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Fatigue Testing Guidelines

These guidelines are a collaboration between Dave Breuer (Curtiss-Wright Surface Technologies) and Charlie Li (DANTE Solutions). Since most shot-peened components receive heat treatment, Mr. Breuer and Mr. Li work together to provide solutions for customers interested in residual stress from both processes.

WHEN QUALIFYING shot peening (SP), engineers utilize data such as computer simulation and fatigue testing in a controlled setting. This data is faster, relatively inexpensive and useful to making decisions on SP. This lower cost data may qualify the SP so when expensive field testing occurs, it verifies what was already proven on subscale components.

The intention of this article is to discuss guidelines for proper laboratory fatigue testing. The following items will be discussed in greater detail:

- Specimen Geometry
- Accelerated Testing
- Stress Gradients

Specimen Geometry

Most fatigue failures occur from bending or torsional loading. Bending/torsion leads to crack initiation at the surface as the applied stress is highest for both types of stress. Shot peening is a surface treatment ideally suited for surface-initiated failures.

Figure 1 shows a finite element simulation of fatigue loading of the tooth root of a test gear. The adjacent graph shows the applied stress plotted against depth. The bending stress is highest at the surface and drops almost 50% at 0.5 mm depth.

It is not unusual for a part to be loaded in an axial direction and the high-stress area to not be axial stress, but rather bending or torsion stress due to geometry (cross holes) or misalignment. A compression spring experiences an axial load along its centerline and produces a torsional stress on the wire.

The most common type of fatigue test equipment performs axial, tension-tension (T-T) pull testing. If possible, the fatigue test engineer should avoid using axial T-T fatigue testing when the shot-peened component experiences primarily bending/torsion stress. Unlike bending/torsion, axial stress is more uniform across the cross section. Subsurface failure can occur, often initiating just below the shot peening compressive layer which is in residual tension (as it balances the residual compression at the surface). It is difficult to quantify shot peening performance on laboratory test coupons that experience subsurface failure when the actual component experiences surface-initiated failure.

Figure 2 (page 20) shows a finite element simulation of an axially loaded round fatigue coupon. The high-stress area occurs at the surface of the narrowest part of the coupon.

The adjacent enlarged view of the center area shows 270 degrees of the surface along with the centerline of the coupon. Under axial loading, the coupon's gradual taper produces a slight bending stress at the surface with the core also being in tension. This coupon is not optimal for a shot peening study on a component that experiences pure bending (or torsional loading).

A potential solution when using an axial fatigue test machine to represent pure bending is to put a "C" shape in the center area of the pull-pull specimen. This produces a bending tensile stress in the weak area of the coupon that is expected to fail while keeping the grip areas in the same location for mounting on the test machine. Additive-manufactured coupons can be printed relatively easily with almost any geometry.

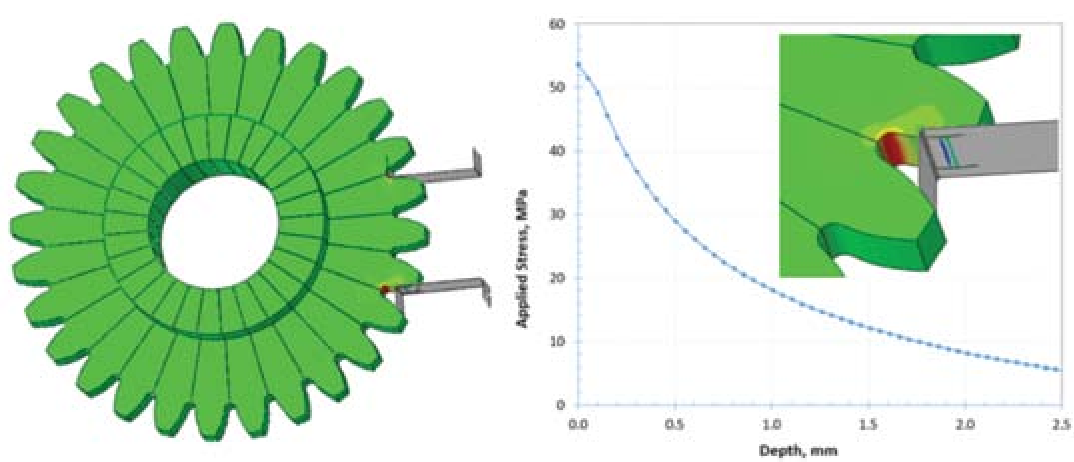

Figure 1.

