PART B: SINGLE SPECIMEN METHODS

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INTRODUCTION

Within the intercomparison program it was the first goal for all participants to produce a series of tests following the multiple specimen method resulting in a valid J-Δa curve and, if possible, also a valid δ-Δa curve. Participants were allowed to test individual specimens within the multiple specimen series using single specimen methods. It was proposed to test two specimens up to Δa_{max} ($\approx$ 1 mm, depending on specimen size) and to stop one additional test in the crack growth range $0 < \Delta a < 0.3$ mm in order to validate the R-curves for evaluation of initiation values.

A total of 100 single specimen R-curves for the three different materials were delivered for this evaluation, 81 of CT-specimens and 19 of SENB-specimens. Some of the tests were performed using partial unloading and a potential drop method in parallel, 56 partial unloading tests and 44 potential drop evaluations. The main effort was done on the reference material M 3 using CT-specimens.

EVALUATION PROCEDURE

The three different methods, used by the participants, are abbreviated in the following by

UC Partial Unloading Compliance
DC Direct Current Potential Drop
AC Alternating Current Potential Drop

The R-curves were defined by sets of J-Δa-points. The number of measured points varied from about 10 up to about 60, depending on the amount of total crack extension, the material, the method and the laboratory. This resulted in general in a significantly greater number of valid data points for a R-curve regression than the minimum number of tests specified for the multiple specimen method.

Part of the evaluations done for the multiple specimen series was repeated for those single specimen tests loaded up to a sufficient amount of crack extension. This discussion will be limited to some specific problems of single specimen methods.

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Δa-Prediction Capability of the Methods

The most important criterion for the applicability of any single specimen method is the capability to predict the crack extension during the test. The only direct check is the comparison of the last estimate of the indirect method (Δa(predicted)) with the crack extension measured on the fracture surface after final fracture of the test specimen (Δa(measured)).

The correlation of measured and predicted Δa-values is shown in Figures 1, 2a and 3a for the three materials. The lines mark the ideal correlation and the upper and lower limits of errors accepted by the procedure, i.e. the greater of 0.15 mm or 15 % of the measured Δa-value. Different methods and specimen types are plotted by different symbols.

For the medium toughness material (M 1, BS 4360) positive and negative errors are nearly evenly distributed. Positive errors predominate slightly, mainly due to the DC-results. With only one exception all errors are within the tolerable error band.

For the low toughness material (M 2, Al 5083) all errors are negative with only one exception. Especially for small amounts of crack extension up to about 1 mm nearly 50 % of the predicted values is significantly smaller than the fracture surface measurements done by optical microscopy. About 30 % of the measurements are outside of the tolerable error band.

In contrast for the high toughness material (M 3, BS 1501) the majority of the errors is positive, negative errors appear only for crack extensions greater than 1 mm. Nearly 30 % of the measurements are outside of the tolerable error band.

Some participants delivered series of 5 to 10 single specimen tests, covering the crack growth range from less than 0.5 mm to more than Δa_{max}. Laboratory specific results of unloading compliance tests for the materials M 2 and M 3 are plotted in Figures 2b and 3b, respectively.

For the material M 2 both series are underestimating the crack extension. For the CT-specimens of laboratory 9 the difference is nearly constant in the range of 0.15 mm while laboratory 6 underestimated the crack growth of the SENB-specimens by about 0.25 mm.

Post examination of some fracture surfaces of M2- specimens by scanning electron microscopy (SEM) indicated that the standard light microscope measurements as done by the participants tend to overestimate at least small amounts of crack extension by about 0.15 mm (Figure 3 in Part C). Though this difference was not checked for larger crack extensions it is likely, that a correction of this order has to be applied to all the tests

compared in Figure 2a. Then the agreement of predicted and measured crack extensions would be nearly perfect for the CT-specimens and acceptable for the SENB-specimens.

