SINGLE SPECIMEN METHODS TO EVALUATE J-R-CURVES FROM INSTRUMENTED CHARPY TESTS: RESULTS OF A ROUND ROBIN

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Based on a previous round robin exercise of the German DVM-group on instrumented impact testing another exercise was performed to explore the possibilities of extended evaluations like single specimen methods. The previously determined multi-specimen cleavage J_R-curve serves as a reference. Different methods like, e.g. the key curve method were applied. Overall, the results are encouraging and the agreement of the calculated J_R-curve with the reference curve is quite good especially for large amounts of crack extension. However, there is some uncertainty left in the first part of the J_R-curve, where notch blunting and initiation of crack growth take place: In this region, the calculated curves tend to overestimate the crack resistance. Thus, the possibilities to determine initiation toughness values from such curves and their physical meaning need to be further clarified.

INTRODUCTION

Recently, within an experimental round robin exercise of the DVM task group "Instrumented Impact Testing" the accuracy of instrumented Charpy tests and the influence of the notch shape on the test results was investigated. Three different notch shapes were considered: V-notches, spark eroded slots (notch root radius: 0.02mm), and fatigued cracks, all of a depth of 2 mm. About 400 specimens have been tested by seventeen participating organisations. The results are reported in Ref. (1). As shown therein, from the specimens tested in the brittle-to ductile transition regime the so-called cleavage resistance curve could be established by plotting the J-values at initiation of cleavage fracture versus the corresponding crack extension (Fig. 1). These points form a multi-specimen J_R-curve, which turned out to be practically independent of the different notch shapes, at least within the observed scatter. Despite usual size requirements are not satisfied this cleavage J_R-curve can be used for an improved comparative characterisation of ferritic steels as discussed in (1).

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Based on the results of this previous DVM round robin the present investigations aimed at the evaluation of approximate J-R-curves, particularly to explore the possibilities of single specimen methods when applied to instrumented Charpy tests. Six out of the seventeen originally participating organisations took part in this task. The participants were free to use an evaluation method of their choice. The contribution of each participant can be seen in Table 1.

An exponential curve $J = C\ \Delta a^p$ fitted through the cleavage data points (see Fig. 1) serves as a reference for comparison with results of single specimen methods. In order to improve the experimental basis for small amounts of crack growth, where especially precracked specimens showed no cleavage events (see (1): "cleavage gap"), and to determine the blunting line, additional low-blow tests using specimens with deeper fatigue cracks were performed by one of the participants (see Table 1). The essential results of this task are summarized here. More details are given in Ref. (2).

SINGLE SPECIMEN METHODS

A well known single specimen method is the so-called key curve method according to Ernst et al (3,4). It is based on the fact, that the shape of the force-displacement curve is directly related to the crack length, i.e. to the ductile crack extension. Therefore, the evaluations of force displacement curves allow to calculate the crack extension and finally the crack resistance in terms of a J_R-curve.

Dahl et al (5, 6) further developed this procedure and applied it to instrumented Charpy tests. They used spline functions to smooth the force-displacement curves. Finally the resulting J_R-data are fitted by exponential functions.

Ott and Böhme (7) proposed to fit the force-displacement signals at first by polynomial functions of the fourth or fifth order, which consequently enables the derivation of analytical solutions.

Schindler (8) derived a single specimen evaluation method by a two-parameter approach that just requires the totally absorbed energy and the plastic energy at the maximum of the force displacement curve as experimental input data.

These three approaches have been applied by the corresponding participants and the results are given in Fig. 2 in comparison with the reference curve. In addition, the results of the low-blow tests performed by Blumenauer et al. (see Table 1) are given. Considering the scatter of the data the agreement of the different approaches with the experimental results is reasonable. This accuracy is often sufficient for engineering purposes. However, for small crack extensions these methods so far may be not accurate enough for the determination of initiation values.

J_R-CURVE ESTIMATES BASED ON THE CHARPY UPPER SHELF ENERGY

Several semi-empirical correlation functions are available to correlate results of Charpy-V tests with fracture toughness, but only few of them enable J-R-curves to be estimated. Two of these approaches were applied during this exercise:

At the BAM/Berlin (9) a procedure was developed to estimate a static J_R-curve from the value of the upper shelf energy of a standardized Charpy test. This procedure was applied by Wobst and his colleagues (see Tab. 1) to one of their round robin experiments.

Another estimation formula was obtained by Schindler (10) by simplifying his above mentioned single specimen method, and more details are also given in (2).

The results of these methods are presented in Fig. 3 in comparison to the reference curve. Again the overall agreement of the results of both approaches to the experimental multi-specimen data is reasonably good, and might often be sufficient for engineering purposes.

DISCUSSION

This comparison of different procedures, however, does not allow for qualifying or disqualifying any of the methods. It must be clearly stated that the participants did not evaluate the same experiment, but just one of their own ones. Furthermore, some input-parameters like, e.g. the strain hardening exponent were chosen by individual best estimate. Therefore, this exercise has to be considered as an attempt within the DVM-group to figure out, whether the procedures yield reliable data. The obtained results are encouraging, leading us to continue with a more detailed and directly comparable procedure.

CONCLUSIONS

Overall, the results of the applied key curve methods and the semi-empirical correlations are encouraging. The agreement of the J_R-curves calculated from a single test of the ductile fracture regime ("upper shelf") with the one obtained experimentally by the multi-specimen cleavage method is quite good for large amounts of crack extension. This is true even for the curves based on just the fracture energy mentioned above. However, there is some uncertainty left in the first part of the J_R-curve, where notch blunting and initiation of crack growth take place: In this region, the calculated curves tend to overestimate the crack resistance. Thus, the possibilities to determine initiation toughness values from such curves and their physical meaning need to be further clarified.

