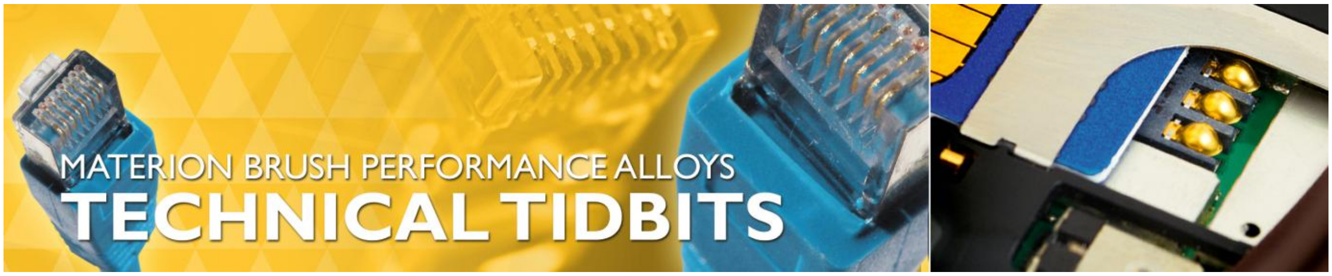

Issue No. 69 – September 2014 **New Publication**

How quickly do your fatigue cracks grow – A discussion on the fracture mechanics approach to fatigue life estimation.

- **Stress Intensity Range (ΔK)**
- **Paris Law**
- **Threshold Stress Intensity Factor (ΔK_{th})**
- **Critical Stress Intensity Factor (K_{IC})**

The next issue of Technical Tidbits will discuss numerical simulation of fatigue behavior.

The Fracture Mechanics Fatigue Method

(This issue of Technical Tidbits continues the materials science refresher series on basic concepts of material properties.) Prior editions of Technical Tidbits have discussed the stress life and strain life methods of fatigue analysis. Las month's edition introduced fracture mechanics concepts. This edition will illustrate how to use these concepts to predict fatigue life.

The fracture mechanics method of fatigue life prediction is less concerned with the state of stress or strain at the macroscopic level on parts, and focuses on what is happening at the tips of existing cracks. The advantage of the fracture mechanics method is that testing actually measures the progress of existing cracks in each loading cycle, instead of merely counting cycles to failure.

The test specimen is machined as shown in Figure 1. There is usually a sharp notch or fillet to provide stress concentration, at the end of which a small crack is established. (ASTM E399 describes the required geoemtric tolerances and initial crack length.) The test speimen is subjected to cyclical, unidirectional tension loading, which pulls the two halves of the crack inteface apart (Mode I). The change in length of the crack, and the stress intensity range of each cycle are both measured as test progresses. If a loading condition other than R=0 is desired, a separate set of tests would have to be run, and the data kept separate.

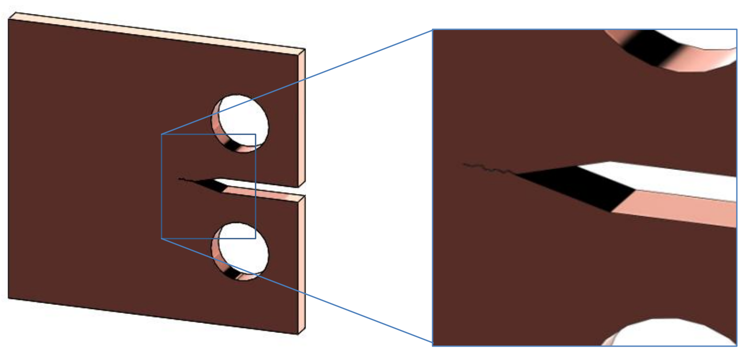

Figure 1. Fatigue Crack Growth Specimen.
The test specimen shown here would be loaded in tension by grips that pass through the two circular holes. The shape of the notch, the length of the notch relative to the holes, and the length of the crack relative to the notch and the holes would be governed by ASTM 399.

Recall from Issue 68 of Technical Tidbits that the stress intensity at the crack tip is a function of the test specimen geometry, and the length of the crack. As the crack increases in length during each cycle, the stress intensity does as well. Therefore, each cycle experiences a change in stress intensity at the crack tip, denoted as **ΔK**, the **stress intensity range**. The change in crack length in each cycle is expressed as da/dN.

Given enough tests over various stress intensity ranges, you can plot a series of data points as da/dN vs ΔK on a log-log chart as shown in Figure 2. There are 3 distinct areas of behavior apparent on such a chart, color coded for easy reference. The first section, shown in blue dots, is an area of very slow crack growth, which can, at the risk of oversimplification, be thought of as the fatigue crack initiation regime.

The second set of points, shown in green, follows a straight line on the log-log chart. This is the stable crack propagation regime. Here, crack growth is fairly predictable, and obeys the **Paris Law**:

$$\frac{da}{dN} = C(\Delta K)^n$$

The Fracture Mechanics Fatigue Method (continued)

The constants C and n are determined by curve fitting the data in green. The third set of data points, shown in red indicate the unstable crack growth regime. If the R ratio of the test is greater than zero, this has the net effect of shifting the data slightly up and to the left.

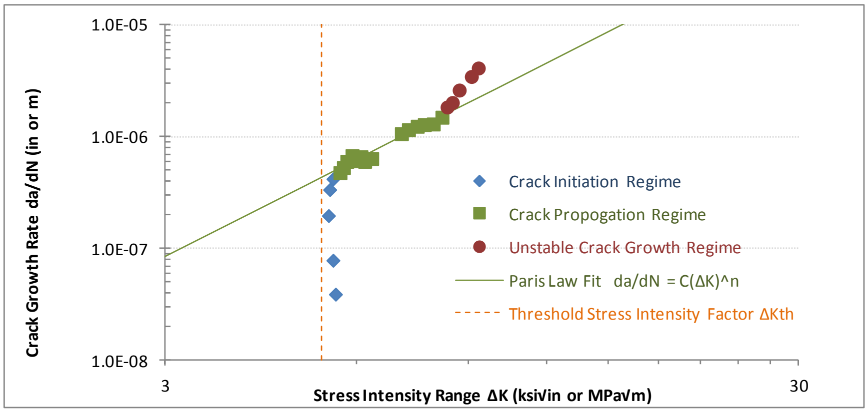

Figure 2. Rate of Crack Growth Per Cycle vs. Stress Intensity Range Per Cycle
The green line indicates the Paris Law curve fit for this example material. The differing behaviors of the three crack propagation regimes is clearly evident.

There are also a couple of bounding points on the chart. There is a certain stress intensity range below which the cracks do not grow, regardless of the size. This is known as the **threshold stress intensity factor ΔK_{th}**. As you might guess, no data points will fall to the right of the critical stress intensity K_{IC}. Naturally, a designer might be tempted to conclude that we would want to keep the stress intensity below the threshold intensity to prevent fatigue failure. However, this value is so low that doing so would be impractical. It is the crack growth rate behavior that is of use to design engineers, not ΔK_{th}.

OK, now that we have the data, how do we use it? (This is best done numerically with finite element analysis software specifically designed for fatigue analysis.) Given an initial crack size, an expected loading history, and the da/dN vs ΔK data, one can determine how many cycles it would take the intial crack to propagate to failure. This can be done for a range of initial crack sizes, so you end up with a relationship between the initial crack size and the time to failure.

So, if you know how many cycles you would like a given part to last, you can then compute the maximum permissible initial flaw size. Then, you can perform some kind of nondestructive test like ultrasonic testing to ensure that there are no cracks defects in your part greater than that particular size.

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