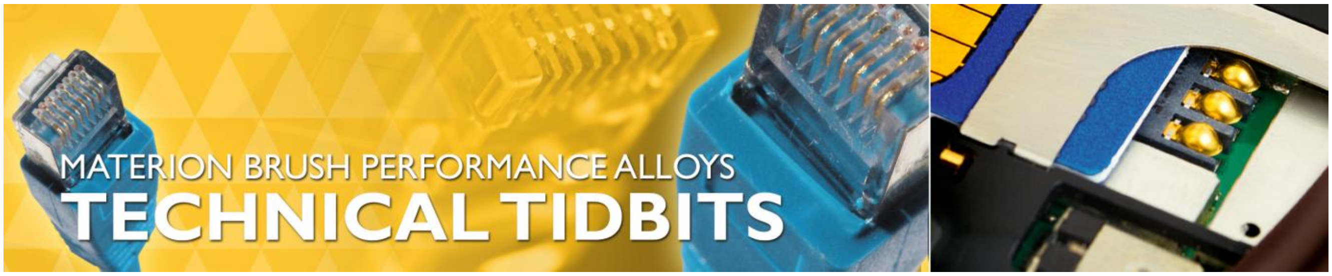

Issue No. 68 – August 2014 **New Publication**

How intense is your stress level – An introduction to fracture mechanics.

- **Stress Intensity**
- **Stress Intensity Factors (K_I, K_{II}, K_{III})**
- **Critical Stress Intensity Factors (K_{IC}, K_{IIC}, K_{IIIC})**
- **Plane Strain Fracture Toughness**
- **Critical Crack Length**

The next issue of Technical Tidbits will introduce the fracture mechanics approach to fatigue analysis.

Stress Intensity and Fracture Toughness

(This issue of Technical Tidbits continues the materials science refresher series on basic concepts of material properties.) In prior editions, we have demonstrated how to estimate the fatigue life of a component through characterization of test specimens using cyclically applied stresses or strain, followed by analysis of the data. The **fracture mechanics** method is fundamentally different, since it is the study of how fatigue cracks grow through a given material, and is more concerned with what is happening at the tips of growing cracks than with macro-scale loading. A quick introduction to fracture mechanics is required before any discussion of how to apply it to fatigue analysis can begin.

A quick overview of the method starts with the test specimens used to generate the data. Each specimen starts with a pre-existing crack of a given length "a". Stress intensity is categorized according to mode, as , shown in Figure 1. Mode I is a spreading apart of the two halves of the crack interface, recognizable as the most severe case. (When people split logs with a wedge, they are using Mode I fracture mechanics, although they are most likely unaware that they are doing so.) Failures due to Mode I crack propagation are by far the most common, while Mode III is mainly of academic interest.

