QUANTITATIVE FRACTURE SURFACE PROFILE ANALYSIS IN ENVIRONMENTAL FATIGUE TESTS*

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Fracture surface profile parameters as the "lineal roughness", the "arithmetic average surface roughness" and the "root mean square average surface roughness" have been evaluated on the trace profiles obtained by vertical sectioning the fracture surface of an environmental fatigued specimen (A 533B steel) along the crack growth direction. The evaluations have been performed by means of an automatic image analysis system interfaced to a minicomputer. The results obtained are compared to the ones previously computed after manually digitizing the crack fracture surface trace profiles, metallographically reproduced. Quantitative indications of microstructural features underlying fatigue processes are deduced as a function of stress intensity factor range.

INTRODUCTION

The quantification of microstructural features involved in fatigued specimens are limited by the existence of non planar fracture surfaces which do not verify the requirement of randomness in orientation.

Quantitative evaluation of fracture surface profile features on two-dimensional sections cut through the fracture surface, though less directly, can easily be obtained, giving indications of the processes underlying crack growth.

Previous work, performed by the author (1), on two dimensional sections of fatigued specimens in a semi-automatic way, appeared time consuming and was limited for this reason only to discrete portions of the crack path: the results obtained suffered from this limitation and can induce misleading conclusions.

The possibility to rely on an image analysis system allows to short down the time needed to examine a trace crack profile and to reproduce it all along the fatigue crack path.

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EXPERIMENTAL PROCEDURE

One A 533B steel 1 CT specimen already used in environmental fatigue tests (R. L. Jones (2)) performed at 288 °C in circulating water simulating boiling water reactor conditions has been vertically sectioned at mid-thickness in the crack growth direction. The specimen was mounted and prepared metallographically to evidence the fracture surface trace profile. A sequence of photomicrographs was taken in order to reproduce all the trace profile length, examined in strips of equal length in the semi-automatic procedure. The same trace profile has been examined by means of the Bausch-Lamb Omnicon 3000 image analyzer, interfaced to a Nova 4 Data General minicomputer, at the same magnification above selected (x500) for semiautomatic analysis.

ROUGHNESS PARAMETERS EXAMINED

Different roughness profile trace parameters have been proposed by Pickens and Gurland (3), Chermant et al (4), Underwood and Chakrabortty (5). Attention has here been focused on:

- the "lineal roughness"parameter, R_L, defined as the ratio between the true profile crack length and its projection in the crack growth direction:

$$R_L = \frac{L_{trace}}{L_{projected}}$$

- the "arithmetic average surface roughness", μ_A, defined as:

$$\mu_A = \frac{\sum_n |h_i|}{n}$$

  where h_i are vertical distances between the trace profile sampled and a line, parallel to the crack growth direction, averaging all the heights of the trace portion examined.

- the "root mean square average surface roughness", μ_{RMS} defined as

$$\mu_{RMS} = \left(\frac{\sum_n h_i^2}{n} \right)^{1/2}$$

  where h_i are the above defined vertical deviations from the mean height value.

The semi-automatic analysis has been performed by computer reproducing the trace profile after manual digitization of the points which best allow to reproduce the crack profile by means of a segmented line. R_L is in this case evaluated as the ratio between the true length of the computer rebuilt profile and its projection along the crack growth direction. μ_A, μ_{RMS} are evaluated by computer sampling, at a fixed step, the rebuilt profile. All the semi-automatic evaluations are performed on crack propagation lengths $\Delta a = 0.95$ mm at 500 x with sampling step of 4 microns.

R_L, μ_A, μ_{RMS} are evaluated in the automatic analysis at the same magnification as above specified both on the same crack profile portion lengths $\Delta a = 0.95$ mm and on crack propagation lengths $\Delta a = 0.475$ mm and $\Delta a = 1.9$ mm.

RESULTS AND DISCUSSION

μ_A, μ_{RMS}, R_L obtained semiautomatically are plotted, in fig. 1, V/S the stress intensity factor range ΔK acting during the environmental fatigue test.

