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Although well known for improving component fatigue life, new techniques including X-ray defraction draw fresh interest in shot peening processes

Improving Fatigue Life through Advanced Shot Peening Techniques

BY ALFRED T. DELITIZIA

The benefits of shot peening metal parts in order to increase component fatigue life are well documented in numerous studies conducted over the past 40 years. The increase in fatigue life can be attributed to the thin layer of uniform compressive stress placed upon the metal. Control of the shot peening process includes wheel speeds, air pressure, and coverage as well as measurement of the process variables through the use of almen strips and almen gages. Fatigue testing has also proven a valuable tool during initial component design stages or later as a control check throughout manufacturing processes.

A recent addition to quality control formulas is the use of X-ray diffraction techniques to measure the residual compressive stresses produced by the shot peening process. Engineers and scientists are discovering that surface measurements are an effective quality control check allowing the direct measurement of shot peened parts. Now, along with measuring the process through almen gages and strips, the surface compressive stress can be nondestructively measured as well. However, it should be noted that the search for an elusive "black box" approach to measuring residual subsurface stresses continues and remains a primary goal of many practitioners.

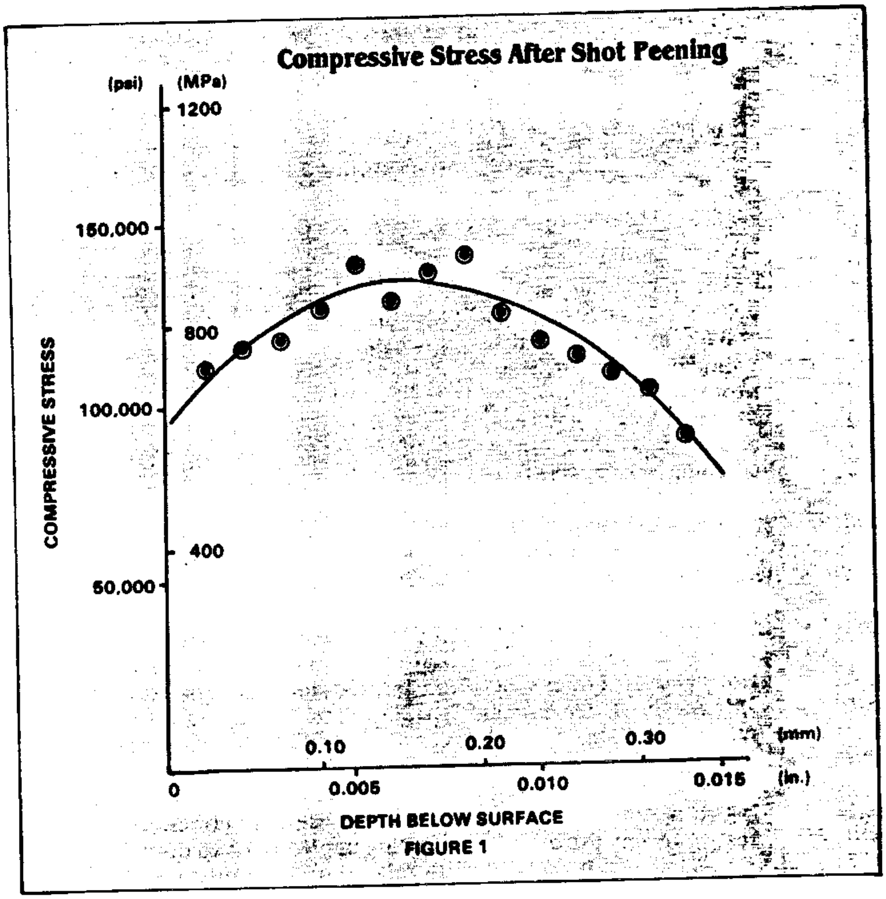


FIGURE 1

X-ray diffraction

Figure 1 shows a conventional 5160 spring material shot peened under controlled conditions. The material was measured by X-ray diffraction to determine the compressive stresses remaining in the spring after shot peening. The stresses were measured in 0.001" (0.02-mm) increments by first removing a layer of material through electropolishing in a sulphuric, phosphoric, and chromic acid electrolyte. This minimizes the alteration of residual subsurface stresses as a result of material removal. Notice that the maximum compressive stress is not at the surface, but approximately 0.005" (0.13 mm) below the surface, and the compressive stress is 0.020" (0.51 mm) deep into the part. This indicates a part in excess of 50 R_C hardness, shot peened to over 0.012 A_2.