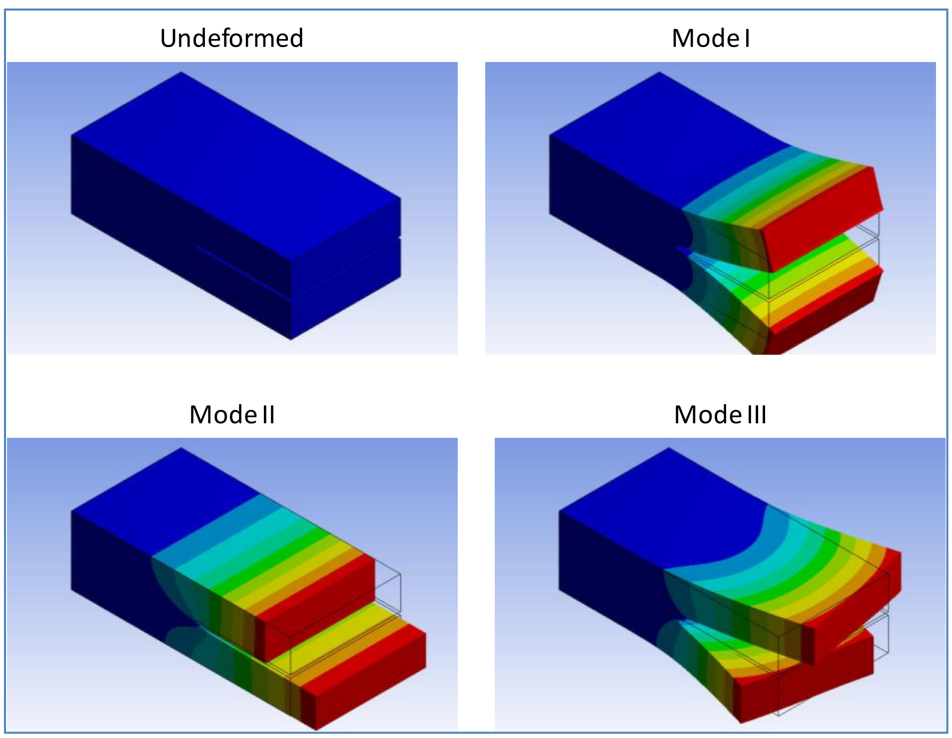

Figure 1. Stress Intensity Modes - In these images, undeformed areas are shown in dark blue, while the highest levels of deformation are shown in red.

The stress intensity factor (K) is a defined as the product applied macroscale stress (σ), the square root of the crack length(a), and a constant that depends on the particular fracture mode and geometry of the test specimen. The stress intensity factor for Mode I is designated K_I, K_{II} for Mode II, and K_{III} for Mode III.

$$K = C_{[f(mode, geometry)]} \cdot \sigma\sqrt{a}$$

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Stress Intensity and Fracture Toughness (continued)

C is a dimensionless constant, but is determined by the fracture mode and test specimen geometry. The mathematics to derive this constant are complex, and its value depends on the crack location in the sample, load orientation relative to the crack, crack length, size and shape of the test specimen, and loading mode. However, these problems have been solved multiple times, and handbooks exist containing the tabulated values for most known conditions. Therefore, the author strongly recommends that you look up the values, as opposed to trying to calculate them on your own, unless you enjoy such academic pursuits, or if you really want to author a new handbook yourself.

The units for stress intensity, probably the ugliest engineering units you will ever see, are expressed as stress times square root of length. In SI units, this would typically be MPa√m, and ksi√in in British imperial (American) units. It is difficult to conceive of a real meaning of square root of length, but it does have real implications in engineering. (It can be thought of in a similar fashion to the concept of imaginary numbers in mathematics, which also have real implications in engineering.)

The **critical stress intensity** factor designates the minimum stress intensity required to get an existing crack in a material to propagate. The critical stress intensity factor for mode I is designated as $\mathbf{K_{IC}}$, that for mode II is $\mathbf{K_{IIC}}$, and that for mode III is $\mathbf{K_{IIIC}}$. If the test specimen is thick enough, Mode I is becomes a plain strain condition, so K_{IC} is often referred to as the **plain strain fracture toughness** of a material.

Given K_{IC} and a loading condition, it is possible to estimate the mimimum length of a crack that will propagate under those conditions. This is known as the **critical crack length**. Cracks smaller than this size will not propagate, but larger cracks will.

Unlike other measures of toughness that calculate the energy required to fracture a material, plane strain fracture toughness is is a measure of the stress intensity necessary to initiate fracture of a material with a known flaw size under plane strain conditions. So, while Izod and Chapry V-Notch (CVN) impact tests will provide fracture toughness data in Joules or foot-pounds, K_{IC} provides fracture toughness data in ksi√in or MPa√m. The two former test methods are relatively easy to measure and understand, while the latter is more complicated, but provides more useful information in terms of shock load bearing capability and crack propagation over time. That is to say, Izod and CVN data will only provide the energy required for fracture in one single catastrophic event, but critical stress intensity factor data allows for predition of failure with slowly propagating cracks overa number of cycles.

Now, recall that a fatigue failure occurs by initiation and propagation of cracks throughout a material undergoing cyclic loading. Fracture mechanics provides a means of relating stress intensity levels to propagation of cracks of various sizes. Therefore, it stands to reason that fracture mechanics methods can be used to predict fatigue behavior of metals. This is the basis of the fracture mechanics approach to fatigue analysis.

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References:

ASTM E1823 Standard Terminology Relating to Fatigue and Fracture Testing

ASTM E399 Standard Test Method for Linear-Elastic Plane-Strain Fracture Toughness K_{IC} of Metallic Materials

ASTM E1820 Standard Test Method for Measurement of Fracture Toughness

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