QUANTITATIVE ASSESSMENT OF FATIGUE CRACK GROWTH PATH ON PROPAGATION CYCLE ESTIMATION

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ABSTRACT

Fatigue crack growth paths, that curvilinear and non-coplanar, pose a challenge for propagation cycle estimation due to the difficulty in determining crack depth of measurement points and uncertainties in the stress field. This investigation aimed to analyse the influence of crack path geometry on the accuracy of striation counting, a method of estimating the number of fatigue propagation cycles. Three striation counts were carried out on separate fracture surfaces from a rig-tested aero-engine component, of type Ti-6Al-2Sn-4Zr-6Mo material, each with different crack path geometries.

A study into the most suitable method for crack depth determination was carried out by evaluation with the known overall crack length, which had been measured directly off the surface. Using this result the propagation cycle estimations for the three fractures could be determined.

An analysis of the choice of striation count path across a region of varying geometry was also carried out. As the density of striations across a geometrical feature, such as a corner, varies along the crack front, the choice of striation count path will vary both the total crack depth and striation density measurements in this region. However it was shown to not significantly affect the overall striation count result.

As greater than half of the fatigue crack propagation had occurred in a linear manner from the origin, an alternative method of estimating the number of fatigue propagation cycles was investigated, in which the striation count was carried out in this linear portion of the fracture. The data was then extrapolated to cover the whole fatigue crack. Results of this study revealed close correlation to full striation counts.

1 INTRODUCTION

Striations are linear features formed on a fatigue fracture surface due to the repeated application of a cyclic stress. They often indicate the amount of crack growth per cycle. The mechanisms of fatigue crack growth are well established [1-5], enabling correlation to be made between the rate of fatigue crack growth and width of striations by striation counting [6].

Striation counting is described as the estimation of the number of fatigue striations on a fracture surface. It is carried out by measuring striation width at a number of points along the crack propagation direction of the fracture surface and then integrating the striation density over the crack length. The materials crack propagation behaviour can then be determined, in terms of the total number of loading cycles seen. However, care must be taken as other crack growth mechanisms may also operate. In such cases the striated area may not be representative of the actual crack growth rate.

Propagation cycle estimation is a useful tool in the analysis of failures and as such it is valuable to validate methods of striation counting. Usually the count is carried out in a straight line from the origin, however some fatigue crack paths are curvilinear and non-coplanar due, for example, to component geometry. This study aims to investigate the most appropriate method of propagation cycle estimation on fracture surfaces with curvilinear crack paths.

2 DETERMINATION OF CRACK LENGTH

When carrying out a striation count along a straight line, the stage coordinates are recorded and Pythagoras' rule is used to determine crack depth for each point, in a direct line from the origin. However, this method is not suitable for determining crack depth for measurements carried out along a curve. As such, other methods were investigated to determine an accurate method of calculating crack depth, which could be used for striation measurements on crack paths with curvilinear geometry.

2.1 Methods

The total fatigue crack length of Specimen B was measured from scaled images and determined to be 24mm. The three methods investigated are illustrated in Figure 1, and were carried out as follows:

1. The crack length was determined in a direct line from the origin.
2. A trendline was plotted through the location coordinates of the measurements taken during the striation count. Using the trendline equation, the lengths of small increments (up to 100μm) were calculated and then summed to estimate the whole crack length.
3. The fracture surface was divided up into sections, the crack length of each section was then determined as a straight line, and the sections were summed together to calculate the total crack length. Determination of the sections was based on the geometry of the specimen.

2.2 Results and Discussion

The results, as a percentage comparison from the total measured crack length, are given in Table 1.

Table 1: Variation in the total crack length using three different methods

Method	Estimated Total Crack Length (mm)	% Variance from Actual Length
1	18.4	-23.3
2	23.3	-2.9
3	23.4	-2.5

Results revealed a large amount of error with Method 1. Methods 2 and 3 however gave very good approximations of crack length. Whilst the result for Method 2 was quite accurate on the fracture surface investigated, it is unlikely that suitable trendlines would be available for fractures with different crack path geometries and so Method 3 was chosen to be the most appropriate.

Whilst Method 3 is not as accurate as striation counts along a straight crack path, most inaccuracies on the fractures studied here would occur towards the end of the fracture, after the crack has 'turned the corner'. This is likely to vary the total cycle estimation by only a few hundred cycles.