X-ray diffraction has proven most effective in examining the shot peening process. It is one of the most powerful means for investigating the microscopic structure of crystalline materials. The characteristic advantage of the X-ray diffraction approach is its ability to measure residual stresses nondestructively, at the surface, instead of by mechanical relaxation techniques, which involve the removal of metal by cutting, grinding, or etching. Residual stresses, which are produced by operations such as grinding, machining, or

Stress Measurement by X-ray Defraction

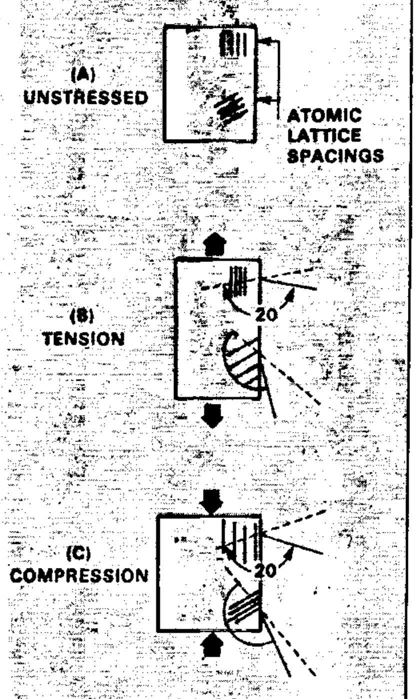


FIGURE 2

shot peening, remain in the metal part, leaving it in a stressed condition even after all external forces are removed. In the case of a shot peened part, these stresses are produced by bombarding the surface with steel shot, cut wire, or glass beads under controlled conditions. Residual compressive stress can be an advantage, but design engineers need to know the magnitude of the stress and whether this stress is tensile or compressive.

Process explained

The X-ray diffraction technique for measurement of stress is shown schematically in *Figure 2*. *A* represents metal in an unstressed state, *B* represents metal in tension, and *C* represents metal in compression. The sets of regularly spaced vertical lines and near-horizontal lines represent the atomic lattice and its spacing of two sets of equivalent crystalled graphic planes in a metal part. In the unstressed state, the atomic lattice spacings of these two sets of equivalent planes are equal. In the tensile stressed state, the part elongates in the direction of the tensile force and contracts in the direction normal to the force. In the compressive stressed state, the part contracts in the direction of the compressive force and elongates in the direction normal to the force. These changes in the atomic spacing result in larger spacing normal to the tensile stress than in the unstrained state. The planes parallel to the tensile force have a narrower spacing in the stressed state than in the unstressed state. This change in atomic spacing alters the angle at which X-rays are diffracted and produces the resulting stress, which can be read in PSI.

X-ray stress-measuring devices are currently used in commercial shot peening applications to determine the magnitude of the residual compressive stresses on such items as steering knuckles, springs, gears, and torsion bars. The residual stress measurement techniques of determining surface and subsurface stresses have enabled engineers to attempt various types of shot peening techniques, particularly on high-strength steels, in an attempt to obtain the most beneficial shot peening parameters. These rapid and accurate stress measurements have resulted in some rather remarkable findings and have also led to further investigations—including an understanding of double shot peening techniques.

Fatigue Test Results

GROUP	PRIMARY TREATMENT	SECONDARY TREATMENT	MEAN LIFE (Bending cycle before rupture.)
A	230	70	479,000
B	660	70	384,000
C	110	70	272,000
D	70	---	207,000
E	110	---	141,000
F	230	---	151,000
G	660	---	82,000
H	NO PEENING	NO PEENING	22,400

