

# Shot peening increases gear life

**JOE BROWN, Senior Editor**

*The shot-peening process has long been known to improve the fatigue life of bearings and shafts, and the bending strength of gear teeth. Now it's used to increase the pitting fatigue life of gear tooth contact surfaces as well.*

Subjecting a metal part to the shot peening process induces a residual compressive stress in its surface. This compressive stress counters the effect of tensile stresses during operation of the part, thereby improving its resistance to fatigue failure.

This method of inducing residual stress increases the fatigue life of PT components, such as rolling-element bearings and shafts. It has long been applied to the root fillet area of gear teeth to improve their bending strength. But

until 1982, it was not used on the tooth face. Then NASA initiated two series of tests that showed how shot peening extends the surface fatigue life of gears in the tooth contact area.

## NASA tests — Part 1

In 1982, researchers at the NASA Lewis Research Center, Cleveland, Ohio, tested two groups of spur gears to determine the effect of shot peening on the surface fatigue pitting resistance in the

tooth contact area. The gears were manufactured from a vacuum-melted (CVM) AISI 9310 steel. Both sets were carburized and case hardened to Rockwell C 58. The test gears had 28 teeth and a 3.5-in. pitch diameter.

On one group, researchers shot-peened the gear tooth surfaces, using a normal shot peening intensity (measure of energy imparted to the component) of 7 to 9A. The second group was not shot peened.

Gears were tested at a temperature of 170 F and a speed of 10,000 rpm, with a maximum Hertz stress of 248,000 psi at the contact surface. Figure 1 illustrates typical pitting of the tooth contact area during the tests.

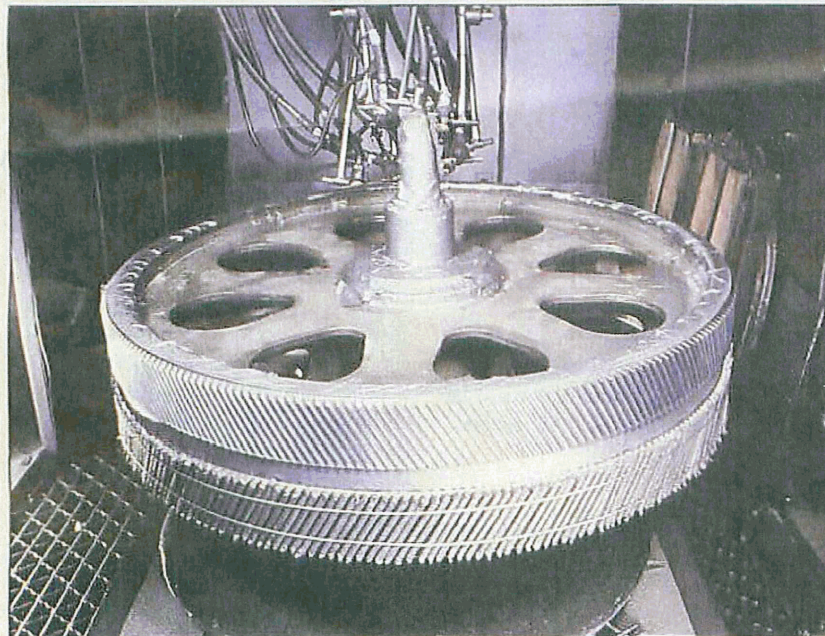
Residual compressive stresses in the shot-peened gears increased 40% over the standard gears at a depth of maximum shear stress (7 mil) for the load conditions, Figure 2. These compressive stresses improved the surface fatigue life, or pitting resistance, of the gears by 1.6 times compared to those that were not shot peened, Figure 3.

After these initial NASA tests, auto manufacturers began to use shot-peened gears in the gearboxes of cars and trucks. These gears are generally made from carburized chrome, nickel, or moly steels. Millions of these automotive gears were subsequently produced for both domestic and offshore use.