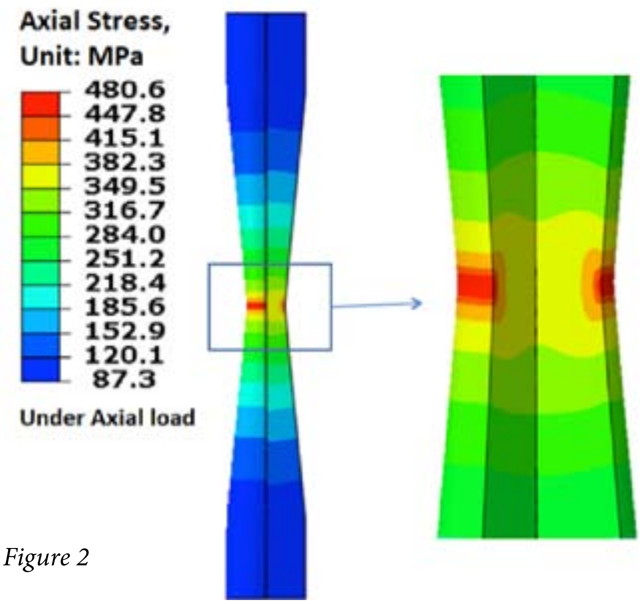

Figure 2

Accelerated Testing

When performing sub-scale component testing, the shot peening provider generally fears the statement, "We don't have a lot of time so we are increasing the test stress." Obviously, higher stress translates to reduced fatigue test life and less time (and cost) in the test lab. The concern with this approach is that shot peening is generally successful in lower-stress, higher-cycle fatigue environments.

If the test stress is increased sufficiently, it becomes a high-stress, low-cycle fatigue environment where shot peening may not prove effective. A decision maker may conclude that shot peening is not a proper solution simply because the test environment deviated significantly from the real world (lower) stress where shot peening would be effective.

A good balance for testing high-cycle fatigue components in the lab is to design the coupon stress and test machine to produce failure at 75,000 ±25,000 cycles in the unpeened condition. This fatigue life is not low-cycle fatigue and significantly less than one million cycles. Different shot peening iterations should produce different outcomes to identify which peening parameters are optimal.

The S-N (Stress versus Number of cycles) curve explains the theory. The vertical axis is a linear scale and the horizontal axis is exponential. As shot peening (residual) compressive stress offsets the (applied) tensile stress of fatigue loading, the component believes it is experiencing lower stress and experiences a large increase in life cycles. The reader may want to investigate the S-N graph for additional background.

Stress Gradients

Shot peening is usually applied to geometry changes at a part's surface (radii, holes, keyways, etc.). This geometry can be referred to as a "notch" and the tendency for fatigue cracks to start in these areas can be attributed to the part's "notch sensitivity".

When qualifying the effect of shot peening on a part, the test apparatus will be designed so the coupon experiences similar stress as the component experiences in the final assembly. In addition to matching the applied stress, the stress gradients from the manufacturing processes should be similar between actual part and test apparatus.

Using DANTE software, Figure 3 shows calculated stress distributions of a four-point bending coupon (with a large radius) and a gear tooth root under bending. Both coupon and gear are loaded in bending to produce similar tensile stress at the surface. The coupon with the large radius has the tensile stress field spread over a larger area.

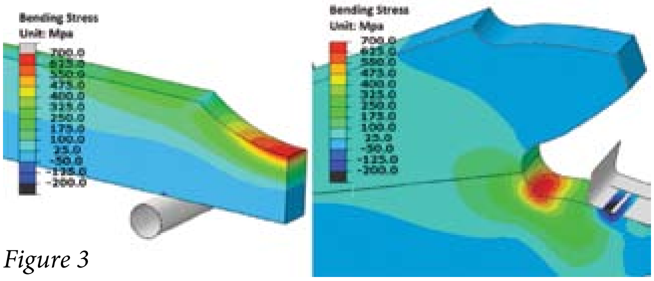

Figure 3

One should not expect the crack behavior (initiation and growth) to be similar if the stress gradients are different. To represent the gear-bending fatigue behavior, it is recommended to design the four-point bend coupon to have the same residual stresses from heat treatment and shot peening processes. With the proper applied load and geometry designs, the combined applied stress and residual stress of the coupon can effectively represent the gear bending stress behavior.

Shot peening compressive stress is concentrated in the 0.003-0.005" closest to the surface. Should one perform the simulation and plot the resultant (residual + applied) stress, different stress gradients may exist. Different stress fields will likely produce different crack behavior in different geometries.

The authors have many years of experience in the collection of fatigue data to validate and apply shot peening. Zhichao (Charlie) Li is president of DANTE Solutions which specializes in computer simulation of residual stress and fatigue life. Dave Breuer works for Curtiss-Wright Surface Technologies, helping customers to understand and apply shot peening on components in many industries.

About DANTE Solutions

DANTE Solutions is an engineering consulting and software company, specializing in metallurgical process engineering and thermal/stress analyses of metal parts and components. The company is the home of the DANTE Heat Treatment Simulation Software.