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LETTERS IN FRACTURE AND MICROMECHANICS

AN INVESTIGATION OF THE GROWTH OF MULTI-SITE FATIGUE CRACKS

R. L. Carlson, M. D. Cappelli and G. A. Kardomateas
School of Aerospace Engineering, Georgia Institute of Technology
Atlanta, Georgia, USA 30332-0150-USA
e-mail:BCCRLC@aol.com

Abstract. Test data obtained within the small crack growth regime of multi-site fatigue cracks are examined. Swain's partitioning criterion (1992) is used to distinguish between cracks that arrest and cracks that continue to grow until fracture. A statistical application of this criterion indicates that the total collection of multi-site cracks on multiple specimens has a bi-modal distribution.

Key words: multi-site fatigue cracks, primary cracks, secondary cracks, bimodal statistical distribution.

1. Introduction. Schijve (1994) has presented a discussion of different, operative, crack initiation mechanisms, and the salient features of small fatigue crack growth. Swain (1992) has examined multi-site cracking, and suggested that since only one crack in a cluster of cracks results in failure by fracture, the data from these cracks should be described as 'valid data', and the remaining data should be described as 'invalid data'. This classification procedure has been applied here. The 'valid data' are described here as 'primary crack data', and the 'invalid data' are described as 'secondary crack data'.

The primary cracks in a cluster of small cracks cannot easily be identified during the early crack initiation phase. The selection process requires the use of Swain's criterion (1992). The objective of the research described here was to obtain the crack growth histories of a collection of primary and secondary cracks. The test procedures used to obtain these histories are described in the next section.

It should be noted that as long as the cracks are within the region of influence of the secondary cracks, they can be expected to be subject to interaction effects. The networks of the secondary cracks, along with grain boundaries, form the neighborhood within which each primary crack grows. These interaction effects should be theoretically investigated in future research.

2. Experimental Details. Test specimens were cut from 6.35mm thick plate of the aluminum alloy 7075-T7351. The longitudinal grain size was 49 microns, and the short transverse size was 57 microns. The long transverse size varied widely about an average of 76 microns. The yield stress was 441 441MPa, and the ultimate strength was 520MPa.

A double edge notch test specimen was used in the experiments. The width of the grip section was 50.8mm, and the notch radii were 19.1mm. The stress concentration with respect to the stress in the grip area was 4.8. The tensile stress at the bottom of the notch surfaces was 1.2 times the average stress in the reduced section. Before testing, the preparation of the two gage section surfaces proceeded with the successive use of 240, 320 and 600 grit abrasive papers. Preparation was completed by polishing with 15, 5, and 1 micron diamond pastes.

The experimental program was designed to trace and record the evolution of the cluster crack patterns on the bottom of each of the notched surfaces as they evolved during cyclic loading. Crack lengths were measured by interrupting loading at cyclic intervals. The crack lengths, and the spaces in each of the crack clusters were measured on both faces of the reduced section. The objective of the procedure was to then identify the primary and secondary cracks on the two surfaces of each test specimen.

The cyclic frequency for the tests was 5Hz. The maximum stress was 329MPa, and the loading ratio R=0.1. Crack lengths were measured by use of a Questar tele-microscope. Each specimen had two gage section surfaces, so two sets of crack length data were obtained from each specimen.

During the initial stages of loading, a separation of the two distributions was difficult. Thus, a procedure of using very early crack length measurement interruptions is not effective for separating the two distributions. By measuring and recording all of the crack lengths for each cyclic load interruption, however, it was always possible to select the emerging, primary crack. Once it was identified, its growth was then traced back to measurements made during earlier load interruptions. A review of these measurement records then made it possible to identify, and to separate the primary cracks and the secondary cracks formed earlier in the test. Crack measurement data were obtained on ten surfaces of five specimens. A total of 55 cracks were measured. Of these, 10 were identified as primary cracks. The remaining were secondary cracks. Summaries of all of the crack data obtained are presented in Figures 1and 2.

