R-CURVES EVALUATION FOR CENTRE CRACKED PANELS

K-H. Schwalbe* and W. Setz**

*GKSS Research Centre Geesthacht, 2054 Geesthacht,
Federal Republic of Germany
**DFVLR, 5000 Köln 90, Federal Republic of Germany

ABSTRACT

Results of R-curve tests on centre cracked tension specimens are reported. There is no size effect of the R-curve based on the effective stress intensity if a certain stress level in the net section is not exceeded. The R-curves were also evaluated in K_J terms. Failure predictions were made using both kinds of R-curves.

KEYWORDS

R-curve; size effect; effective stress intensity; prediction of instability.

TEST PROGRAMME AND PROCEDURES

R-curves were determined on centre cracked panels made of 2 mm thick sheets of the aluminum alloy 2024-T3, 7075-T6, and 7475-T761. The tests were done as described by Schwalbe (1980). The specimen width was varied between 60 and 600 mm, the normalised crack length a_o/W was varied between 0.2 and 0.8. The aim of this investigation was to obtain informations about a possible influence of specimen width and crack length on the shape of the R-curve. Detailed information about the results will be given by Schwalbe and Setz. In the present paper a selection of the experimental findings will be presented along with some further evaluations of the raw data.

The R-curves were determined as effective stress intensity (Eq. (9) in [1]) versus effective crack length increase. The effective crack length was determined by the compliance method and by the electric potential method as describes by Schwalbe (1980). The calculation of the stress intensity using the effective crack length was intended to account for plasticity effects.

In addition, the crack growth resistance was also evaluated via the J-integral as K_J (Landes, Walker, and Clarke (1979)):

$$J = \frac{(1-\nu^2)K^2}{E} + \frac{A}{B(W-a_{phys})} \tag{1a}$$

$$K = \sigma\sqrt{\pi a_{phys}} \cdot \sqrt{\sec\frac{\pi a_{phys}}{2W}} \tag{1b}$$

$$K_J = \sqrt{\frac{J \cdot E}{1-\nu^2}} \tag{2}$$

A is the area shown in Fig. 1. For the J-Integral evaluation the total elongation of the specimens was measured by an LVDT across two points of the specimens close to the clamps.

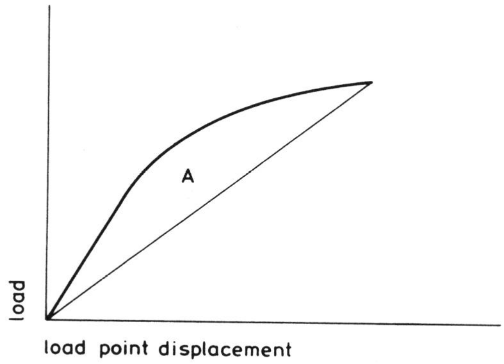

Fig. 1: Area A used for the determination of J for centre cracked tension specimens [3].

RESULTS AND DISCUSSION

Figs. 2 and 3 show examples for the generally observed behaviour of the R-curves $K_{eff} = f(\Delta a_{eff})$: there is no influence of specimen width and crack length at the initial part of the R-curve. However, at larger values of crack resistance individual R-curves start to deviate from the scatter band of all specimens. This deviation occurs the later the wider the specimen is and the longer the crack is. It was tried to find a criterion for the deviation points. A certain degree of net section plasticity $\sigma_n/\sigma_{o,2}$ seems to give a reasonable criterion. From Figs. 2 and 3 and from the other results not shown here the condition

$$\sigma_n \simeq 0.9\sigma_{o,2} \tag{3}$$

can be derived as an upper limit of degree of plasticity.
Beyond this point the effective stress intensity does no longer serve as a correlation parameter for crack growth. It should be pointed out that this statement holds for situations which are comparable with centre cracked tension specimens.

