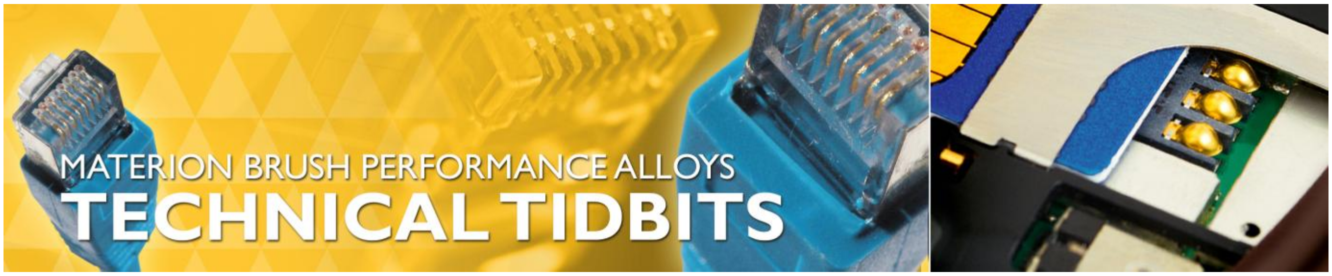

Issue No. 70 – October 2014 **New Publication**

Most people do not need to simulate fatigue – A discussion on modeling and simulation of fatigue behavior.

- **Miner's Rule**
- **Cycle counting**
- **Loading Blocks**
- **Rainflow Counting**

The next issue of Technical Tidbits will discuss diagnosis of fatigue failures.

Simulating Fatigue Behavior

(This issue of Technical Tidbits continues the materials science refresher series on basic concepts of material properties.) Prior editions of Technical Tidbits have discussed fatigue life prediction using stress, life, strain life, and the fracture mechanics approach. All three methods required physical testing, interpretation, statistical analysis, and/or curve fitting of data. Now it is time to discuss practical analysis using finite element simulation.

The simplest way to use finite element analysis (FEA) to predict fatigue life would be to perform a nonlinear static structural analysis. This would enable you to determine the peak stresses and strains in a part at peak load. The point that has the highest peak 1st principal tensile stress is a point in the model where failure by fatigue is likely, so that peak stress value can be manually compared the S-N curve for that material (preferably statistically analyzed), with the appropriate modification factors. This is a simple and easy approach, but there is a danger to this method.

Note the careful wording above, where the phrase "is a point where failure by fatigue is likely" is used, not the phrase "is the point where fatigue failure is most likely to occur." It is quite possible that the loading history in other areas of the model, can initiate or propagate cracks more quickly, even at a lower peak tensile stress. So, while you are comfortable that the area in peak tensile stress will survive the given number of cycles, an early fatigue failure may occur due to crack initiation in an area with lower peak stress. There is also the problem that very few loads experienced in real life have constant amplitudes and periods, so real life loading does not resemble fatigue testing (See Figure 1).

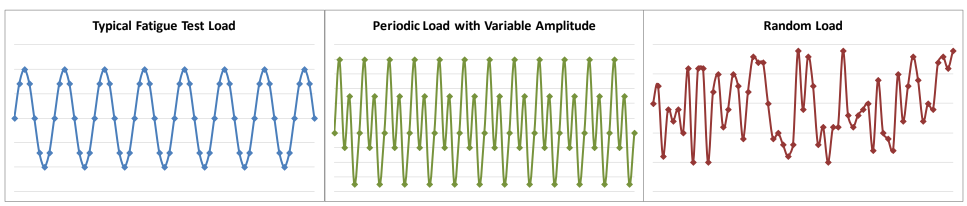

Figure 1. Typical Fatigue Test Loading vs. More Realistic Loading.
In reality, loading many have variable or even random amplitudes, periods, and reversals. Fatigue testing is usually done with perfectly periodic loading.