## NASA tests - Part 2

In 1991, NASA expanded on its earlier study by investigating the effect of shot peening gears to a higher-than-normal intensity. The new tests involved two sets of spur gears that were manufactured from vacuum-induction-melted, vacuum-arc-remelted (VIM-VAR) AISI 9310 steel. The gears were case carburized, hardened to Rockwell C 60, and ground.

Researchers peened one set of gears to



A large herringbone bevel gear awaits treatment in a shot-peening chamber. Multiple nozzles will direct shot at the gear teeth to increase their resistance to surface fatigue.

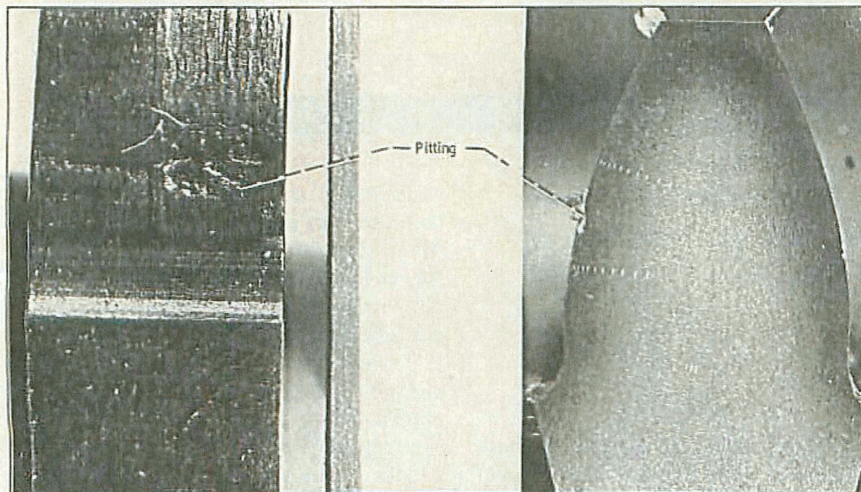


Figure 1 — Pitting on the tooth face of a shot-peened test gear.

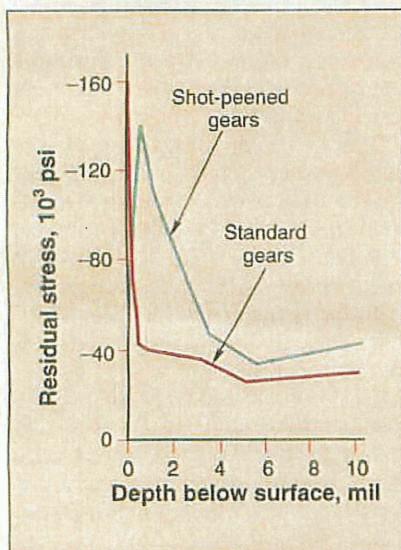


Figure 2 — Residual compressive stresses in shot-peened spur gears exceed those in gears that were not shot-peened.

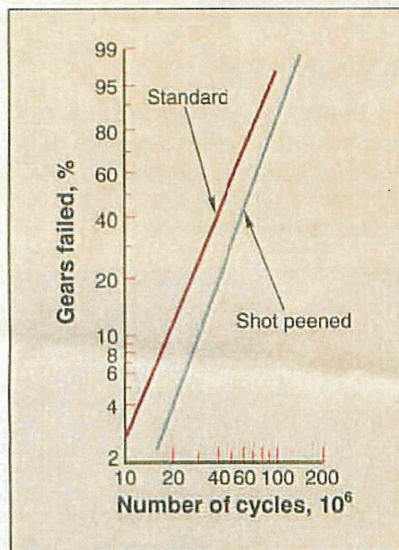


Figure 3 — Shot-peened spur gears exhibit 1.6 times longer surface pitting fatigue life than gears that were not shot-peened (from a 10% gear failure life of  $19 \times 10^6$  cycles to a life of  $30 \times 10^6$  cycles).

a medium intensity (7 to 9A) and the second set to high intensity (15 to 17A). Both sets were honed after peening to improve the surface finish to  $16 \mu\text{in. rms}$ . As in the earlier tests, gears had 28 teeth and a 3.5-in. pitch diameter. Test conditions were the same as in 1982: 170 F, 10,000 rpm, and a maximum Hertz stress

of 248,000 psi.