For the material M 3 the three series in Figure 3b differ by less than 0.15 mm. But below 1 mm of crack extension all predictions are overestimating. Only the CT-specimen tests of laboratory 9 are underestimating beyond 1 mm. At least the first finding seems to be systematic and independent of the specimen type. It is not yet known whether this is due to compliance evaluation problems for large deformations and low crack extensions or to the optical measurement of crack extensions as found for M 2.

These results show that the prediction capability of the unloading compliance technique is sufficient to meet the requirements of the procedure in the majority of tests. The quality may depend on the material toughness, but apparent inaccuracies may be due to the light optical measurement as applied in the multiple specimen evaluation as well. The agreement is best for the medium toughness material. There is a tendency to underestimate crack extension for lower toughness and to overestimate for higher toughness as compared to the light optical measurements. If this trend is true critical J-values derived from these R-curves may be overestimated for low toughness and underestimated for high toughness materials as compared to multiple specimen results. Similar checks for potential drop evaluations are not possible, because some of the laboratories use the measured final crack extension for calibration of each individual test.

Resulting Shape of R-Curves

All R-curves were plotted and evaluated using the data points as returned by the participants. These curves agreed in general with the scatter band of the multiple specimen series. Deviations can be understood based on the Δa-prediction errors discussed above. But some of the curves showed deviations from the behaviour normally expected from R-curves. Some of the problems are:

- scatter, crack growth steps forward or backward in the initial part of UC-tests causing problems how to define $\Delta a=0$.
- "negative crack growth" in the initial part of UC-tests and DC-tests causing problems how to define $\Delta a=0$.
- S-shape of the initial part of R-curves from DC-tests

To give an estimate of the probability of these problems the number of curves concerned is given:

M1:	3	out of	12
M2:	5	out of	16
M3	7	out of	16

These R-curves may become comparable only after appropriate corrections not supplied by the procedure.

DISCUSSION

These results show that the capabilities of the single specimen methods applied to predict Δa and to derive R-curves is sufficient to meet the requirements of the procedure in the majority of tests. To ensure this, specific experimental problems of the single specimen methods (e.g. "negative crack growth", calibration for potential drop) contributing to crack growth prediction errors and badly defined inititial parts of R-curves have to be handled carefully.

In addition it should be considered that the prediction error allowed by the procedure is comparable to the accuracy that can be expected for the optical fracture surface measurement itself. Thus errors slightly greater than the allowed error do not necessarily indicate serious deficiencies of the applied indirect methods. The errors seem to depend on toughness systematically, but possible errors in the light optical measurement as indicated especially for the aluminium alloy M 2 should be considered as possible sources for multiple specimen series as well.

Because of the impact of possible problems in the initial part of R-curves on derived fracture parameters the procedure requires one test unloaded at a small amount of crack extension. This ensures that the R-curves resulting from single specimen evaluations are comparable with multiple specimen results and the scatter bands are of similar width, if R-curves with obvious problems in the initial part are consequently excluded from further evaluation.

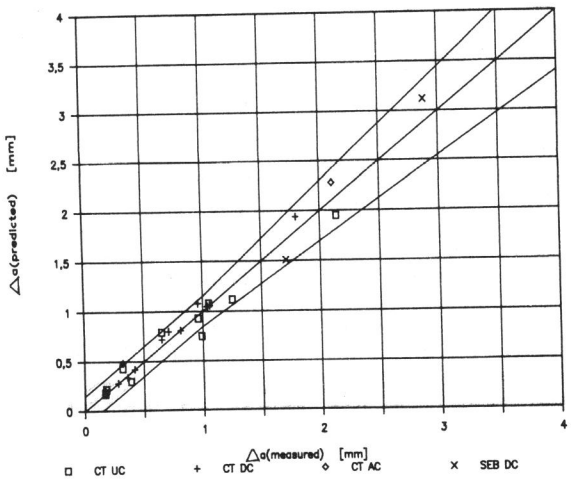

Fig. 1. Correlation of measured and predicted crack growth; M 1 steel BS 4360 Grade 50 E

