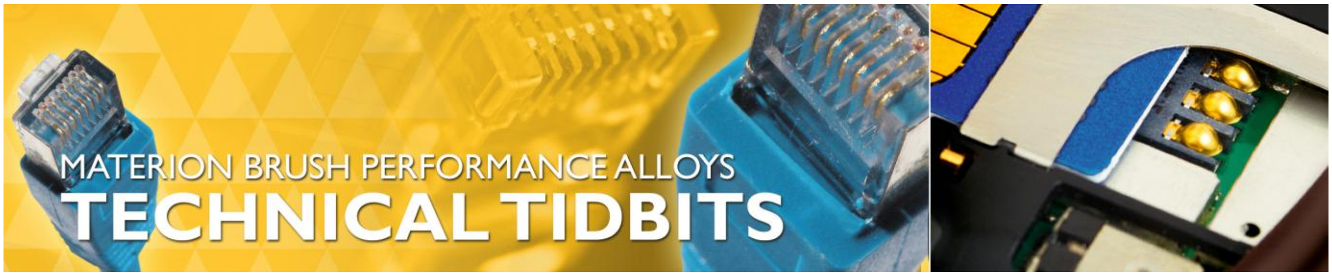

Issue No. 64 – April 2014 **New Publication**

There's a Goodman method, but is there a Betterman method? – A discussion of alternative methods of predicting fatigue life from R=-1 data.

- **Modified Goodman Diagram**
- **Gerber Equation**
- **Morrow Equation**
- **Soderberg Equation**
- **Smith Watson Topper Equation**
- **Walker Equation**

The next issue of Technical Tidbits will finish the discussion on stress-life methods for fatigue analysis.

Goodman (Haigh) and Other Related Diagrams

(This issue of Technical Tidbits continues the materials science refresher series on basic concepts of material properties.) Last month's edition of Technical Tidbits introduced the concepts of mean stress and alternating stress, as well the Goodman (Haigh) diagram.

The modified Goodman diagram (shown below in Figure 1) accounts for yielding as a failure mode. For this particular example, suppose we have a material that has a fully reversed bending fatigue strength of 60 ksi at the desired number of cycles. The ultimate tensile strength is 120 ksi, and the yield strength in tension is 100 ksi. The true stress at fracture is 150 ksi. (Note that these numbers were chosen for illustrative purposes, to make the math easy.) With alternating stress on the y axis and mean stress on the x axis, we draw a straight line from the positive fatigue strength to the coordinate equivalent to the tensile strength on both axes, and back down to the inverse of the fatigue strength on the y axis.

For a given mean stress, we can then find a maximum allowable alternating stress range as the corresponding distance between the orange lines. We can further limit the allowable stress envelope by setting the yield strength as the upper limit on both axes, as shown in the figure. Theoretically, if the maximum and minimum stress values fall within the orange diagram at the mean stress level, the design should last for the required number of cycles. (For a different number of cycles, the end points on the left would move closer together for higher number of cycles and further apart for a lower number of cycles.)

Of course, this analysis is subject to the same caveats as discussed in the previous edition of Technical Tidbits. There are also other means of connecting the dots, so to speak, which we will now discuss.