As previously pointed out μ_A, μ_{RMS} are a sensitive function both of the applied ΔK and of the local microstructural features, increasing in general with ΔK during crack growth. R_L values, less sensitive to the applied stress state, suffer in this case from the approximation introduced to rebuild the profile.

μ_A, μ_{RMS}, R_L values V/S ΔK, obtained with the image analyzer, are given in figgs. 2 ÷ 5, for the different crack propagation lengths examined. All the evaluations rely in this case on all the points of the crack profile.

Samplings of the crack profiles have been performed with steps of 2, 4, 6, 8 10, 12 microns: maximum deviations of 15% have been obtained on R_L and of 2 ÷ 3 % on μ_A, μ_{RMS}. The values obtained sampling a crack profile length $\Delta a = 0.95$ mm are exemplified in Table 1.

TABLE 1

R_L	μ_A (μm)	μ_{RMS} (μm)	step (μm)
1.192	5.852	7.312	all points
1.095	5.845	7.311	2
1.072	5.846	7.285	4
1.052	5.821	7.225	6
1.047	5.837	7.270	8
1.041	5.884	7.298	10
1.024	5.676	7.019	12

As it can be seen (fig. 5) R_L values are here totally independent from the crack length examined: R_L is a plain function of ΔK under $\Delta K = 45$ MPa $\sqrt{m}$. Beyond this value, corresponding to the limit load for elastic conditions, it increases steeply.

Sampling of the profile introduces on R_L values variations unacceptable to exploit these data and confirms the results obtained in semi-automatic evaluation (see Table 1).

μ_A, μ_{RMS} values, on the contrary, are practically independent upon sampling but rely on the crack length adopted for the evaluation: an increase in Δa crack length smears oscillations in μ_A, μ_{RMS} V/S ΔK curves. The values obtained with $\Delta a = 0.95$ mm follow ASTM E24 recommandations for the calculation of da/dn V/S ΔK curves and should be representative of an average situation.

Oscillations found seem to be attributed to the drawbacks of μ_A, μ_{RMS}, significant of average values.This can be appreciated when considering, for instance, the mean deviation distribution of the crack profile height from the mean value, from which μ_A is deduced (fig. 6). The spread from the mean value increases in general with ΔK but the distribution is strictly related to the crack profile section examined.

CONCLUSIONS

R_L values, in order to be representative of the crack profile features, must rely on all the points of the crack path considered: sampling is to be avoided to have reliable results.

μ_A, μ_{RMS} values can be obtained reliably in both the ways above outlined but of paramount importance is the trend of μ_A, μ_{RMS} V/S ΔK. At low ΔK values microstructural features with dimensions typical of substructural grain size units give low μ_A, μ_{RMS} values. At higher ΔK values the mean deviation from the average crack path can be comparable or higher than the grain size. Fractographic scanning electron microscope micrographs obtained on the fracture surface supported the same conclusions.