Residual compressive stresses for the high-intensity shot-peened gears were 57% higher than that for the medium-intensity shot-peened gears at a depth of 5 mil, Figure 4. This is the calculated depth of maximum shear stress when the effect of surface friction is considered. The

compressive stress in the high-intensity shot-peened gears was also much higher at 1 to 6 mil below the surface.

As a result, the high-intensity shot-peened gears exhibited a surface fatigue (pitting) life 2.13 times that of the gears that were peened to medium intensity, Figure 5.

### Other PT applications

Manufacturers and researchers have also applied shot peening to gears made of special materials as well as to other PT components. Here are some examples.

**Austempered ductile iron (ADI).** Shot peening increases the fatigue strength of ADI gear teeth, and it increases their hardness to achieve more wear resistance. Recent applications for ADI include crankshafts and camshafts, as well as gears.

**Powder metallurgy.** Peening has raised the endurance limit of some powder metallurgy (sintered) steel alloys by 22% and the fatigue life by a factor of 10. This suggests that highly stressed automotive components, such as gears and connecting rods, are good candidates for shot-peened sintered steel.

**Shafts and axles.** Many types of shafts and axles are shot peened to improve their fatigue properties, Figure 6. In some cases, peening is required only in keyways, splines, fillets, shear sections, or other section changes.

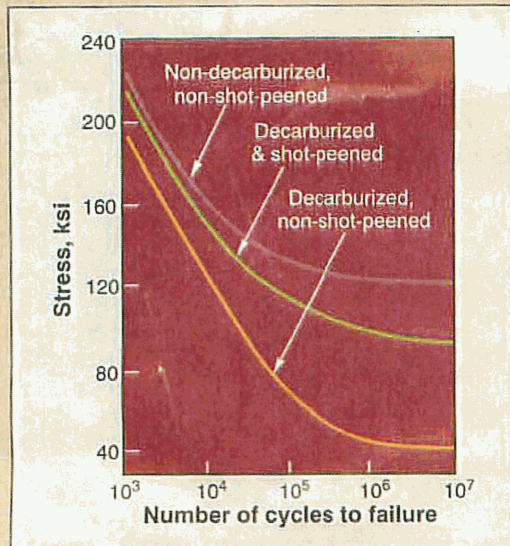
To protect driven equipment, many shafts have a shear section that fails when the shaft is overloaded. Because the shear section is thinner than the rest of the shaft, fatigue failures often start at this location. Shot peening the shear section increases shaft life, while retaining the overload protection.

**Diaphragm couplings.** Metal diaphragm couplings have recently been used in turbomachinery applications to accommodate misalignment through flexing. Shot peening significantly improves the flex fatigue life of these couplings.

U:ENG LIBRARY PEENING Shot peening increases gear Life of manufacturing processes

Some manufacturing processes induce residual tensile stresses into parts, thereby lowering their fatigue strength. Such processes include through-hardening, grinding, abusive machining, plating, and welding. Nontraditional machining methods, such as electro-discharge machining (EDM) and electro-chemical machining (ECM) also shorten fatigue life.

For example, decarburization due to heat treatment reduces the fatigue strength of high strength steels (240,000 psi and up) by 70 to 80%, see figure, and lower strength steels (140,000 to 150,000 psi) by 45 to 55%. Shot peening restores most, if not all, of the fatigue strength lost due to decarburization.



Decarburization reduces the fatigue strength of steel (in this case SAE 4340), but shot-peening restores much of this lost strength.

