SHOT PEENING APPLICATIONS

METAL IMPROVEMENT COMPANY

A Subsidiary of Curtiss-Wright Corporation

CHAPTER 1
THEORY

THE SHOT PEENING PROCESS

Shot peening is a cold working process in which the surface of a part is bombarded with small spherical media called shot. Each piece of shot striking the metal acts as a tiny peening hammer imparting a small indentation or dimple on the surface. In order for the dimple to be created, the surface layer of the metal must yield in tension (FIGURE 1-1). Below the surface, the compressed grains try to restore the surface to its original shape producing a hemisphere of cold-worked metal highly stressed in compression (FIGURE 1-2). Overlapping dimples develop a uniform layer of residual compressive stress.

It is well known that cracks will not initiate nor propagate in a compressively stressed zone. Because nearly all fatigue and stress corrosion failures originate at or near the surface of a part, compressive stresses induced by shot peening provide significant increases in part life. The magnitude of residual compressive stress produced by shot peening is at least as great as half the tensile strength of the material being peened.

In most modes of long term failure the common denominator is tensile stress. These stresses can result from externally applied loads or be residual stresses from manufacturing processes such as welding, grinding or machining. Tensile stresses attempt to stretch or pull the surface apart and may eventually lead to crack initiation (FIGURE 1-3). Compressive stress squeezes the surface grain boundaries together and will significantly delay the initiation of fatigue cracking. Because crack growth is slowed significantly in a compressive layer, increasing the depth of this layer increases crack resistance. Shot peening is the most economical and practical method of ensuring surface residual compressive stresses.

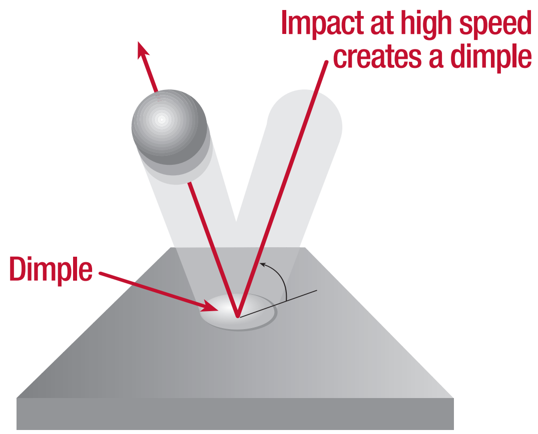

FIGURE 1-1 *Mechanical Yielding at Point of Impact*

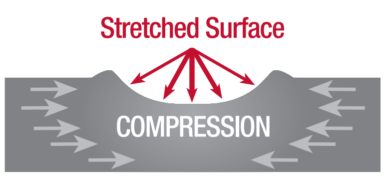

FIGURE 1-2 *Compression Resists Fatigue Cracking*

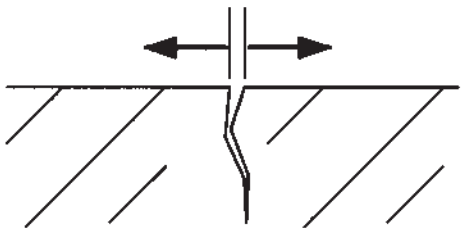

FIGURE 1-3 *Crack Initiation and Growth Through Tensile Stress*

Shot peening is primarily used to combat metal fatigue. The following points pertain to metal fatigue and its application to the Typical Stress versus Load Cycles graph shown in FIGURE 1-4.

- Fatigue loading consists of tens of thousands to millions of repetitive load cycles. The loads create applied tensile stress that attempt to stretch/pull the surface of the material apart.
- A linear reduction in tensile stress results in an exponential increase in fatigue life (Number of Load Cycles). The graph (FIGURE 1-4) shows that a 38 ksi (262 MPa) reduction in stress (32%) results in a 150,000 cycle life increase (300%).

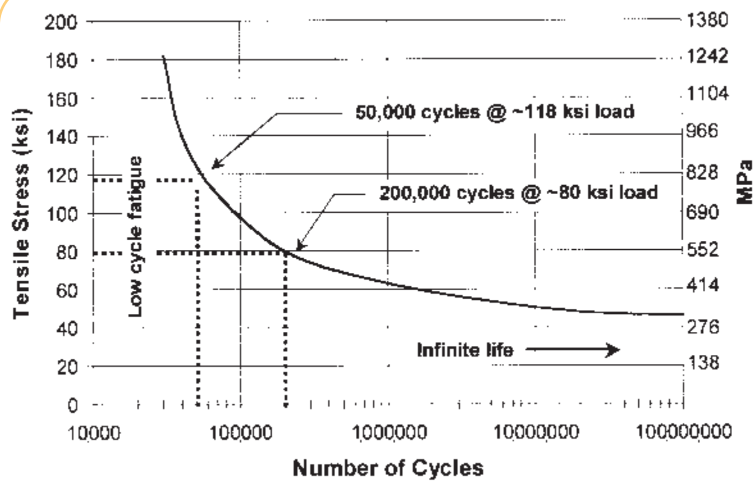

FIGURE 1-4 *Typical Stress vs Load Cycles*

SHOT PEENING RESIDUAL STRESS

The residual stress generated by shot peening is of a compressive nature. This compressive stress offsets or lowers applied tensile stress. Quite simply, less (tensile) stress equates to longer part life. A typical shot peening stress profile is depicted in FIGURE 1-5.

