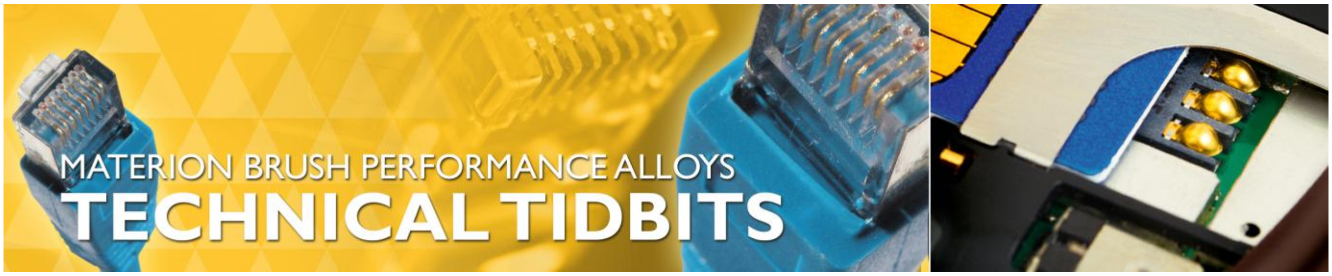


Issue No. 71 – November 2014 **New Publication**

It doesn't look tired to me! – A discussion on how to determine if a part failed by fatigue.

- **Fatigue Striations (Beach Marks)**
- **Microvoid Coalescence**
- **Chevrons**
- **Cyclical Strain Softening**
- **Mechanical Hysteresis**

The next issue of Technical Tidbits will complete the long series on fatigue.

Fatigue Failure Diagnosis

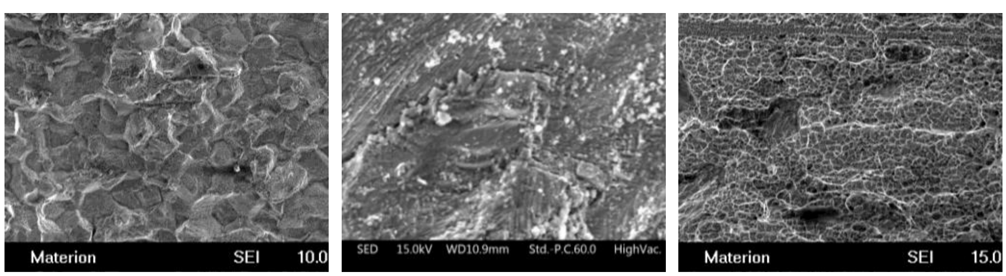
(This issue of Technical Tidbits continues the materials science refresher series on basic concepts of material properties.) So far we have covered fatigue testing, data analysis, and life predictions based on such data. So, what do failures actually look like?

First, let's start with a quick definition, and two observations, underlined and italicized for emphasis, since this is a very important point. *Fatigue failure is fracturing due to initiation and propagation of small cracks in the material due to cyclical loading at stresses far below the tensile strength, until the loading exceeds the ability of the material to carry it, resulting in final overload failure. However, not every failure under cyclical loading is due to fatigue, and the process of fatigue does not always result in failure*.

Fatigue failures occur suddenly and without warning. However, this is not enough to diangose a fatigue failure, since a single catastrohpic overload event would also create a fracture without warning. Fatigue failures can only be diagnosed by carefully examining the fracture surface. The failure analysts will look to see if the fracture mode is transgranular (through the grains), intergranualar (between the grains), or a combination thereof. They will also determine if there is any telltale corrosion products on the surface. Finally, they will determine if there are any features on the fracture surface typical of fatigue failure. They will compare the appearance with known failure modes for that particular material.

The crack pattern on the surface of the fracture will vary depending on the specimen geometry, loading condition (bending, torsion, tension, etc.) and stress amplitude. Representative images may be found in he referenced literature on page 2.