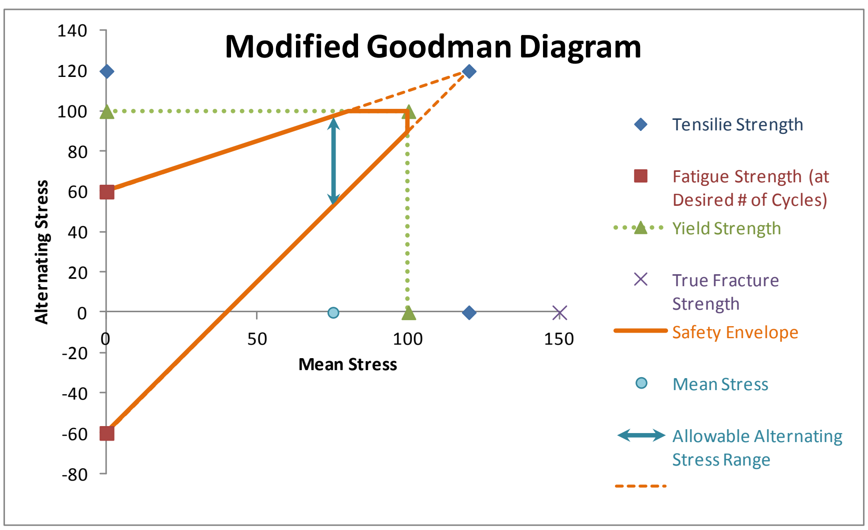

Figure 1. Modified Goodman Diagram, Accounting for Yielding as a Failure Mode. This interpretation allows you to predict the maximum allowable alternating stress for a given mean stress. In this example, at a mean stress of 75 ksi, the peak permissible alternating stress is 45 ksi, or a peak maximum stress of 92.5 ksi and a peak minimum stress of 52.5 ksi. If the maximum and minimum stress levels fall within the orange envelope, the design is predicted to be safe for the number of cycles represented by the fatigue strength.

Goodman and Other Related Diagrams (continued)

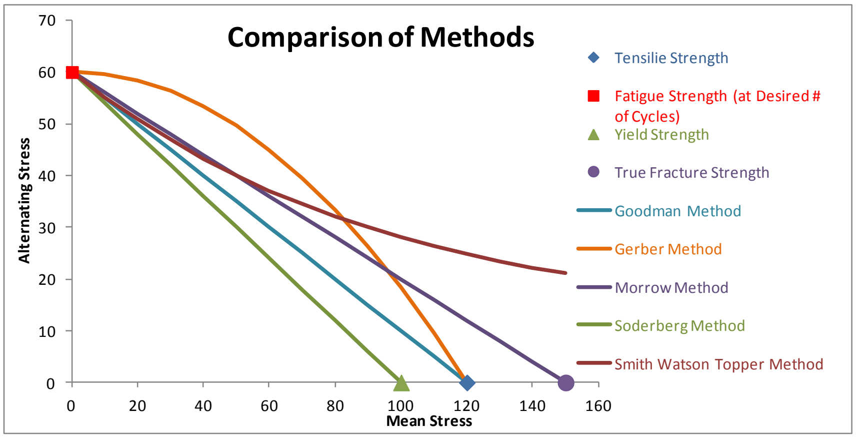

Figure 2. Comparison of Methods for Estimating Allowable Mean and Alternating Stresses. Combinations of mean and alternating stresses under the lines would be expected to survive the required number of cycles, while those points above the lines would be expected to fail early.

The methods listed above all try to empirically model fatigue performance by coming up with a relationship between mean stress, alternating stress, the fatigue strength at a particular number of cycles, and another material property such as yield strength, tensile strength, and true fracture strength. The exception is the Smith Watson Topper method, which only uses fatigue strength, mean stress, and alternating stress, which is why it does not intersect the x axis. The Walker method is not shown above, because it requires curve fitting of fatigue data based on testing at multiple R ratios, and so appears different for every material. The shape of the curve generated would be similar to the Smith Watson Topper method. The equations used for each of the methods are listed below:

$$\text{Gerber}: \frac{\sigma_a}{S_N} + \frac{\sigma_m}{UTS} = 1$$

$$\text{Goodman}: \frac{\sigma_a}{S_N} + \left(\frac{\sigma_m}{UTS}\right)^2 = 1$$

$$\text{Solderberg}: \frac{\sigma_a}{S_N} + \frac{\sigma_m}{YS} = 1$$

$$\text{Morrow}: \frac{\sigma_a}{S_N} + \frac{\sigma_m}{\sigma_{fracture\_true}} = 1$$

$$\text{Smith Watson Topper}: \frac{\sigma_a + \sigma_m}{\sigma_a} = (S_N)^2$$

$$\text{Walker}: \sigma_a\left(\frac{2}{1-R}\right)^{1-\gamma} = S_N$$

σ_a = alternating stress
σ_m = mean stress
UTS = ultimate tensile strength
YS = 0.2% offset yield strength
$\sigma_{fracture\_true}$ = true fracture stres
S_N = fully reversed fatigue strength at desired number of cycles
γ = constant derived from curve fit
R = stress ratio

Written by Mike Gedeon of Materion Performance Alloys Marketing Department. Mr. Gedeon's primary focus is on electronic strip for the automotive, telecom, and computer markets with emphasis on application development.

TECHNICAL TIDBITS

Materion Performance Alloys
6070 Parkland Blvd.
Mayfield Heights, OH 44124
(216) 486-4200
(216) 383-4005 Fax
(800) 375-4205 Technical Service

MATERION

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