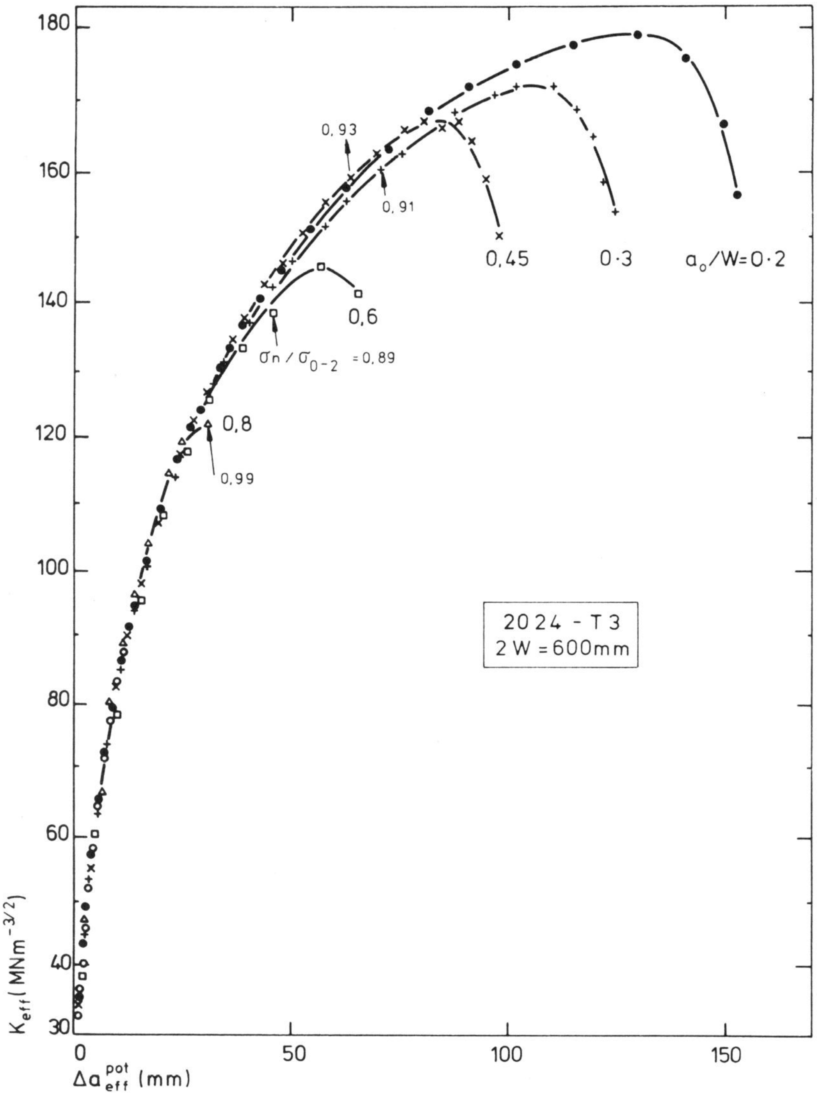

Fig. 2: R-curves for 600 mm wide specimens of 2024-T3 with varying crack length.

For the results described above, nonlinearity of the deformation behaviour was accounted for by the effective stress intensity, K_{eff}, whereby the small scale yielding plastic zone radius was added to the physical crack length. In addition, an approach was applied which uses K_J as a loading parameter (see Eqs. (1) and (2)). The J-integral was formally evaluated using the current physical crack length, a_{phys}. The results are shown in Figs. 4 and 5. It can be seen that K_J is not a better correlation parameter than K_{eff}. Furthermore, the limit beyond which crack growth can no longer be corre-

