ANALYSIS OF FRACTURE SURFACES BY QUANTITATIVE FRACTOGRAPHY

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A method for quantitative analysis of fatigue fracture surfaces is presented, which consists in the determination of the spatial distribution of significant fractographic features. It is shown that this method can be successfully applied to fracture surface analysis under variable amplitude loading conditions.

INTRODUCTION

Different methods have been developed to analyse fatigue fracture surfaces which call for different techniques in microscopy. In the recent past quantitative analysis of fracture surfaces has attracted considerable attention. The main aim of these techniques to correlate some measurable parameter, characteristic of the fracture surface, to the loading conditions which led to fracture.

The methods used in the litterature depend on the measurement of striation spacing (1), the aspect ratio of striations (2), the shear lip width (3), the fracture surface roughness or the fractal dimension (4).

Methods based on striation measurements are limited to materials and environmental conditions where striations are observed and, moreover, one cannot unambiguously correlate striation spacing to the crack growth rate, especially at low growth rates (5). The same criticism is valid for shear lip width measurements as they are observed only under plane stress conditions and at high K_{max} values. The method based on fracture surface profile or fractals should be applicable to all loading conditions, but the fractal nature of fracture surfaces needs to be verified for a particular material - environment combination.

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A method has been developed in our laboratory which consists in the determination of the global appearance of the fracture surface. In this paper, salient features of this technique are first presented and results pertaining to the 2024 T351 Al alloy are discussed.

Finally variable amplitude test using a transport aircraft wing spectrum are carried out on the same alloy. It is shown that quantitative analyse of the fracture surface permits the determination of an equivalent K_{max} level and R ratio, which would lead to a similar evolution of fracture surface appearance under constant amplitude conditions.

DESCRIPTION OF THE METHOD

This method is based on the experimental fact that various fractographic features can be observed on a fracture surface depending upon the K level, R ratio and hence the crack growth rate. In most of the conventional aluminium alloys tested in air the following main features are observed [6] :

i) Herringbone Patterns
ii) Striations Ductile and Fragile and
iii) Dimples (circular or elongated)

These features are present at various proportions depending upon the loading conditions ; an example is shown in fig. 1.

The quantification method is based on that proposed by Underwood and Starke (7). The fracture surface is observed in a scanning Microscope and a grid is applied on the screen and the space occuped by different fractographic details at randomly selected orientations are determined by an appropriate quantification technique (6). The magnification used is X200 or X400 and the surfaces scanned for a particular loading condition is about 1.2×10^{-6} m^2 and 6×10^{-7} m^2 for the two magnifications.

An initial analysis of the fracture surfaces showed that for constant amplitude (CA) loading conditions, starting from near threshold, formation of herringbone patterns (H) and striations (S) were found in adjacent regions. As K_{max} (or ΔK) increases, striations are more predominant in such areas. Thus these two aspects were added together in the determination of the spatial distribution. An example is shown in fig. 2 for R = 0.01 and 0.7 for the 2024 T351 Al alloy. In this paper K_{max} is systematically used to describe the evolution of fractographic features as this is the only parameter easily identifiable under variable amplitude (VA) loading conditions.

It can be seen that the two curves are quite distinct and show a progressive decrease from about 100 % to 20 % as K_{max} increases. For a particular K_{max} value, for example $K_{max} = 25$ MPa$\sqrt{m}$, the space occupied by these features is about 80 % at R = 0.7, while it is about 60 % at R = 0.01. Similar results can be obtained of other R ratios as well (6). The space occupied by dimpled areas is next presented in fig. 3, for three R ratios. Again the effect of R ratio is clearly distinguished from this figure. At a given K_{max} value, dimples occupy a much lower space at a high R ratios than at lower ones.

This analysis shows that the study of the spatial distribution of significant fractographic features permits the determination of the effect of loading conditions in fatigue, i.e. K_{max} and R ratio, under CA conditions.

The same technique is now applied to examine the fracture surface obtained under a variable amplitude loading condition.

EXPERIMENTAL CONDITION

The tests were carried out using a transport aircraft wing spectrum consisting of 1000 different flights and 22547 cycles on the 2024 T351 alloy using compact tension specimens 12 mm thick and 75 mm wide. The tests were carried out in computer control at a frequency of 20 Hz. The crack length was monitored using "Crack - Gages" with a precision of 0.02 mm. Compressive loads were not applied and the minimum load chosen was 10 daN.

