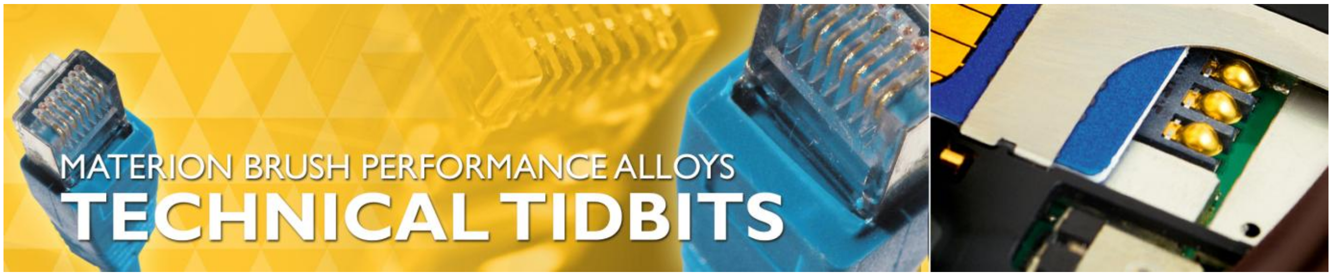

Issue No. 55 – July 2013 **New Publication**

S-N is Easier to Say than Sigma-Epsilon –
An in-depth discussion on how fatigue data can be graphically presented.

- **S-N Diagram (Wöhler Diagram)**
- **Runouts**
- **Endurance Limit**
- **10^8 Cycle Fatigue Strength**

The next issue of Technical Tidbits will continue the discussion on Fatigue.

S-N (Wöhler) 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 discussed how fatigue tests are conducted. This month, we will discuss how the data may be presented in an **S-N diagram (Wöhler diagram)**.

The result of running a number of fatigue tests is a list of the applied peak stress level in each sample, and the number of cycles that it took for each sample to fail. These data points are plotted on a chart, with the number of cycles to failure (N) on the horizontal axis, and the applied stress (S) on the vertical axis. **Runouts** (samples that did not fail in the elapsed time of the test) are conventionally designated by an arrow pointing to the right, located at the applied stress level and the number of cycles after which the test was stopped. Figure 1 below displays a schematic of typical curves (not including runouts).

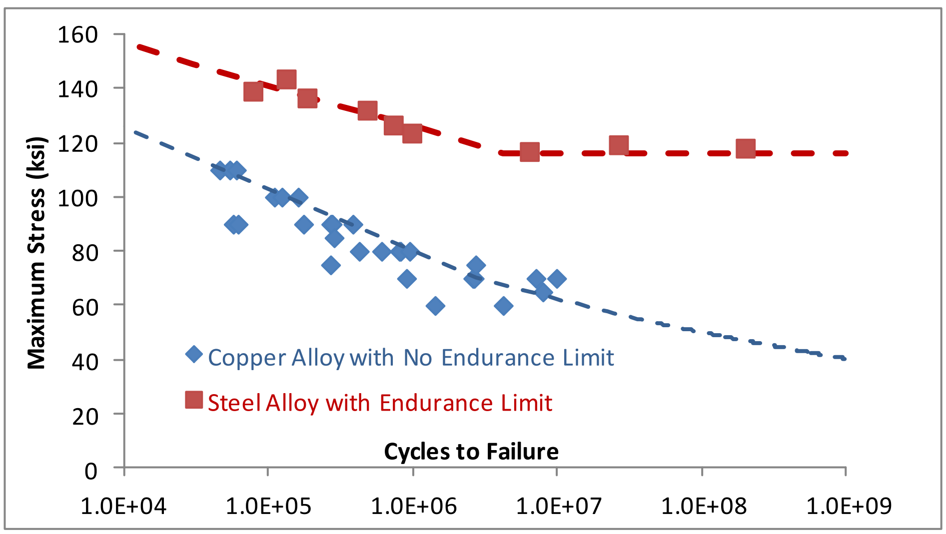

Figure 1. S-N Diagram of a Copper and a Steel Alloy. The endurance limit is a stress level below which the failure rate will not increase, no matter how many cycles the material sees. Most nonferrous alloys (based on copper, aluminum, titanium, etc.) have no such limit.