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REFERENCES

1. Airoldi, G., 1981 ICCGR Meeting, Erlangen, 18-19 May

2. Jones, R.L., 1981, Int. AIEA Specialist Meeting on "Subcritical Crack Growth", Fraunhofer Institute, Freiburg

3. Pickens, J.R., Gurland, J., 1976, Proceed. 4th Int. Conf. for Stereology, NBS Special Publ. 431

4. Chermant, J.L., Coster, M., Ostertock, F., 1976, Metallography 9, 503

5. Underwood, E.E., Chakrabortty, S.B., 1979, ASTM STP 733, 337

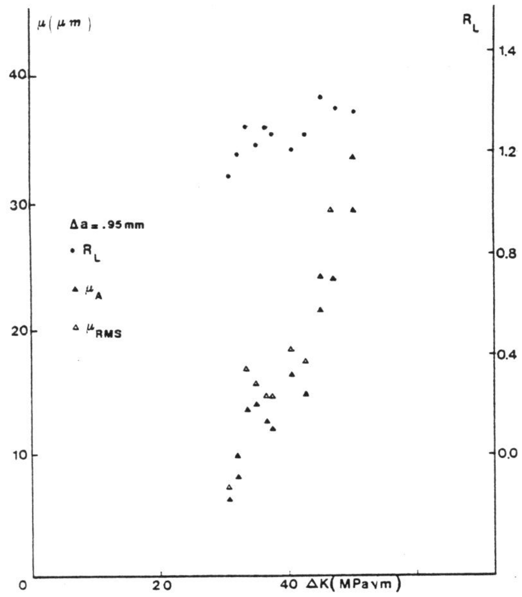

Fig. 1 - R_L, μ_A, μ_{RMS} V/S ΔK (semi-automatic procedure) with Δa = 0.95 mm

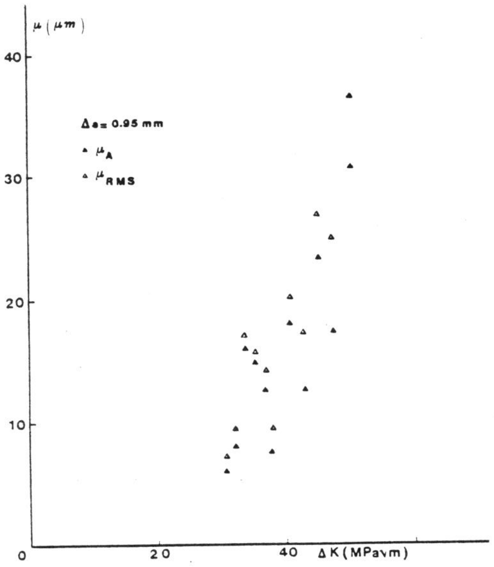

Fig. 2 - μ_A, μ_{RMS} V/S ΔK (image analyzer procedure) with a = 0.95 mm

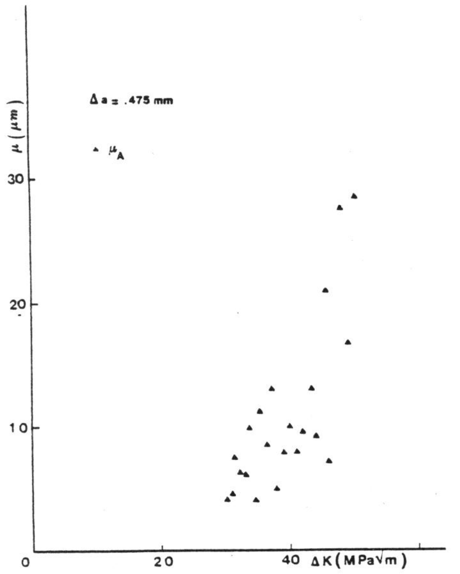

Fig. 3 - μ_A V/S ΔK with Δa = 0475 mm (image analyzer procedure)

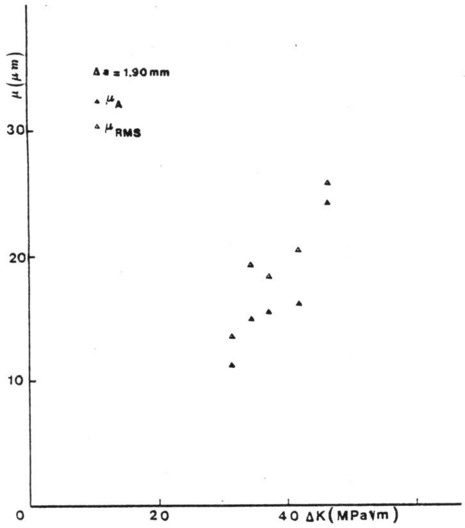

Fig. 4 - μ_A, μ_{RMS} V/S ΔK with Δa=1.9mm (image analyzer procedure)