Most finite element analysis software suites offer fatigue analysis packages for these occurrences. First, the model would be created in CAD, imported into the FEA program, and then boundary conditions (constraints, points of contact, initical temperatures, etc.) would be applied. Next, a typical loading history for a similar part is specified (more to follow on this topic). The user can then choose what kind of analysis to perform (stress-life, strain life, fracture mechanics), and will input the relevant fatigue data or numerical constants needed for the particular fatigue law used.

The program will then calculate the expected life of each point in the model, which can then be plotted. The outputs also may be compared to a desired lifetime to determine a factor of safety at each point, or to predict the amount of life remaining at a given point in time. This is all accomplished by calculating the "damage" created by each load cycle at each point, and then summing all of the damages over time. Cumulative damage is calculated by Miner's rule, also known as the Palmgren-Miner rule:

$$D = \sum_{i=1}^{N} \frac{n_i}{N_{fi}},$$

Here, D is the cumulative damage, n_i is the number of cycles at load level i, and N_{fi} is the number of cycles to failure at that particular load level. (In this case, load level can be stress, strain, etc. depending on the fatigue analysis method used.) In an ideal world, failure would occur when the damage level equals one. However, sometimes failure can occur when D is greater than one, usually when large amplitude cycles occur after small amplitude cycles. Even worse, when larger cycles occur early and smaller cycles occur

Simulation of Fatigue Behavior (continued)

later, the part can fail when the accumulated damage is substantially less than one. Therefore, the designer would have to know the particular failure criterion for the material and given loading history.

So, how is the damage from each cycle calculated, prior to summation? This is accomplished by a procedure callled **cycle counting**. In cycle counting, a complex, variable loading history is converted into a series of peaks and valleys. Various numerical techniques are employed to extract the damage expected to occur in each cycle or reversal.

Width periodic loading (green line in figure 1), the technique is fairly easy. The order of the loading is rearranged so that the first part of each cycle is grouped into one block, the second part into another block, etc. Each individual **loading block** will thus have a perfectly repeatable load of constant amplitude, with its own mean stress and stress amplitude, so the amount of life used up in each block is easily calculable using stress-life or strain-life techniques.

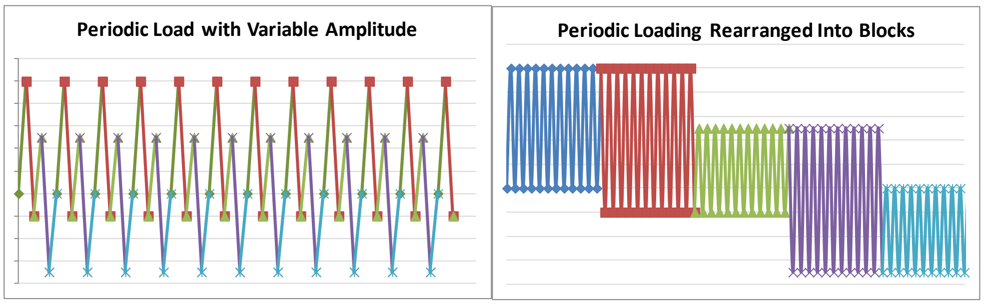

Figure 2. Periodic Loading with Variable Amplitude (Middle Chart of Figure 1) Rearranged into Loading Blocks. The expected life of each block can be easily calculated, as the mean stress and amplitude are known. The damage of each block can be summed to predict life.

For a random loading history, each peak and valley would have to be counted and calcualted individually, by methods known as peak counting, range counting, level crossing counting, or **rainflow counting**. Rainflow counting provides the best results, and is the method typically used by finite element software for fatigue life calculations.

In each of these methods, every single change in loading per half cycle (reversal) is noted, and its magnitude and mean are recorded. Half cycles with similar magnitudes and means can be combined into full cycles, where the damage is easily calculated. These methods differ in the criteria used to identify peaks and valleys. The rainflow technique adjusts the magnitude of each half-cycle by taking into account the magnitudes of neighboring peaks and valleys, so this provides additional accuracy.

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References:

ASTM E1049 Standard Practices for Cycle Counting in Fatigue Analysis

SAE Fatigue Design Handbook
SAE International 1997

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