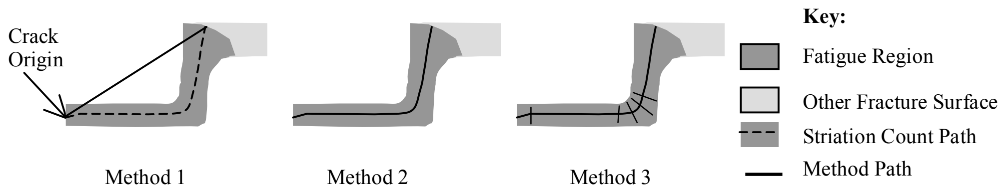


Figure 1: Illustration representing the three methods investigated

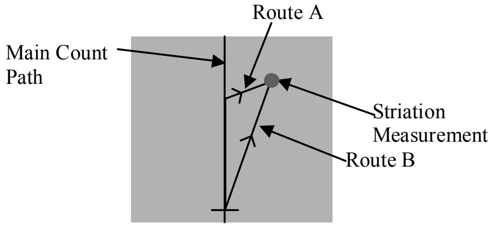


Figure 2: Illustration representing potential error calculating crack depth

In addition, errors in Method 3 were increased when the number of sections was reduced, and consideration had to also be given to potential errors when calculating the last increment between the main count path and striation measurement. This is shown in Figure 2, where Route A is longer and less accurate than Route B.

3 STRIATION COUNT ON FRACTURES A-C

3.1 Method

The striation counts were carried out along paths O-P as indicated in Figure 3. Method 3 was used to calculate crack depth (as described in Section 2). The estimated number of propagation cycles for each fracture was then determined between points O-P.

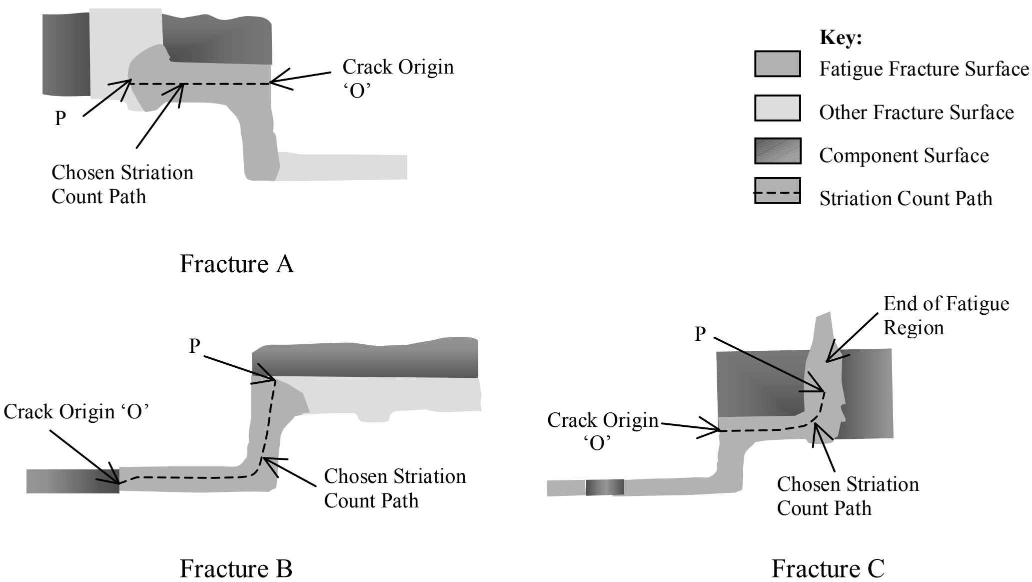
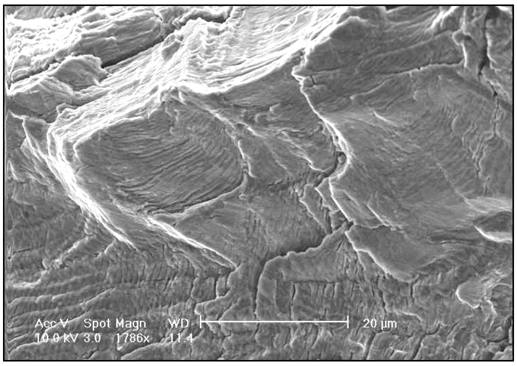


Figure 3: Schematic of the top view of fracture surfaces A-C (not to scale)



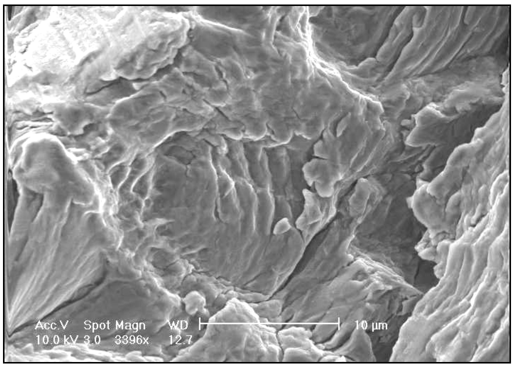


Figure 4: Fractographs of the fracture surface, showing typical striated regions

3.2 Results

The results of the striation count are given in Table 2. These results were consistent with other striation counts carried out on the same fractures. Representative fractographs recorded during the count are given in Figure 4.