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Organisation	Participant	Procedure
IEHK Aachen	Stark-Seuken	*key-curve method*
BAM Berlin	Wobst	*correlation with Charpy energy*
EMPA Dübendorf	Schindler	*EMPA-single specimen method; correlation with Charpy energy*
IWM Freiburg	Böhme	*key-curve method*
Otto von Guericke University, Magdeburg	Blumenauer, Eichler, Ude	*low-blow tests (multiple specimen technique)*
Forschungszentrum Rossendorf	Viehrig, Richter	*acoustic emission (multiple specimen technique)*

TABLE 1 Participants of this round robin exercise

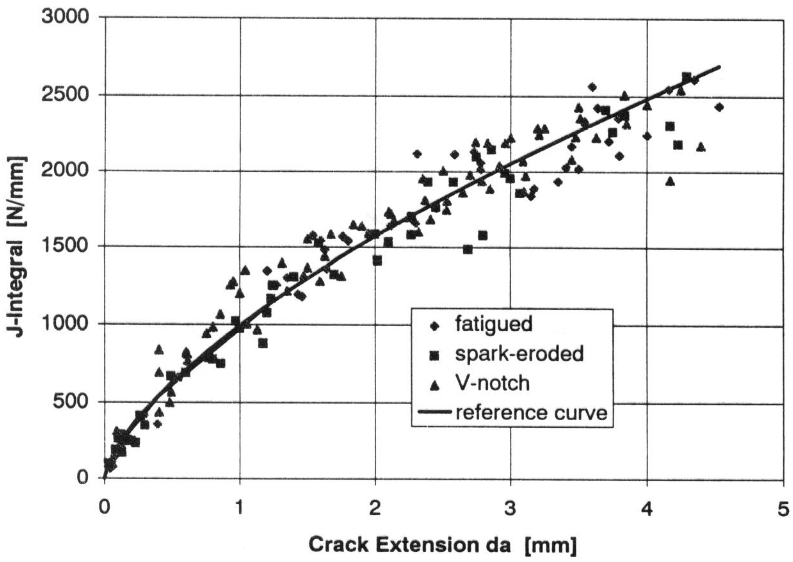

Figure 1 "Cleavage R-Curve" data of the previous DVM round robin (1) and exponential fit as reference curve

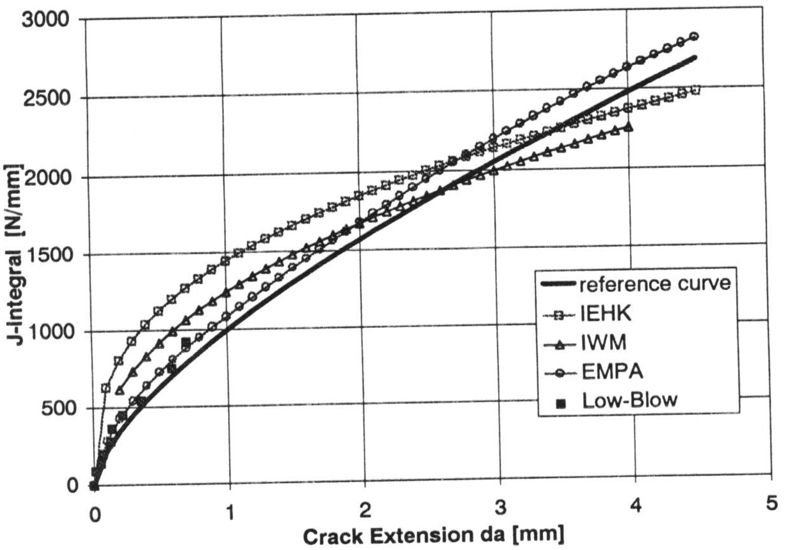

Figure 2 Results of single specimen evaluations and low-blow tests in comparison to the reference curve

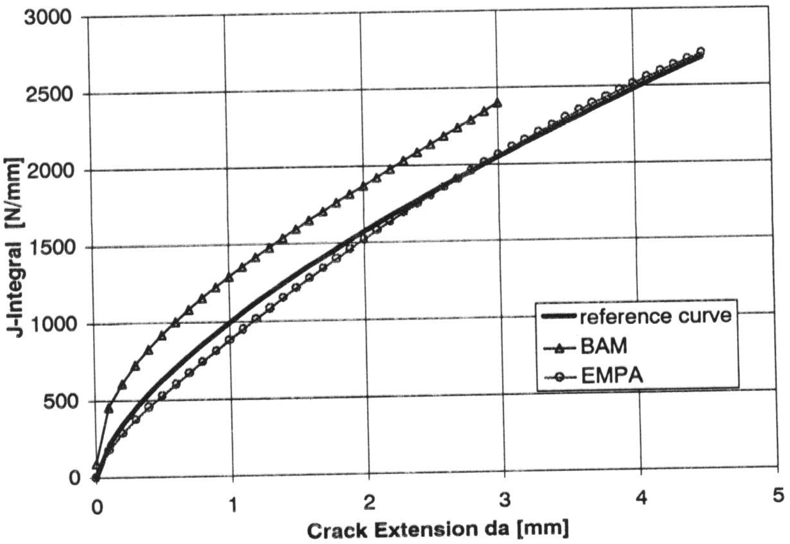

Figure 3 Results of semi-empirical calculations in comparison to the reference curve