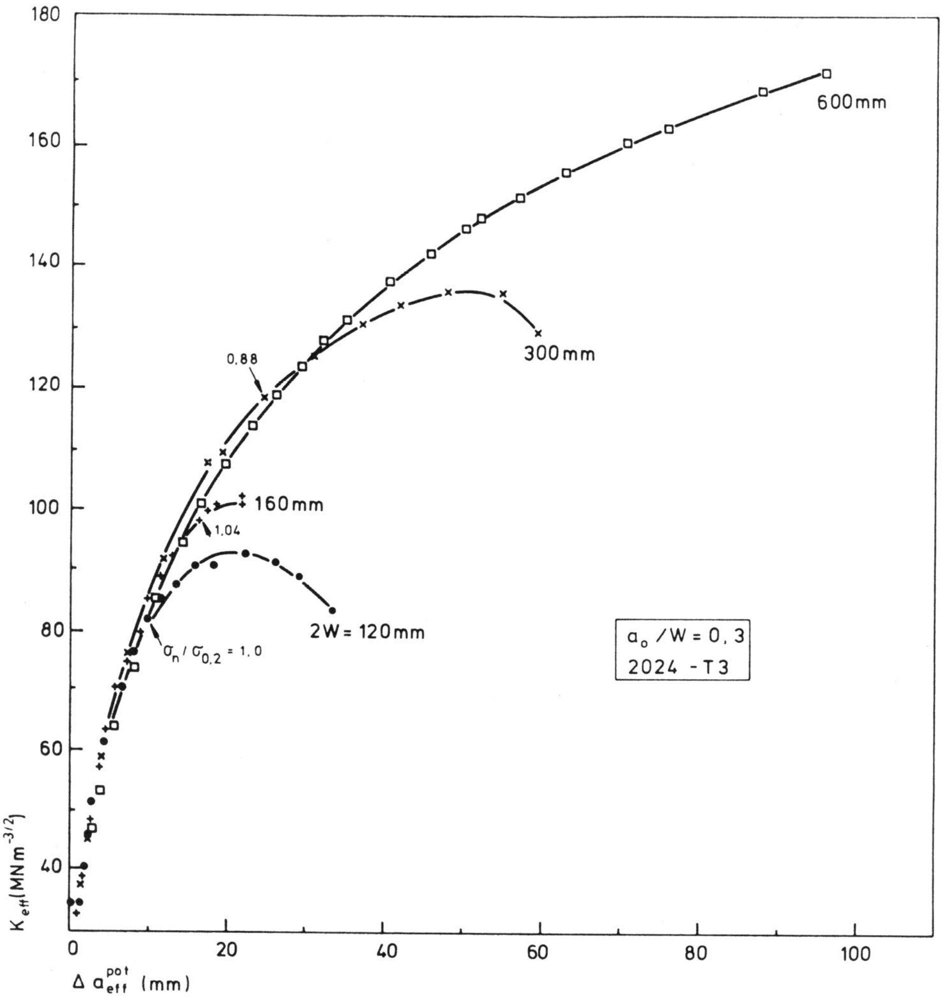

Fig. 3: R-curves for specimens of 2024-T3 with $a_o/W \simeq 0.3$ with varying width.

lated with K_J is not given by a certain percentage of crack growth, since at the deviation points the normalised crack growth $\Delta a_{phys}/a_o$ ranges from 2.2 to 59 per cent, the crack growth normalised by the remaining ligament ($W-a_{phys}$) from 1.4 to 25 per cent. The present data does not support the suggestion of Shih, de Lorenzi, and Andrews (1979) that the limit of J-controlled crack growth is given by a certain percentage of crack growth. Rather, the very same condition seems to apply as in the case of the K_{eff} based R-curves.

A further conclusion can be drawn: the J-integral at least in the form of Eq.(1) is by no means a better correlation parameter than K_{eff}.

