{1-b}}{D} \right)^2$$

a is the non-detection measurement risk .
b is the erroneous measure detection risk
The method works to reduce the standard deviation s by the repetition of tests where the minimum limit is the testing sensitivity D required by the client.

4.4 Conclusion

Much progress has yet to be made regarding the quantification and interpretation of uncertainties in mechanical testing. The notion of uncertainty is still unclear, as often for testing clients as it is for the majority of laboratories. It is important to spread the idea that, whilst repeat tests reduce the uncertainty by a significant amount, too many repetitions are costly and often outside the client’s budget and timescale. Each laboratory should create their estimates in discussion with its clients according to the precision required, the number of tests to be performed, and by taking account of the testing uncertainties linked to the methods it uses. The limit of ‘precision’ that the laboratory will not be able to exceed will then be fixed by the variation in the material itself. The laboratory’s main target should be to respond precisely to the client’s demand.

References

1. Jacques Demonsant, Comprendre et mener des plans d'expériences, AFNOR, 1996.