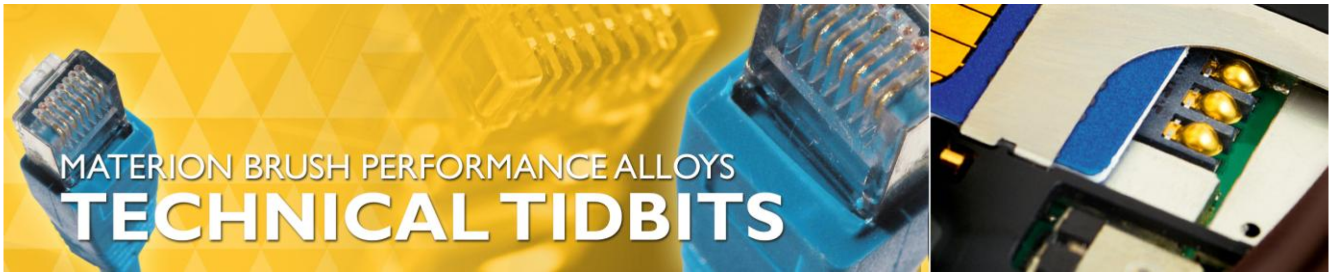

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Either way, it ends up broken – A discussion on the differences between stress life and strain life fatigue data, and what it means to the design engineer.

- **Stress Life**
- **Strain Life**
- **Coffin-Manson Relationship**

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

Stress Life vs. Strain Life

(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 strain life methods for estimating fatigue life. This month discusses the differences between stress life and strain life techniques.

Stress life methods are most useful at high cycle fatigue, where the applied stresses are elastic, and no plastic strain occurs anywhere other than at the tips of fatigue cracks. At low cycles, scatter in the fatigue data makes these methods increasingly less reliable. On the other hand, **strain life** methods can be used for low cycle fatigue, where there the loading is a combination of elastic and plastic on the macro scale.

For most stress life calculations, the math is relatively easy, since there is only one stress component. In strain life calcualtions, the math is more difficult, as the elastic and plastic components of the strain must be dealt with separately.

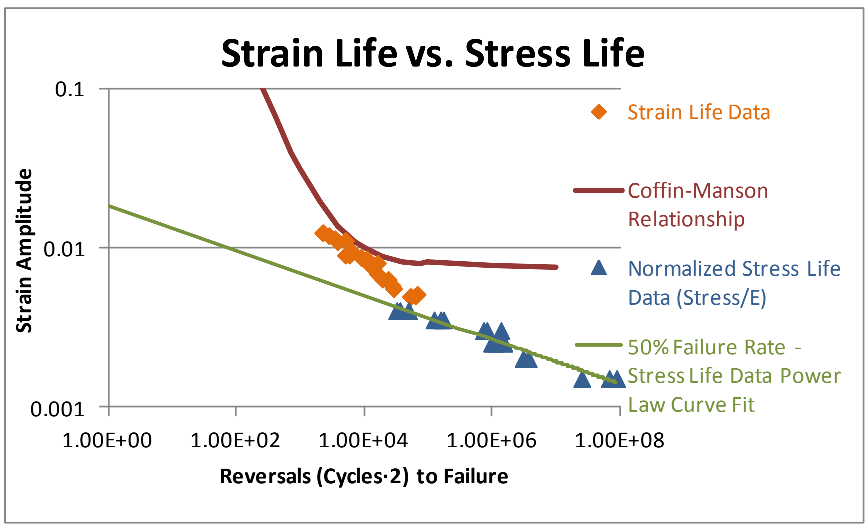

Figure 1. Stress Life Data and Curve Fit vs. Strain Life Data and Curve Fit. The diagram shows that there is not an "apples to apples" correlation between the two methods. This is even after the stress life data are converted by dividing stress amplitude by elastic modulus to obtain an equivalent strain amplitude, and the cycles to failure are multiplied by two to obtain reversals to failure. Part of this is due to the fact that the fully reversed stress life data were obtained in bending, and the strain life data was obtained in tension.

