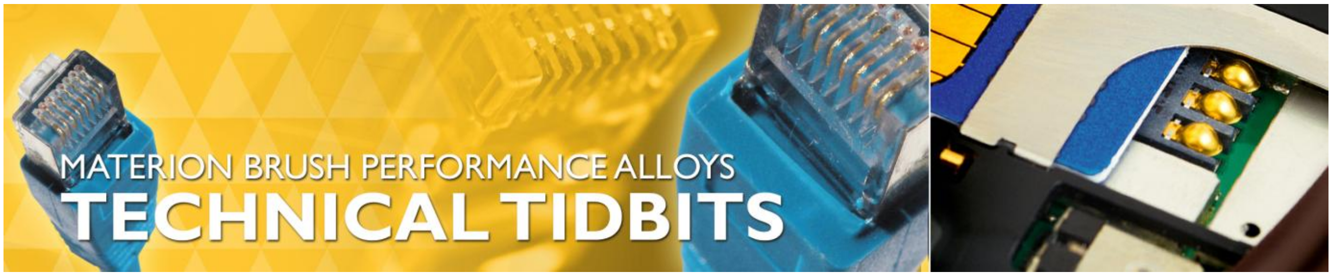

Issue No. 60 – December 2013 **New Publication**

I have to concentrate... concentrate...concentrate... – Continuation of the discussion on how to modify the calculated fatigue strength value to account for real-world conditions.

- **Stress Concentration**
- **Stress Concentration Factor**
- **Stiffness Singularities**
- **Notch Sensitivity**
- **Notch Sensitivity Ratio (q)**

The next issue of Technical Tidbits will continue the discussion on fatigue strength modification factors

Effect of Stress Concentration on Fatigue 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 discussed how to modify the fatigue strength of a material to account for differences in loading, size and shape between the test piece and the part being designed. This month discusses how to account for stress-concentrating features in geometry.

Engineering stress, particularly in a tensile test, is defined as the applied force divided by the cross sectional area over which the force is applied. This is very easy to calculate, and engineering would not be hard if all load-bearing parts were shaped as perfect rectangles or cylinders. Of course, in reality parts have variable cross sections, and are often loaded with stress concentrating features such as holes, notches, grooves, flanges, tapers, embossments, etc. Most of the time, such features are there to serve an important purpose, so they cannot be eliminated.

The effect of all these abrupt changes in cross section is to concentrate the stress at those features. Figure 1 below shows the results of a finite element analysis (FEA) of a number of plates, with a tensile load placed on the top and bottom edges. The plate on the far left, which is a perfect rectangle, is completely uniform in stress (note the solid teal color associated with this moderate stress level). The plates nearby with the grooves and notches show stresses up to three times higher than the nominal level (yellow, orange and red). Areas outside the area of concentration are much lower (dark blue). Note that in all cases, the cross section of the reduced area is the same, but the stress levels vary. Sharper notches will concentrate stress more than smoother notches.

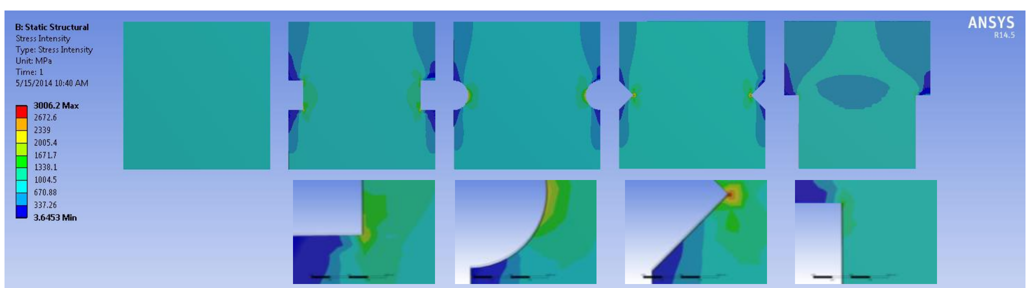

Figure 1. Effect of Various Notch Types on **Stress Concentration** in a Plate Under Tensile Load. Discontinuities in geometry, whether due to notches are changes in cross section, multiply the intensity of the stress field relative to a smooth, uniform specimen under stress. Sharper features have a greater multiplier than smoother features.