THAMES POLYTECHNIC LIBRARY

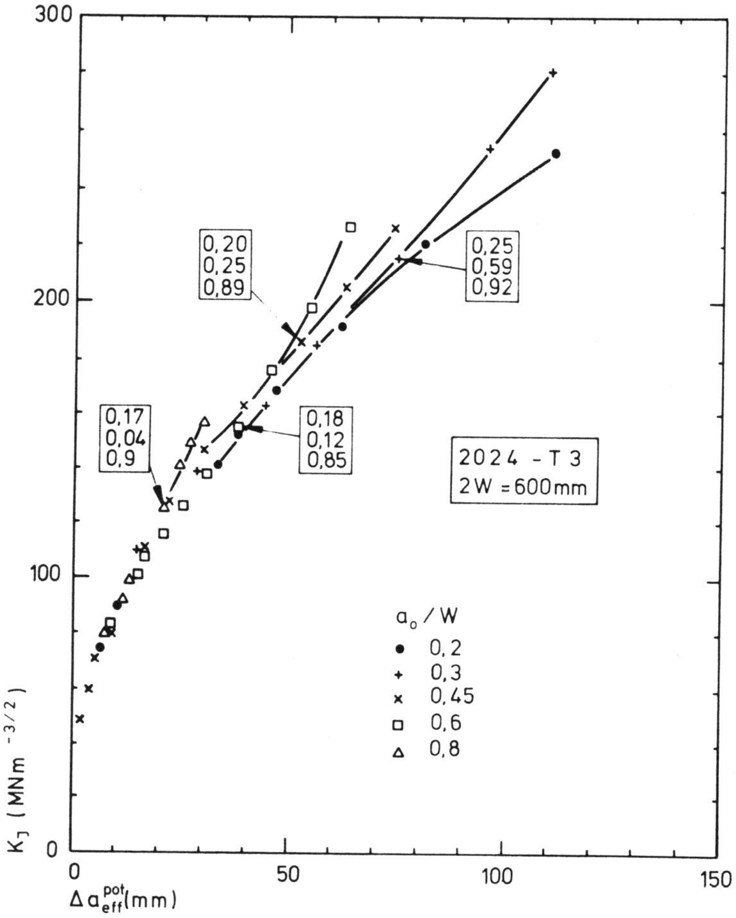

Fig. 4: R-curves for variable a_o/W on K_J basis. Upper-numbers at the arrows indicate $\Delta a_{phys}/(W-a_{phys})$, second numbers indicate $\Delta a_{phys}/a_o$, lower numbers indicate $\sigma_n/\sigma_{o,2}$.

In order to explore the significance of both kinds of R-curves with respect to instability failure predictions were made for the 600 mm wide specimens. Fig. 6a shows the experimental failure stresses along with the values predicted from the K_{eff}-curves plotted versus the fatigue precrack length. The prediction yields a scatterband due to the scatter of the R-curve. As can be seen the critical stress is reasonably well predicted. However, although Fig. 6a characterizes the practical situation, where one is interested to get the failure stress for a given precrack length it does not represent the physically true loci of instability. As can be seen in Fig. 6b plotting the instability data versus the critical crack length (experimental σ_c versus experimental a_c/W, theoretical σ_c versus theoretical a_c/W) shifts the loci of fracture versus the locus of general yield. Here the prediction yields a slight overestimation which may be due

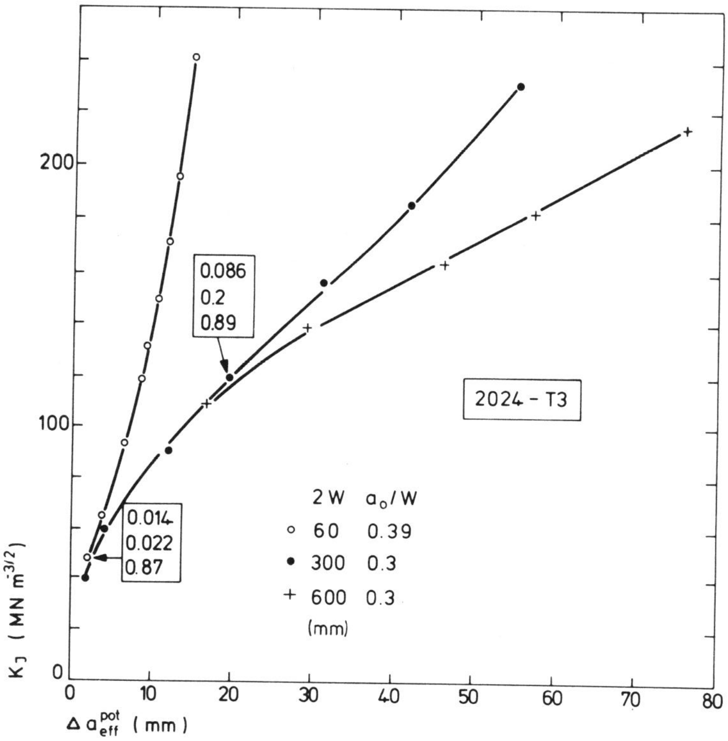

Fig. 5: R-curves for variable width on K_J basis. The numbers at the arrows have the same significance as in Fig. 4.

to the difficulties to derive the proper crack length from the graphical construction.