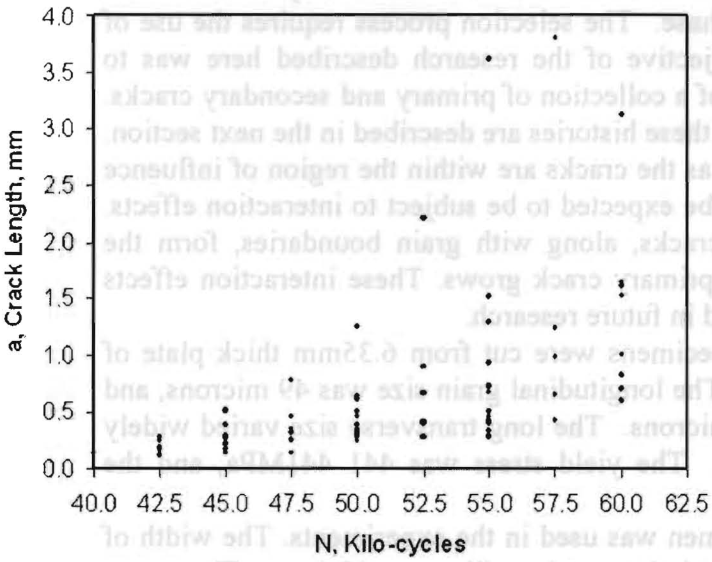

Figure 1. A summary of the primary crack data.

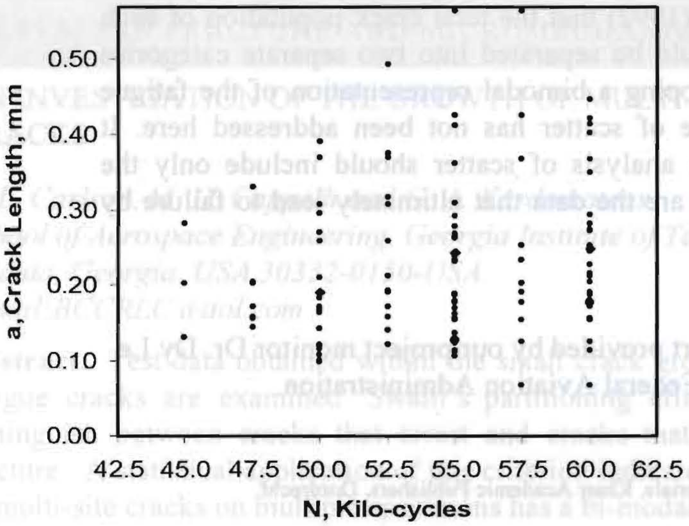

Figure 2. A summary of the secondary crack data.

An examination of Figures 1 and 2 reveals that the range of the secondary cracks is substantially smaller than that for the primary cracks. Also, note that primary cracks exhibit increasing growth rates, whereas the secondary cracks indicate the onset of arrested growth.

The data obtained for the primary and secondary cracks have been used to construct the cumulative frequency polygons (Hald,1957) presented in Figures 3(a) and 3(b) for N=55,000 cycles of loading. Each horizontal step represents the probability for one data value. As would be expected, there are more secondary steps than primary steps. Also, note that the largest secondary cracks are of the order of the smallest primary cracks.

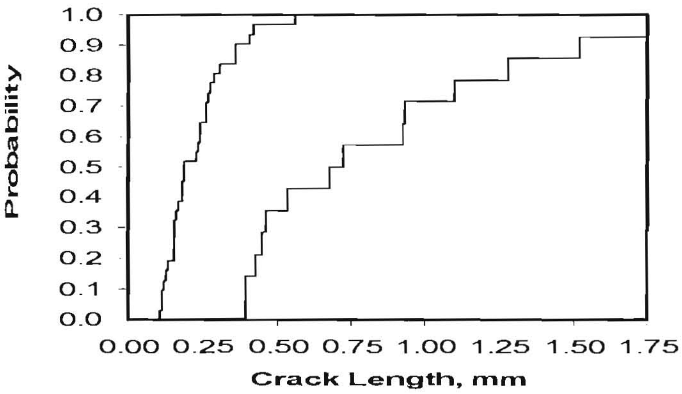

Figure 3. Probabilities for (a) secondary cracks and (b) primary cracks

3. Summary. Swain's observation (1992) that the total crack population of each cluster of small fatigue cracks should be separated into two separate categories has been used as a basis for developing a bimodal representation of the fatigue crack test data obtained. The issue of scatter has not been addressed here. It should be noted, however, that an analysis of scatter should include only the primary or 'valid' data, since these are the data that ultimately lead to failure by fracture.

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References

Schijve, J.(2001) Fatigue of Structures and Materials, Kluer Academic Publishers, Dordrecht, The Netherlands, 20-22.

Swain, M. H. (1992) Monitoring small-crack growth by the replication method. In:*Crack Test Methods, ASTM STP 1149*, (Edited by J. M. Larsen and J E Allison), ASTM, 34-56.

Hald, A. (1957) Statistical theory with engineering applications, New York, Wiley, 51-55.