The evolution of crack length versus number of flights and the relationship between the crack advance per flight and maximum value of K_{max} for the spectrum called $K_{max\ SP}$ are shown in fig. 4 and 5 respectively. This value is estimated from the maximum load of the spectrum [600 daN] which occurs once every 1000 flights.

Fractographic anlysis and determination of the equivalent CA loading.

As for CA conditions, the significant fractograhpic features are herringbone patterns, striations and dimples. The same quantification procedure, as described before, is applied to analyse the fracture surfaces. For a particular crack length, ie $K_{max\ SP}$ value, three randomly oriented location are chosen and the significant features are measured. These measurements are carried out at the centre of the specimen representative of plane strain conditions.

The results are shown in fig 6 and 7, where average curves under CA conditions at R = 0.01 and 0.7 are also shown. These two R ratios represent the peak to peak R ratio and the most frequent R ratio in the VA loading spectrum.

From these figures, it appears that the equivalent CA loading condition, which would lead to a similar distribution of the significant fractographic features obtained under the VA conditions studied here, is $K_{max} = K_{max\ SP}$ and $R = 0.01$.

DISCUSSION

It follows from the above that the peak load occuring in a loading spectrum and the load ratio corresponding to the minimum load to the peak load are important factors that determine the appearence of the fracture surface under the VA spectrum studied.

From the equivalent CA loading this established, the estimation of evolution of the crack length can be determined from the crack growth law established for this material (8). Comparison between the estimated and measured crack lengths is shown in fig. 8. It is seen time that an acceptable correlation is obtained. The total number of equivalent flights is 119000 which is within 20% of the measured result of 139000 flights.

This method appears thus to be quite promising for the study of in service fatigue to determine the causes which led to failure.

CONCLUSIONS

i) The method for quantitative analysis of fracture surfaces presented in this study can be successfully applied to study the fracture appearance under variable amplitude loading.

ii) This technique permits the definition of an equivalent constant amplitude loading condition which would lead to a similar fracture surface evolution, as for variable amplitude loading.

iii) A reasonable estimation of the crack length evolution for spectrum loading can be prediced based on the analysis developed here.

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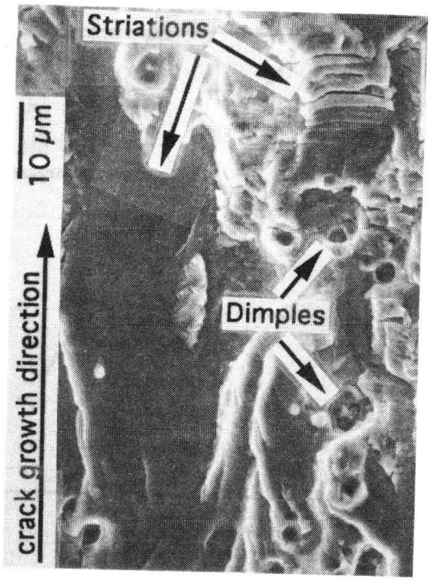

Fig. 1 Different fractographic features.

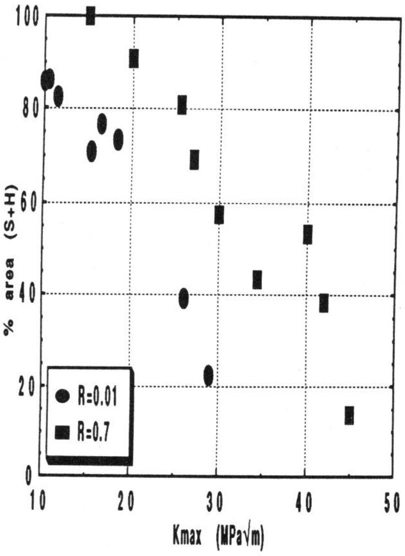

Fig. 2 Striations and Herringbone patterns for CA conditions.