How shot peening works

The shot peening process prevents or delays metal fatigue cracking and stress corrosion cracking (SCC) of parts in the automotive, aerospace, chemical, petroleum, and power-generation industries.

In this process, spherical shot made from cast, wrought, or stainless steel, as well as from ceramic or glass beads, are propelled against a part to cover the surface with cold-working dimples.

This dimpling induces residual compressive stresses in the surface.

The compressive stresses eliminate detrimental residual tensile stresses caused by some manufacturing processes. In addition, when the part is subjected to tensile or bending loads, the compressive stress reduces the level of tensile stress in the surface where fatigue or SCC cracks are likely to occur. Shot peening is most effective in areas containing local stress raisers,

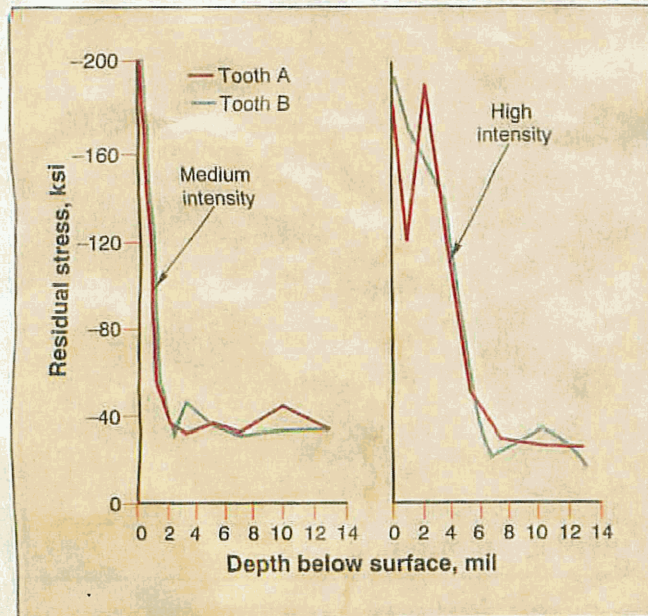


Figure 4 — High-intensity shot-peening causes residual stresses that penetrate deeper below the surface than with gears that received only medium-intensity shot-peening.

such as notches, fillet radii, section changes, and surface defects.

**Process controls.** The effectiveness of shot peening depends on the magnitude, depth, and stress distribution of compressive stresses below the part surface. Companies that apply shot peening, such as the Metal Improvement Co. Inc., Paramus, N.J., can predicted these values from the part's mechanical properties and the shot peening parameters, using either manual or computer calculations.

To ensure process consistency, these companies must control the following parameters: intensity, media, and coverage.

- Intensity indicates the amount of energy transferred from the shot stream into the part. It depends on shot size, shape, material, hardness, velocity, and impingement angle. Intensity is determined using an Almem gage to measure the curvature in a spring steel strip after it is exposed to the shot stream.

- Media (shot) should be spherical and of uniform size, with no rough edges

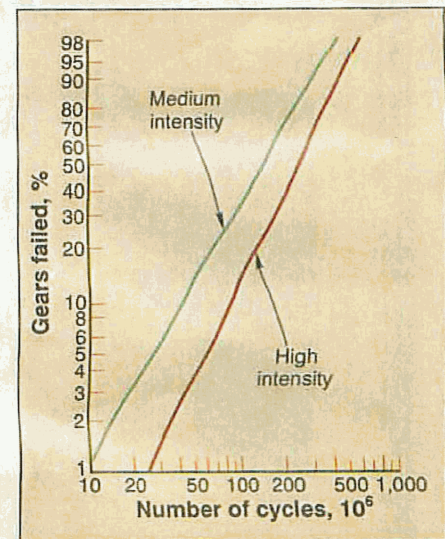


Figure 5 — Increasing the intensity of shot-peening from medium to high boosts the surface fatigue pitting life of spur gears by 2.13 times (from a 10% gear failure life of  $42 \times 10^6$  cycles to a life of  $89 \times 10^6$ ).