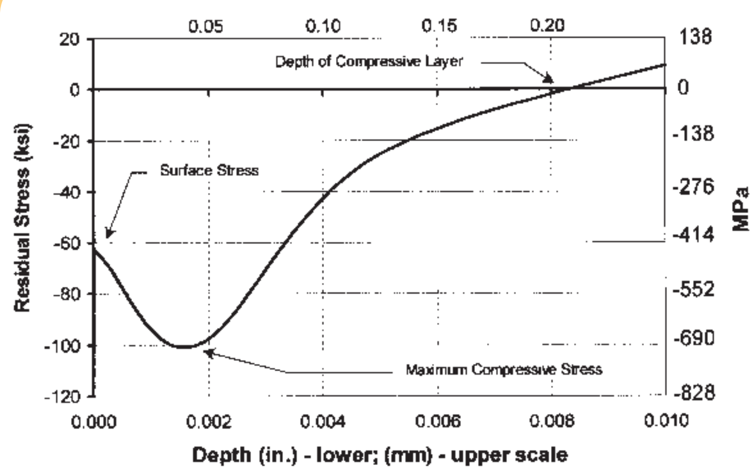

FIGURE 1-5 *Typical Shot Peening Residual Stress Profile*

Maximum Compressive Stress – This is the maximum value of compressive stress induced. It is normally just below the surface. As the magnitude of the maximum compressive stress increases so does the resistance to fatigue cracking.

Depth of Compressive Layer – This is the depth of the compressive layer resisting crack growth. The layer depth can be increased by increasing the peening impact energy. A deeper layer is generally desired for crack growth resistance.

Surface Stress – This magnitude is usually less than the Maximum Compressive Stress.

SUMMATION OF APPLIED AND RESIDUAL STRESS

When a component is shot peened and subjected to an applied load, the surface of the component experiences the net stress from the applied load and shot peening residual stress. FIGURE 1-6 depicts a bar with a three-point load that creates a bending stress at the surface.

The diagonal dashed line is the tensile stress created from the bending load. The curved dashed line is the (residual) compressive stress from shot peening. The solid line is the summation of the two showing a significant reduction of tensile stress at the surface.

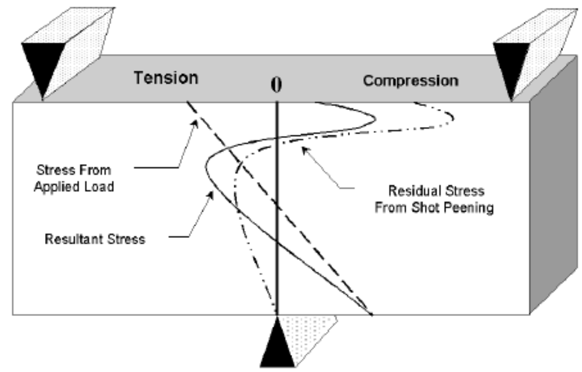

FIGURE 1-6 *Resultant Stress in a Shot Peened Beam with an External Load Applied*

Shot peening is highly advantageous for the following two conditions:

- Stress risers
- High strength materials

Stress risers may consist of radii, notches, cross holes, grooves, keyways, etc. Shot peening induces a high magnitude, localized compressive stress to offset the stress concentration factor created from these geometric changes.

Shot peening is ideal for high strength materials. Compressive stress is directly correlated to a material's tensile strength. The higher the tensile strength, the more compressive stress that can be induced. Higher strength materials have a more rigid crystal structure. This crystal lattice can withstand greater degrees of strain and consequently can store more residual stress.

APPLICATION CASE STUDY

NASA LANGLEY CRACK GROWTH STUDY

Engineers at NASA performed a study on crack growth rates of 2024-T3 aluminum with and without shot peening. The samples were tested with an initial crack of 0.050" (1.27 mm) and then cycle tested to failure. It should be noted that the United States Air Force damage tolerance rogue flaw is 0.050" (1.27 mm).

It was found that crack growth was significantly delayed when shot peening was included. As the following results demonstrate, at a 15 ksi (104 MPa) net stress condition the remaining life increased by 237%. At a 20 ksi (138 MPa) net stress condition the remaining life increased by 81%.

This test reflects conditions that are harsher than real world conditions. Real world conditions would generally not have initial flaws and should respond with better fatigue life improvements at these stress levels.