Table 2: Estimated number of propagation cycles (O-P)

Specimen	A	B	C
Estimated Number of Cycles (O-P)	20568	21561	24766

4 INFLUENCE OF COUNT PATH

This study aimed to analyse the effect of striation count path on the propagation cycle estimation of Specimen B.

4.1 Method

Particular attention was paid to the corner feature between crack depths A and B due to the variation in striation density across the crack front. In this region striation density measurements were taken across the corner as shown in Figure 5. In order to estimate the number of cycles between depths A and B, each of the measured points was determined as the length of an arc. By assuming the density did not vary as a function of radial position, the number of cycles around the corner could be estimated. Since there was essentially no variation in striation density across the crack front both before and after the corner, the striation count on Specimen B could be re-evaluated to give results for equivalent shorter and longer striation count paths.

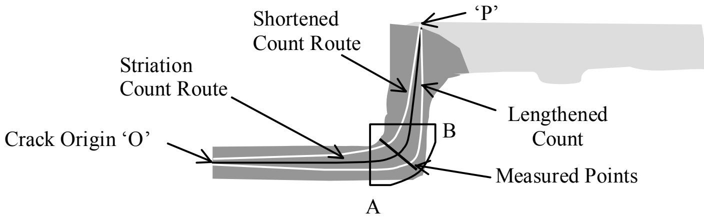


Figure 5: Diagram illustrating location of measured points

4.2 Results and Discussion

The results for the variation in propagation cycle estimation, between points O-P, as a function of striation count path are given in Table 3, as well as the estimated number of cycles between points A and B determined from the length of an arc.

Table 3: Variation in the propagation cycle estimation as a function of crack length

Variation in Crack Length (%)	-0.9	+2.4	+7.1	+12.2
Variation in Cycle Estimation (%)	+4.2	+6.6	+10.6	+14.6
Estimated Number of Cycles (A to B)	2186	1854	3076	3544

The measurements taken across the corner illustrate how the striation density varies along the crack front due to specimen geometry. Whilst density across the crack front both before and after the corner feature did not vary much across the crack front, the density was 858 cycles/mm near the inner radius of the corner, and decreased to 413 cycles/mm near the outer radius. The effect of shorter and longer crack depths on the estimated number of cycles is relatively large, which is likely to be due to the lower number of measurements around the corner feature, reducing the accuracy of the trendline, and ensuring that crack length is the dominating factor for integration. This indicates that the choice of striation count path may be significant, and so the path of crack growth must be followed closely, by the use of indicators such as the direction of striations and river patterns.

5 EFFECTS OF STRAIGHT LINE COUNT EXTENSION

This investigation analysed the effect of only carrying out a striation count from the origin along the straight line portion of the fracture, then extending the trendline to cover the whole crack length and hence estimating the number of propagation cycles.

5.1 Method

On Specimen B counts carried out up to 12.5mm from the origin were included. A power law trendline was fitted through and extended to a crack depth of 22.3mm (the distance from points O-P on Specimen B). On Specimen C counts carried out up to 15.5mm from the origin were included. Again, a power law trendline was fitted through and extended to a crack depth of 25.2mm (the distance from points O-P on Specimen C).

5.2 Results and Discussion

The results are given in Table 4 below.

Table 4: Variation in the propagation cycle estimation for straight line only counts

Fracture	All Data Included	Straight Line Data Only	% Variation
B	21562	21383	-0.8
C	24766	24246	-2.1

Results revealed that carrying out a striation count on only the first half of the data gives a value that is very close to that with all the data included. However it relies on a good trendline being fitted through the data and there being little variation in stress field by, for example, a change in cross section. Although the inaccuracy of estimating the crack length around the corner is reduced, there is increased error due to the reduced amount of data towards the end of the crack. This method may be suitable if the crack path geometry is complex and there is enough of an initial straight-line portion on which to carry out the count (i.e. covering at least one half of the fracture path).

6 CONCLUSIONS

1. When carrying out striation counts on specimens with a curved fracture surface it is essential that the crack path length is calculated accurately.
2. Determination of the striation count path should follow the path of fatigue crack growth as closely as possible, by following indicators such as the direction of striations and river patterns.
3. The method recommended for determining crack length for striation measurements is to divide the crack path up into sections and determine the crack length for each section using Pythagoras' rule. The crack depth of each striation measurement is calculated by summing the relevant sections.
4. Although errors are increased, it is possible for striation counts to be carried out purely on the portion of the crack path that is in a direct line from the origin. However this is not recommended if this portion represents less than one half of the total fracture path.

7 REFERENCES

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