**SHOT PEENING**

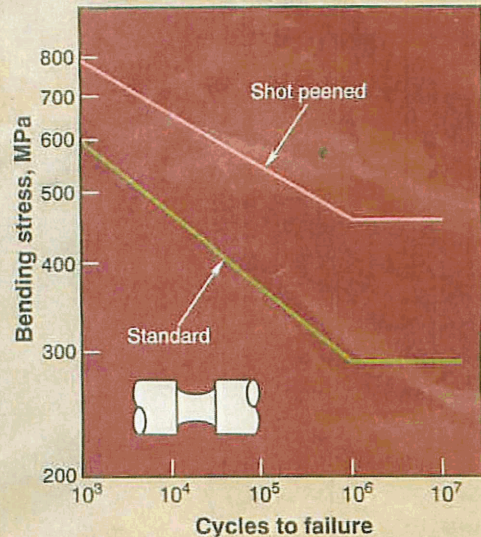
that can damage the part surface. It must be small enough to cold work the smallest radius of the part, and large enough to produce the required intensity. Shot-classifying devices segregate peening media by both size and shape.

- Peening dimples must completely cover the part surface in most applications. Inspectors traditionally use low-power magnification (10X) to verify 100% coverage. In an alternate method, they examine the part under ultraviolet light to determine the amount of a liquid fluorescent dye that was removed during peening.

**Computer enhancement.** In recent years, control of the shot peening process has advanced with computer monitoring systems that control critical machine settings such as air pressure and shot flow at each nozzle, workpiece rotation or translation rate, nozzle reciprocating rate, nozzle-to-workpiece distance, and cycle time. At least once every second, the computer compares each processing pa-

rameter to preset limits. When a deviation is noted, it shuts down the peening operation and displays the fault. After corrective action is taken, the process is restarted. ■

*For details on NASA Lewis gear fatigue tests, see 1982 NASA Technical Paper 2047, "Effect of Shot Peening on Surface Fatigue Life of Carburized and Hardened AISI 9310 Spur Gears;" and 1992 Technical Memorandum 105678, "Improvement in Surface Fatigue Life of Hardened Gears by High-Intensity Shot Peening." For a copy of either paper, call Dennis Townsend at 216-433-3955 or write to him at Mail Stop 77-10, NASA LeRC, 21000 Brookpark Rd., Cleveland, OH 44135. Or circle 405 on the reader service card.*



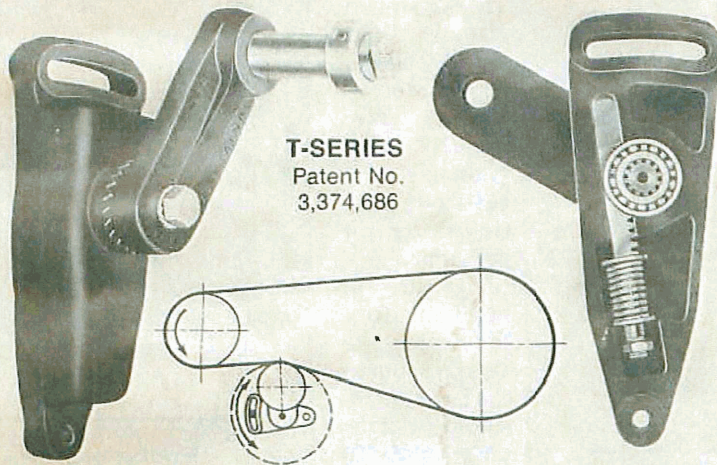
**Figure 6 — Fatigue tests on notched rotating shafts (stress concentration factor  $K_t = 1.76$ ).**

*For more on shot peening from the Metal Improvement Co. Inc., circle 406 on the reader service card.*

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