How to Improve Metal Fatigue Life

Shot peening is a cold working process applied to metal parts to increase fatigue strength. It consists of bombarding the surface with steel shot, glass beads or other round media under carefully controlled conditions. The peening causes the material to yield on the surface, thus placing a thin layer in uniform compression. Fatigue cracks cannot originate in or propagate into a surface that is stressed in compression. As nearly all fatigue cracks start at the surface at a stress-concentrated area, such as machine marks, scratches, sharp corners of holes, fillets, keyways and other changes of sections, the compressive stress induced by shot peening greatly increases the fatigue life.

One of the most common applications of shot peening is in plating. In building up undersized parts, a hard metal electrodeposit, such as chrome or nickel, is commonly used. On July 1, 1957, the federal chrome plating specification QQC-320 was amended calling for parts that are designed for unlimited life under dynamic loads to be shot peened and baked at 190.5°C (375°F) for not less than three hours. This applies practically to all steel parts having a hardness above Rc 40.

Hard metal plating tends to reduce the fatigue strength of the basis metal. The magnitude of residual stresses varies greatly with the composition of the bath, thickness of the deposit and bath temperature. One of the causes of reduction in fatigue strength by plating is the fine cracks that develop in the plate and propagate into the basis metal. These fine cracks constitute notches, which are stress risers just as notches would be on the surface of the basis metal (see Figure 1).

If the surface of the basis metal can be residually stressed in compression prior to plating, such as by shot peening, the cracks in the deposit will not propagate into the basis metal. See Figure 2 for typical SN (stress versus cycles to failure) curves showing shot peened and nonshot peened 4340 steel.

On 4340 steel (180,000 psi tensile strength) electroless nickel plated (0.001 in. thickness of plate), the fatigue life on flat-type bending specimens to 90,000 psi was:

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Cycles to Failure</th>
</tr>
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<tbody>
<tr>
<td>Polished</td>
<td>54,000</td>
</tr>
<tr>
<td>Shot peened</td>
<td>200,000</td>
</tr>
<tr>
<td>Nickel plated</td>
<td>39,000</td>
</tr>
<tr>
<td>Shot peened and nickel plated</td>
<td>141,000</td>
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Electroplating did not alter the static strength of the steel. Note in Figure 3 the typical stress SN curve showing shot peened and nonshot peened nickel plated parts.

Silver plate used in many critical aircraft engine applications must be checked to be sure the deposit is well bonded to the basis metal and will not peel or chip off during service.

Shot peening of the silver plate often is employed to determine adhesion (allowing for final machining of plating af-
ter shot peening tests). Blistered or peeled plate indicates a poor bond between the plating and the basis metal.

Normal commercial grinding will induce residual tensile stresses in the ground surface. Frequently these residual stresses, which can be quite high at the surface depending upon the severity of grinding, have been ignored by manufacturers as long as the stresses were not of a magnitude high enough to cause grinding cracks.

These high tensile stresses produced by grinding may frequently approach the ultimate strength of hard steels and eventually cause premature fatigue cracks. It is for this reason that industry has used shot peening after grinding to change the residual tensile stresses at the surface to residual compressive stresses, avoiding premature failures.

Shot peening has a tendency to leave a dimpled orange peel finish at the surface. To retain a smooth finish one may polish, hone or lap the shot-peened surface provided more than 10% of the induced compressive layer is not removed.

When steels are operating at a tensile strength above approximately 180,000 psi (40 Rc) the fatigue strength begins to drop off because of brittleness and notch sensitivity at the surface. By prestressing the surface in compression through shot peening, the fatigue strength of a shot peened specimen can be almost three times that of a nonshot peened specimen at a tensile stress level of approximately 280,000 psi (53 Rc) (see Figure 4).

Reference has been made to developing a compressive stress on the surface of material being shot peened. This needs to be controlled and measured as accurately as possible. Over peening or shot peening a thin part at too high an intensity will lead to deformation. Incomplete coverage of shot peening may not demonstrate the desired fatigue resistance.

Control of shot peening means that the depth of the compressive stress can be held constant from piece to piece. This type of precise control is accomplished by the use of Almen strips, which are strips of cold rolled spring steel (SAE 1070) that come in thicknesses of 0.031 in., 0.051 in., and 0.0938 in. and are known respectively as N, A and C strips. Measurement of peening intensity is accomplished by saturating one side of the strip with a given particle size of shot of either steel or glass at a given air pressure. This causes the strip to bend or arc according to the degree of compressive stress applied on the one side. Peening intensities are expressed in terms of the arc height of curvature of the Almen strip as measured on a standard Almen gauge. Intensity is written as, for example, 0.005 to 0.007A. Use of Almen strip measurement allows duplicating the peening intensity at different times by different operators using different equipment but with identical results.

In shot peening, the operator technique or use of the control methods is most critical. Accurate gradation of the particle sizes is also extremely important, as can be demonstrated by the effect of the mass on intensity at any single pressure. Shot peening is a function of time versus exposure to glass bead or steel shot streams capable of producing given intensities. This must be automated for all operations to obtain repeatability and highest production rates.

Shot peening has been used for various applications ranging from the standard improvements in fatigue life to retarding stress corrosion cracking, intergranular corrosion, cavitation, fretting, scoring and galling.

Shot peening also has been effec-
tively used in electrochemical machining (ECM) and electrodischarge machining (EDM). Electrochemical machining is the controlled dissolution of workpiece material by contact with a strong chemical reagent. Although ECM is considered to be a relatively stress-free process not inducing any significant stresses on the surface, the reduction in endurance strength at the 10^7 cycle measuring point is caused by the frequently observed surface softening (Rebinder effect) and the random surface imperfections that are contribu-
tors to this reduction. Shot peening has been found to be a good post treatment to restore the endurance limit.

Although the EDM spark erosion process is essentially force-free, eroded components are not necessarily stress-
free. Not all the molten metal produced during the discharge is expelled into the working gap. That which remains reso-
lidifies to form a hard skin on the work surface. Accompanying thermal stresses, plastic deformation and
shrinkage induce a residual tensile stress in the workpiece, which under certain conditions has been found to
approach the ultimate tensile strength of the material near the surface. Shot peening has been utilized as an excel-
 lent tool to restore the fatigue life of parts that have been electrodischarge-
machined.

Work hardening is another unique area in which shot peening has been used. Some materials that have a rela-
tively high work hardening coefficient, such as austenitic stainless steels, In-
conel, manganese steel, Stellite and Hastelloy can be shot peened to get a
relatively hard surface. Shot peening austenitic stainless steels can increase
the hardness at the surface by approximately 20%. The value of utilizing shot peening for cold working and hardening
these materials is because these mate-
rials cannot be heat treated and in
many cases require a hard surface to
resist wear.

Figure 5 shows the increase in hard-
ness that can be obtained by shot
peening Hastelloy C. Figure 6 shows
the effect of work hardening by shot
peening Stellite.

Shot peening coverage is normally
defined as the uniform and complete
dimpling or obliterating of the original
surface. Quality control evaluation of
coverage has been done using a 10-
power magnifying glass. However,
many parts that are relatively hard,
such as case-hardened carburized

<table>
<thead>
<tr>
<th>Figure 5. Hardness vs. distance from surface for shot peened Hastelloy C samples</th>
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<tr>
<td><img src="image" alt="Graph Showing Hardness vs. Distance" /></td>
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<tr>
<th>Figure 6. Hardness vs. depth for shot peened Stellite thrust runner segment.</th>
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<tr>
<td><img src="image" alt="Graph Showing Hardness vs. Depth" /></td>
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