NON-SHOT PEENED TEST RESULTS

Net Stress	*Number Of Tests*	*Average Life Cycles*
15 ksi	2	75,017
20	3	26,029

SHOT PEENED TEST RESULTS

Net Stress	*Number Of Tests*	*Average Life Cycles*	*Percent Increase*
15 ksi	2	253,142	237%
20	3	47,177	81%

Note on sample preparation: A notch was placed in the surface via the EDM process. The samples were loaded in fatigue until the crack grew to ~ 0.050" (1.27 mm). If samples were shot peened, they were peened after the initial crack of 0.050" (1.27 mm) was generated. This was the starting point for the above results. [Ref 1.1]

DEPTH OF RESIDUAL STRESS

The depth of the compressive layer is influenced by variations in peening parameters and material hardness [Ref 1.2]. **FIGURE 1-7** shows the relationship between the depth of the compressive layer and the shot peening intensity for five materials: steel 30 HRC, steel 50 HRC, steel 60 HRC, 2024 aluminum and titanium 6Al-4V. Depths for materials with other hardness values can be interpolated.

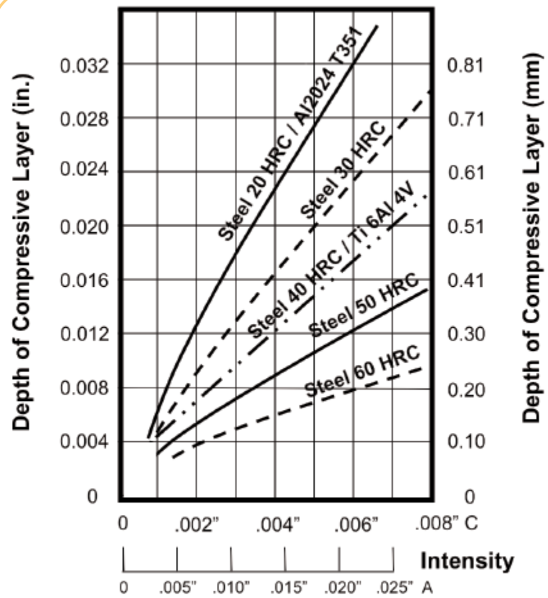

FIGURE 1-7 *Depth of Compression vs. Almen Arc Height*

SHOT PEENING MEDIA

Media used for shot peening (also see Chapter 11) consists of small spheres of cast steel, conditioned cut wire (both carbon and stainless steel), ceramic or glass materials. Most often cast or wrought carbon steel is employed. Stainless steel media is used in applications where iron contamination on the part surface is of concern.

Carbon steel cut wire, conditioned into near round shapes, is being specified more frequently due to its uniform, wrought consistency and great durability. It is available in various grades of hardness and in much tighter size ranges than cast steel shot.

Glass beads are also used where iron contamination is of concern. They are generally smaller and lighter than other media and can be used to peen into sharp radii of threads and delicate parts where very low intensities are required.

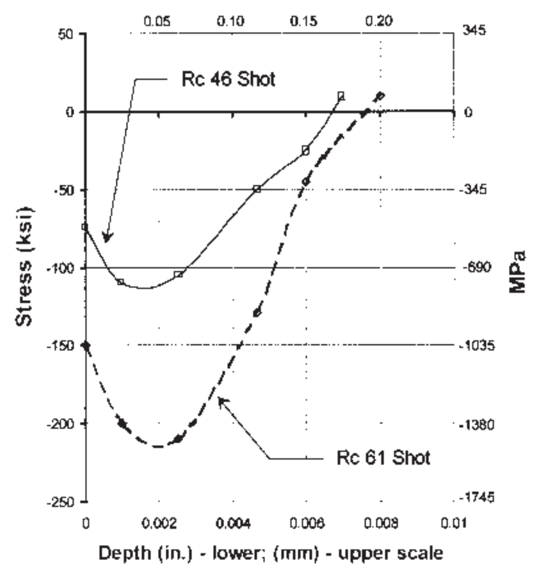

FIGURE 1-8 *Peening 1045 Steel (Rc 50+) [Ref 1.3]*

EFFECT OF SHOT HARDNESS

It has been found that the hardness of the shot will influence the magnitude of compressive stress **(FIGURE 1-8)**. The peening media should be at least as hard or harder than the parts being peened unless surface finish is a critical factor. For a large number of both ferrous and nonferrous parts, this criterion is met with regular hardness steel shot (45-52 HRC).

The increased use of high strength, high hardness steels (50 HRC and above) is reflected in the use of special hardness shot (55-62 HRC).

REFERENCES:

1.1 *Dubberly, Everett, Matthews, Prabhakaran, Newman; The Effects of Shot and Laser Peening on Crack Growth and Fatigue Life in 2024 Aluminum Alloy and 4340 Steel, US Air Force Structural Integrity Conference, 2000*

1.2 *Fuchs; Shot Peening Stress Profiles*

1.3 *Lauchner, WESTEC Presentation March 1974, Northrup Corporation; Hawthorne, California*