In Fig. 7 the same situation is shown for the K_J-curves. It is obvious that the K_J-curve yields inadequate predictions.

CONCLUSIONS

R-curve tests were carried out on centre cracked tensile specimens of 2 mm thick sheets of three aluminum alloys. From the experimental data the following conclusions can be drawn:

- The effective stress intensity, K_{eff}, serves as a correlation parameter for crack growth up to a load level which can approximately be described as a net section stress criterion. The criterion reads

$$\sigma_n \leq 0.9\sigma_{o.2}$$

- R-curves based on K_J were generated from the raw data. K_J correlates crack growth up to the same net section load level as above.

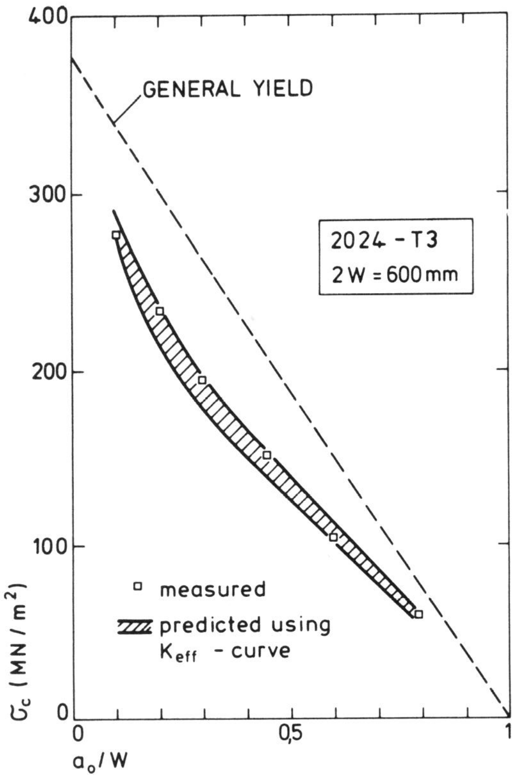

Fig. 6a:

Experimental and predicted failure stress as a function of the precrack length. The prediction is based on the K_{eff}-curve.

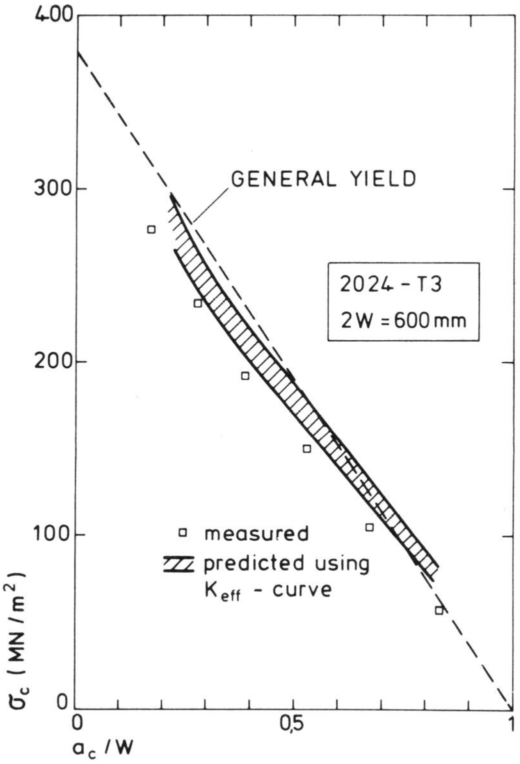

Fig. 6b:

As Fig. 6a, however plotted versus experimental and predicted critical crack length, respectively.