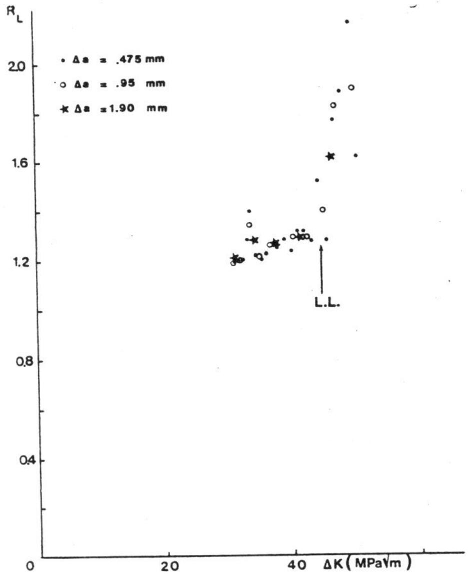

Fig. 5 - R_L V/S ΔK (image analyzer procedure)

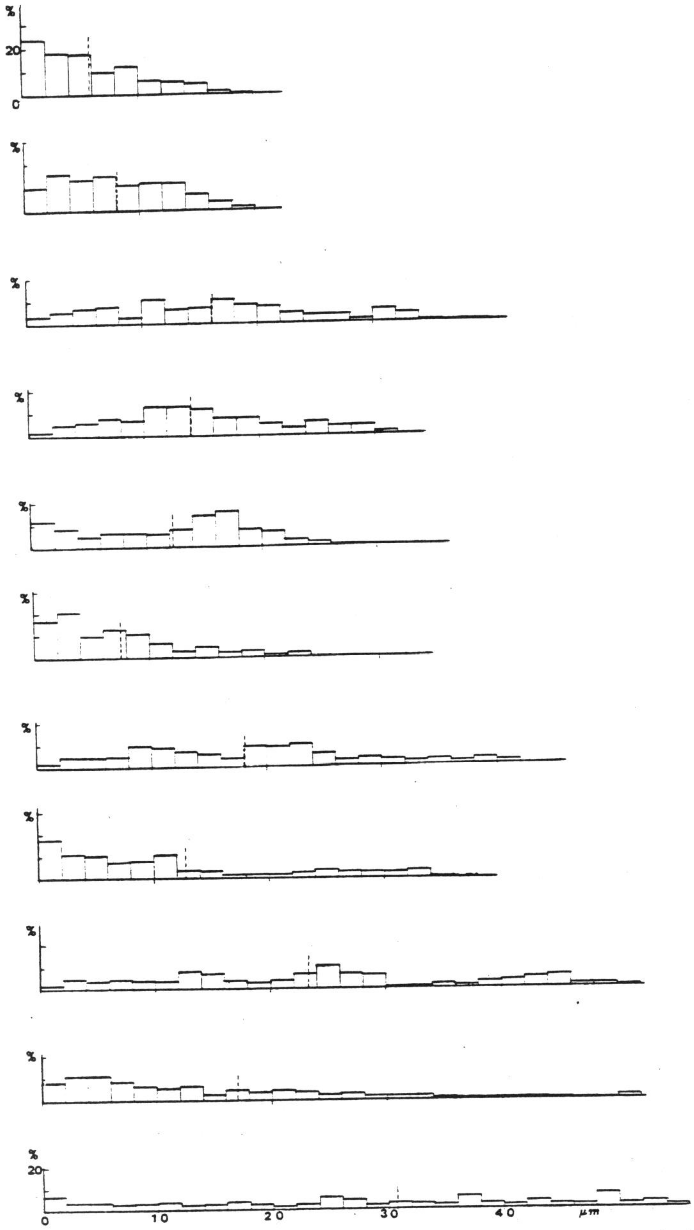

Fig. 6 - Mean deviation distribution of the crack profile height from the mean value at increasing ΔK (Δa = 0.95 mm). The dotted line corresponds to the μ_A value for each profile.