Stress life and strain life test data often do not correlate well to each other, as shown above in Figure 1. The data points are for the same material, albeit different forms. The strain life data were measured in relatively thick plate, while the stress life data were measured in thin strip, which may account for some additional differences. In order to attempt a reasonable comparison, the stress amplitude data points from the stress life method were divided by the elastic modulus of the material to convert them to strain amplitude. Additionaly, the stress life cycles to failure were multiplied by two to obtain reversals to failure. Note that the data points do not quite line up, as well as the different shapes of the curve fits used for the different techniques. Again, remember that stress life techniques are not used in low cycle (below about 10^4 cycles). The stress-life curve fit below indicates why, as it does not account for the ability to handle greater strain amplitudes at low cycles.

Stress Life vs. Strain Life (continued)

The apparent poor fit of the **Coffin-Manson relationship** in Figure 1 is due to the narrow strain range of the gathered data, demonstrating a caveat of the strain-life method: It requires testing at strain amplitudes of multiple orders of magnitude in order to get the exponents and coefficients correct. In other words, as the strain amplitue range gets wider, the accuracy of the calculated slopes and intercepts will increase, and the calculated curve fit will look more like the data. It is abolutely critical to minimize the variation and error in these quantities, as all subsequent calculations depend on them.

The most graphical means of demonstrating the difference between the two methods is a side by side comparison of common relationships, as illustrated in table 1, taken from N.E. Dowling's 2004 paper, Mean Stress Effects in Stress-Life and Strain-Life Fatigue", with some minor rearrangment. On the stress life side, the allowable alternating stress amplitude is estimated based on the desired number of cycles to failure and a number of other parameters. On the strain life side, the allowable strain amplitude is estimated from the number of reverals to failure and other parameters, mainly taken from the Coffin-Manson curve fit relationships. Which calculations would you perform, knowing that accuracy increases both from top to bottom and from left to right? As an engineer, you would need to determine which relationship best fits your situation and data.

Relationship	Stress Life Equation	Strain Life Equation
Morrow	$\sigma_a = S_N \cdot \left(1 - \frac{\sigma_m}{\sigma_{fracture\_true}}\right)$	$\varepsilon_a = \frac{\sigma'_f}{E} \cdot \left(1 - \frac{\sigma_m}{\sigma'_f}\right) \cdot (2N_f)^b + \sigma'_f \varepsilon'_f \cdot (2N_f)^{b+c}$
Smith Watson Topper	$\sigma_a = S_N \cdot \left(\frac{2}{1-R}\right)^{-1/2}$	$\varepsilon_a = \frac{\sigma'_f}{E} \cdot \left[2N_f \cdot \left(\frac{1-R}{2}\right)^{1/2b}\right]^b + \varepsilon'_f \cdot \left[2N_f \cdot \left(\frac{1-R}{2}\right)^{1/2b}\right]^c$
Walker	$\sigma_a = S_N \cdot \left(\frac{2}{1-R}\right)^{-\gamma}$	$\varepsilon_a = \frac{\sigma'_f}{E} \cdot \left[2N_f \cdot \left(\frac{1-R}{2}\right)^{1-\gamma/b}\right]^b + \varepsilon'_f \cdot \left[2N_f \cdot \left(\frac{1-R}{2}\right)^{1-\gamma/b}\right]^c$

Table 1. Fatigue Relationships in Stress Life and Strain Life Forms. As discussed in prior issues, σ_a is the stress amplitude, S_N is the fully reversed fatigue strength at the desired number of cycles, R is the stress ratio, σ_m is the mean stress, $\sigma_{fracture\_true}$ is the true stress at fracture, and γ is a constant curve-fit to stress-life data. On the strain life side, ε_a is the strain amplitude, E is the elastic modulus, $2N_f$ is the number of reversals to failure in the strain life test, and σ'_f, ε'_f, b, and c are constants curve fit to the strain life data using the Coffin-Manson relationship.

This concludes the discussion of stress life and strain life methods of estimating fatigue life. Next month will introduce the fracture mechanics approach.

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