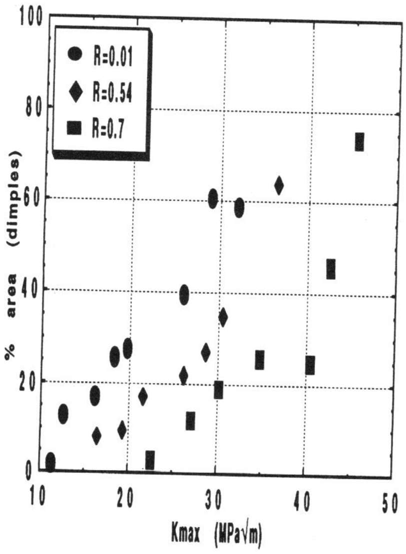

Fig. 3 Dimples for CA conditions.

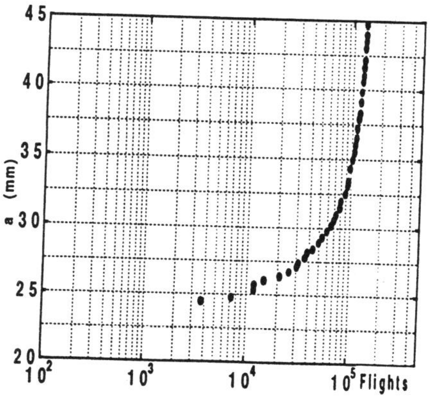

Fig. 4 Crack length evolution : VA conditions

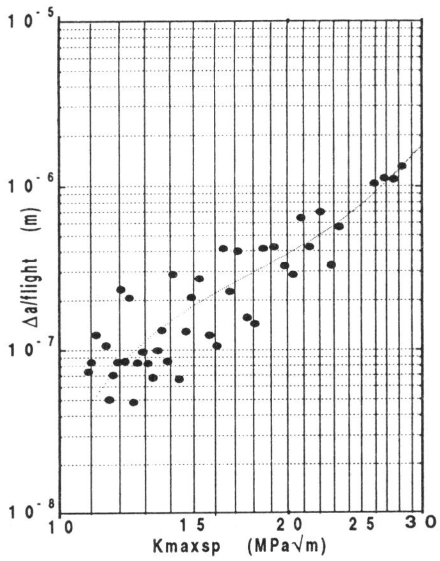

Fig. 5 Crack advance per flight, VA conditions.

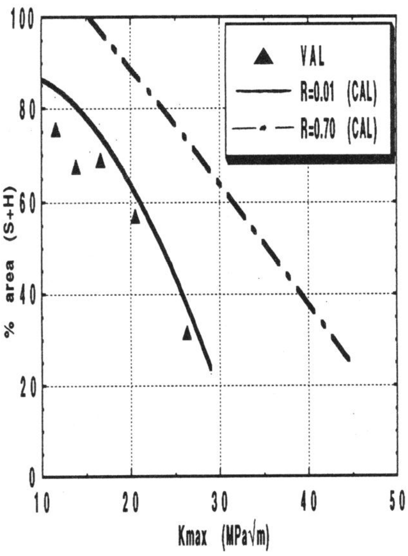

Fig. 6 Striations and Herringbone patterns for VA conditions.

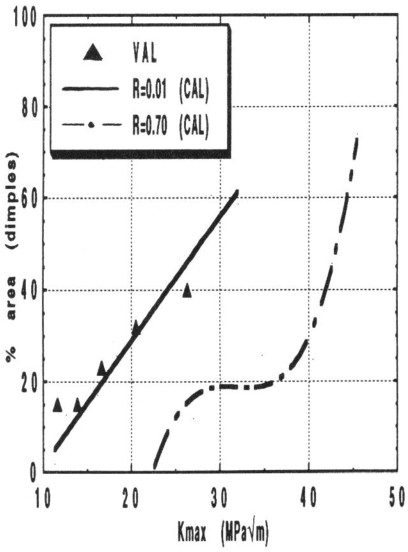

Fig. 7 Dimples for VA conditions.

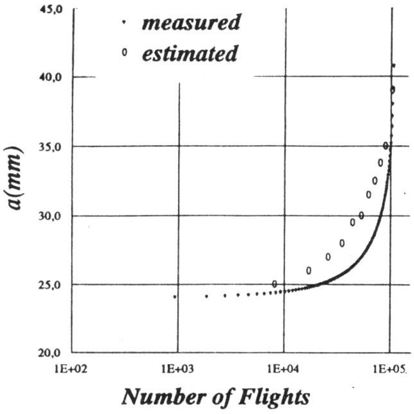

Fig. 8 Comparison of estimated and measured crack lengths.