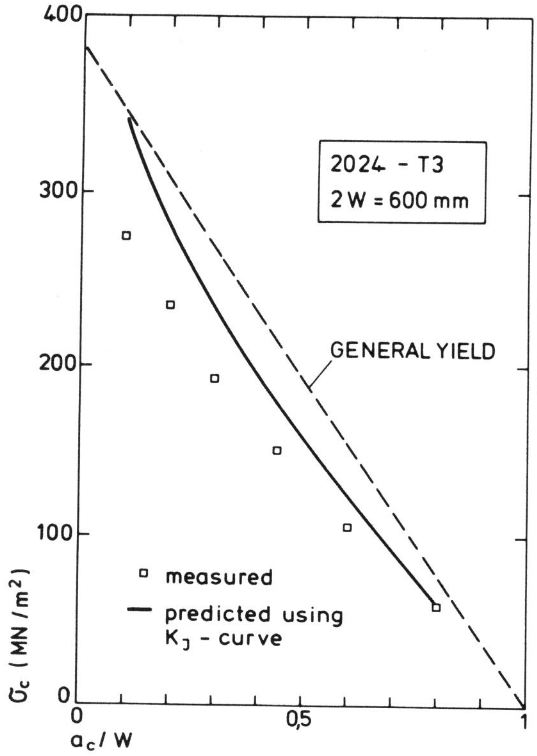

Fig. 7a:

Experimental and predicted failure stress as a function of the pre-crack length. The prediction is based on the K_J-curve.

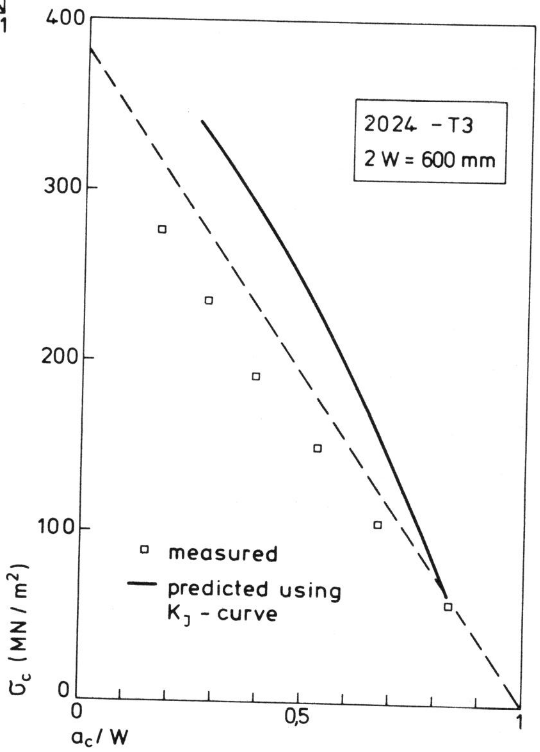

Fig. 7b:

As Fig. 7a, however plotted versus experimental and predicted critical crack length, respectively.

- Failure stresses were predicted using both kinds of R-curves. It was found that the K_{eff}-curve yields good results whereas the results based on the K_J-curve exhibited poor coincidence with the experimental data.

ACKNOWLEDGEMENTS

The financial support of this work by the Deutsche Forschungsgemeinschaft is gratefully acknowledged.

NOMENCALTURE

a_o	fatigue precrack length
a_c	critical crack length (physical)
a_{phys}	physical crack length
Δa_{eff}	effective crack length minus a_o
A	area under the load/load point displacement diagram as shown in Fig. 1
B	specimen thickness
K	stress intensity calculated with a_{phys}
K_{eff}	effective K calculated with a_{eff}
K_J	K calculated by Eq. (1)
J	J-Integral
σ	applied stress
σ_c	critical stress
σ_n	net section stress
$\sigma_{0.2}$	0.2 percent yield strength

REFERENCES

Landes, J.D., H. Walker, and G.A. Clarke (1979). Evaluation of Estimation Procedures Used in J-Integral Testing, ASTM STP 668, 266-287.

Schwalbe, K.-H. (1980). Introduction to Session Nine: Thin Sheet Fracture Mechanics, this conference.

Schwalbe, K.-H. and W. Setz (submitted for publication). R-Curve and Fracture Toughness of Thin Sheet Materials.

Shih, C.F., H.G. de Lorenzi, and W.R. Andrews. Studies on Crack Initiation and Stable Crack Growth, ASTM STP 668, 65 - 120.