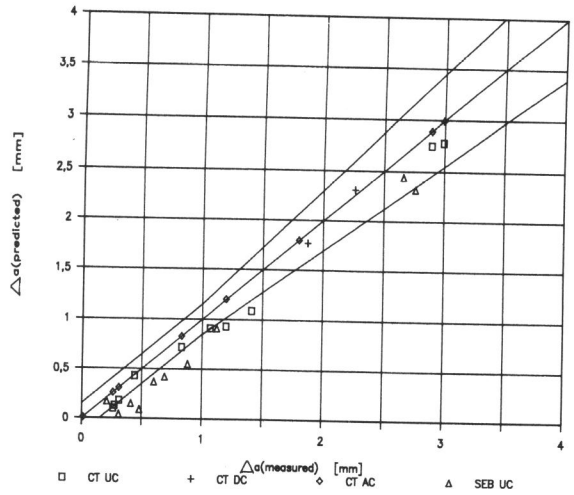

Fig. 2a. Correlation of measured and predicted crack growth; Al 5083-0

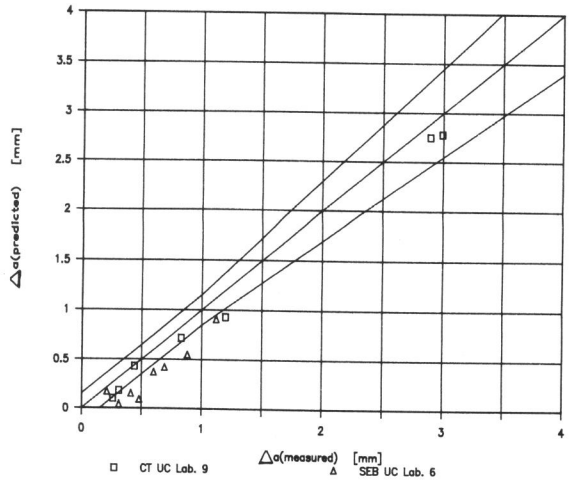

Fig. 2b. Correlation of measured and predicted crack growth; Al 5083-0; UC-results of two laboratories

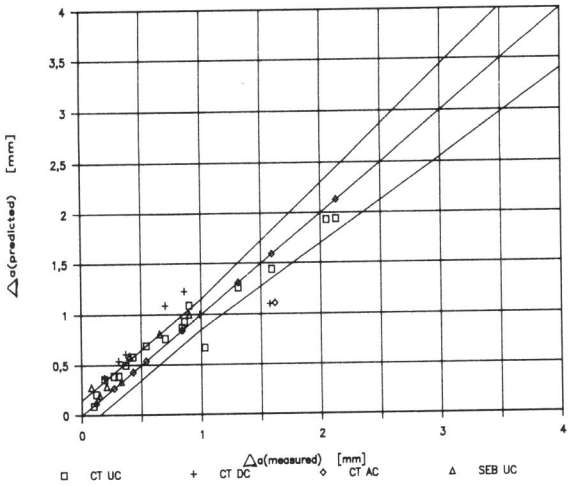

Fig. 3a. Correlation of measured and predicted crack growth; steel B S 1501 224 Grade 490 B

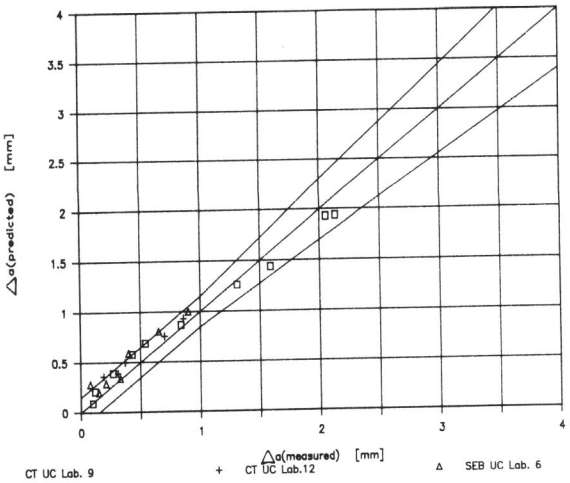

Fig 3b. Correlation of measured and predicted crack growth; steel BS 1501; UC-results of three laboratories