Most engineering mechanics textbooks will have a long list of tables and charts detailing the theoretical **stress concentration factor** of various geometries. These should cover the most common types of loading, part shape, and stress risers. However, since no textbook has ever been written with the infinite number of possible combinations, there will always be some cases where you will be unable to find the proper stress concentration factor, and you will be forced to use FEA to determine the actual stress distribution.

Be warned, however, that in a lot of cases, FEA programs will tend to over predict the amount of stress concentration, even with high order elements and adaptive mesh refinement. This is not meant to disparage the capabilities of the various software packages, it's just that no computer yet has been able to successfully divide by zero. Finite element analysis programs work by solving gigantic systems of equations in matrix form. Sharp corners will usually result in singularities in the stiffness matrices of finite element models, but most software packages will have mathematical techniques to compensate for these **stiffness singularities**. Even so, it is usually best to check the stress level in the elements near the stress riser, and not those at the stress riser itself.

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Effect of Stress Concentration on Fatigue Life (continued)

So what effect does a stress riser have on fatigue life? Since the stress is much higher in these areas than in the rest of the part, fatigue failures will usually initiate in these regions. This is part of what makes fatigue life estimation difficult. Therefore, when designing a part subjected to cyclical loading, it is best to minimize the amount of stress concentration. This means eliminating grooves and notches where possible, or at least replacing sharp corners with gentle radius fillets.

The simplest way to account for stress concentration would be to use a modifying factor that this the inverse of the theoretical stress concentration factor: $S_n = \frac{1}{K_t} S_n'$, where S_n is the adjusted fatigue strength at the given number of cycles, S_n' is the calculated fatigue strength without stress concentration, and K_t is the stress concentration factor. Assume, for example, that you have a rotating, round component under a bending load, and you want it to last for 100 million cycles. You can look at the S-N diagram for the maximum allowable stress level for this design, and let us say that this is 900 MPa. Now, if the area under the peak stress had a notch with a theoretical stress concentration of 3, then you would multiply the maximum stress level by 1/3, to come up with a maximum allowable stress of only 300 MPa. This is why it is a good idea to keep features that concentrate stress out of your design, if at all possible. If not possible, then keep them away from the areas of peak stress under load.

OK, that seems simple enough. Now comes the expected dose of "hold on, it's not that easy." Materials possess varying degrees of a property called **notch sensitivity**. A fully notch sensitive material would experience the full theoretical stress concentration. Ductile metals can distribute the strain at a notch (or a crack tip) more evenly, thus blunting the crack and reducing the effect of stress concentration. This is property is measured by the **notch sensitivity ratio (q)**, which is the ratio of the ultimate tensile strengths of a smooth tensile sample relative to a notched tensile sample. The appropriate modified stress concentration factor is defined by the following equation: $K_f = 1 + q \cdot (K_t - 1)$, where K_t is the theoretical stress concentration factor for the given geometry, and q is the notch sensitivity ratio of the material. For a notch sensitivity ratio of 1, the full stress concentration factor is used. If the notch sensitivity ratio is 0, then the stress concentration factor will be 1. If you do not have data for the notch sensitivity ratio of the material you are using, assume it is 0 and use the full theoretical stress concentration factor.

One way to protect against early fatigue failure would be to minimize the effect of stress concentration. This can be accomplished by replacing sharp corners in high stress area with rounded fillets, preferably with a fillet radius as large as practically possible. Any other unavoidable notches should be made blunt or rounded, to minimize the stress concentration. Any burrs on machined or stamped parts could also function as stress risers, so mechanically deburring or tumbling such parts would be a good way to increase the fatigue life. Such steps may add minor costs to the production of the parts, but would often be far less costly than a rash of field failures due to careless design.

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