In ductile materials, there will be a noticeable difference between in appearance between the area of final ductile overload fracture, and the section created by the gradual advancement of cracks. The crack propagation area typically would have an overall brittle-fracture appearance. (See the left image of Figure 1). At high magnifications, you may be able to see fine lines on the fracture surface, indicating where the crack front stopped on each cycle. These are known as **fatigue striations**, or more colloquially as **beach marks**. (See the middle image of Figure 1). The area of final fracture would have a more ductile looking appearance, as evidenced by **microvoid coalescence**, giving the surface a dimpled appearance. See the right image in Figure 1.



Brittle Overall Appearance of Crack Propagation Area at Low Magnification | Fatigue Striations Visible at High Magnification | Ductile Appearance of Final Fracture Area at High Magnification

Figure 1. Features of Fatigue Fracture Surfaces.
The left image shows a brittle-appearing fracture surface, typical of fatigue failures. The middle image shows fatigue striations visible in the crack propagation area at high magnification. The right image shows a ductile fracture surface with microvoid coalescence, such as would be found in the area of final fracture of a ductile material.

Fatigue Failure Diagnosis (continued)

Depending on the material and loading conditions, some fracture surfaces may show **chevrons**. These are triangularly shaped marks which point towards the fatigue crack origin (or origins, since multiple cracks may have been propagating simultaneously.) Such marks make failure diagnosis relatively easy. However, in 17 years of failure analysis, this author has never seen such easy indications, which is why there is no picture of chevrons in Figure 1.

Another hallmark of fatigue failures is that they happen over time, under fluctuating or cyclical loading. However, this is also a necessary but not sufficient condition to diagnose a fatigue failure. Sometimes, repeated cyclical loading may result in a part taking an unexpected permanent set over a prolonged period of time, even if the stresses are below the yield strength. However, a close inspection reveals no cracking. This would be an example of **cyclical strain softening** (an example of **mechanical hysteresis**) in the material used. This usually occurs if the maximum applied stress is above the elastic limit of the material, although not necessarily above the yeild strength. In cyclical softening, each cycle of shows diminishing stress at a constant strain range while traversing hysteresis loops. Cyclical strain hardening materials show increasing stress at constant strain. This is <u>not</u> a fatigue failure. To mitigate, you would need to reduce the stress or use a material with a higher elastic limit.

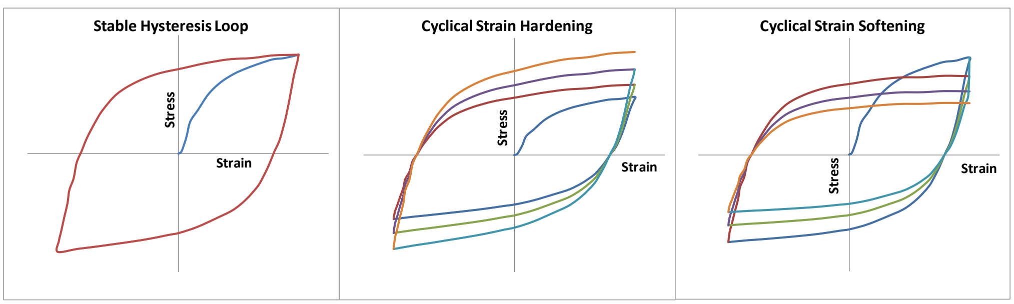


Figure 2. Mechanical Hysteresis Loops. The left figure is a stable, steady state hysteresis loop. With initial load shown in blue, idealized final steady state in red. The middle figure shows strain hardening behavior, and the right figure shows strain softening behavior. In each figure, the cycles progress from dark blue through red, green, purple, light blue and orange.

Fatigue failures occur without warning and over time in cyclical loading. These are necessary but not sufficient conditions to diagnose a failure by fatigue. Such a determination can only be made through careful study of the fracture interface at high magnification, coupled with experience and familiarity with how each particular material fails under various conditions.

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