Note that there is may be a large amount of variation in the data. A best fit trend line can plotted through the center of the scattered points. Note that this trend line is not terribly useful, other than to provide an estimate of when about half of your parts would be expected to fail. The question that should be asked is "At what stress level would all of my parts, or at least an acceptably low amount of them, be expected to fail?" For a proper answer to this question, we would need to turn to statistics. This will be discussed in next month's edition of Technical Tidbits. For now, we will discuss crude approximations.

Note that the two metals above show different behavior. For the steel alloy, there comes a point where the trend line becomes horizontal. The stress level at which this occurs is called the **endurance limit**. A case could be made that this would be the limiting stress level for any design using this steel. However, note that the line is still around the 50% failure point, as there will be an equal number of failures above and below the endurance limit. Therefore, there should be a safety factor added in to the design stress value large enough to account for this scatter. This reduced value would be the stress level below which the material would not be expected to fail, no matter how many times it is cycled, unless acted on by some external factor like corrosion.

S-N (Wöhler)Diagrams (continued) The copper alloy shown in Figure 1 has no endurance limit, but instead has a curved trend line of continuously decreasing slope. Therefore, to define a safe stress level, one needs to know how many cycles the part would be expected to survive in service. From this, one can use the S-N data to identify the range of stresses that would result in that given number of cycles. This value would be the **fatigue strength** at the given number of cycles. For materials that do not have an endurance limit, this would normally be specified as the 10^6 (1 million), 10^7 (10 million), or 10^8 (100 million cycle fatigue strength). Care must be taken when comparing the fatigue strengths of several materials to ensure that the numbers are all reported for the same number of cycles.

There are two ways to use an S-N (Wöhler) diagram. The first would be to compare the peak stress level in a cycled design to determine the expected number of cycles to failure. This would usually be given as a range. In Figure 2 below, a design using this material with a peak cyclical stress of 80 ksi would be expected to last approximately 10^5 to 10^6 cycles. The second method would be to determine the minimum required number of cycles for your design, and find the minimum stress that results in a failure in that time frame. This minimum stress level would then be the limiting stress in your design, instead of the endurance limit. In Figure 2 below, a design expected to last 500,000 cycles should have no more than about 67 ksi peak cyclical stress.

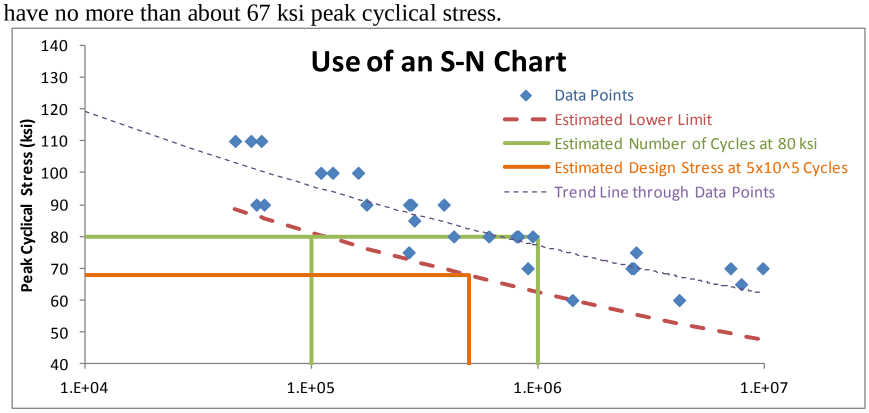

Figure 2. The two simple uses of an S-N Diagram. The green lines illustrate the expected number of cycles for a peak stress of 80 ksi, and the orange lines illustrate the maximum stress allowable for a design required to last for half a million cycles. The lower limit (red dashed line) could be manually estimated or (more appropriately) derived statistically.

It would also be prudent to add a safety factor onto this limiting stress level, since are many effects that would reduce the expected lifetime, such as temperature, corrosion, surface finish, stress concentration, etc. These factors will be discussed in future editions of Technical Tidbits.

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TECHNICAL TIDBITS

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ASTM E468: Standard Practice for Presentation of Constant Amplitude Fatigue Test Results for Metallic Materials

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Atlas of Fatigue Curves
ASM International
Materials Park, OH 1985

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