FIGURE 3

Fatigue Life Increase through Dual Peening Technique

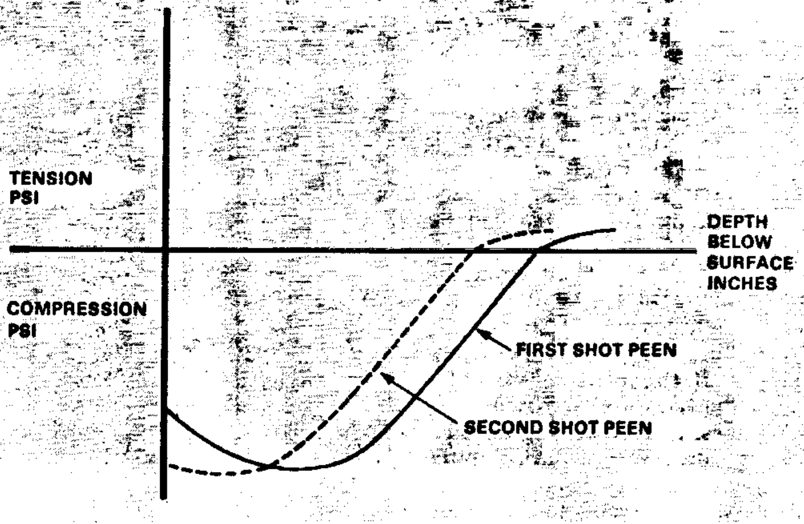


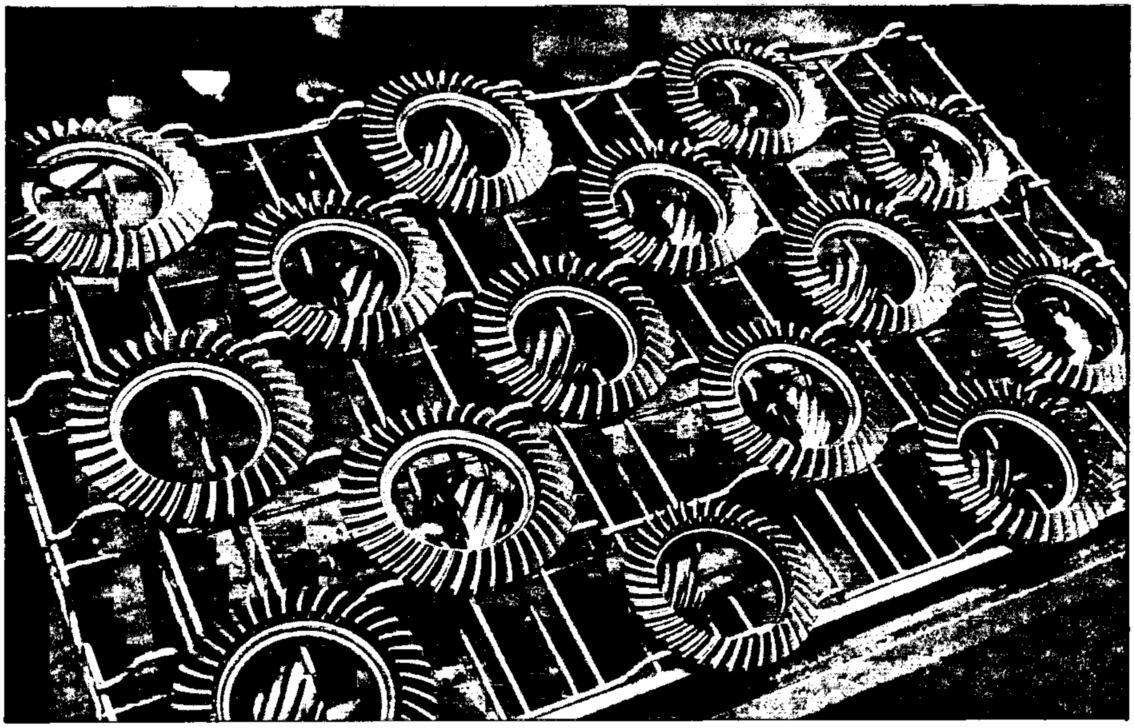
FIGURE 4

Double shot peening

One such technique is first to shot peen a component in the conventional manner and then subject the part to a second shot peen at a calculated, reduced intensity. This dual process has resulted in a large increase in the fatigue life of parts. In one case, leaf spring specimens formed from 5160 spring steel were shot peened under three sets of dual shot peening conditions and four sets of single shot peening conditions. The parts were then fatigue tested. The results, *Figure 3*, dramatically show the increase in fatigue life achieved with the dual shot peening techniques.

In addition, an increase in fatigue life can also be obtained by grit-blasting the surface of a previously shot peened metal part. In some cases, grit-blasting can be used as the secondary treatment process for parts that were previously shot peened.

Figure 4 provides a better under-



Severe cutter marks, such as the tooth fillets on these carburized and hardened gears, require increased shot usage due to high shot breakdown.

standing of why the above methods have resulted in increased fatigue life. In the typical residual stress curve of a shot peened part, the maximum compressive stress is below the surface. The first shot peening operation drives the stress 0.005 to 0.020" (0.13 to 0.51 mm) deep into the part. The second shot peening operation results in a higher compressive stress at just below the surface. This combination of deep compressive stresses and high stresses results in an increase in part fatigue life and operating stress level.

In the case of grit-blasting after shot peening, similar benefits, as well as material removal, occur. The resulting material removal exposes the surface to higher compressive stress levels. Both techniques are an improvement over a single shot peening application. Although improvements in fatigue life are obtained when using grit as the second medium, the overall results are not as satisfactory overall as those obtained when using steel shot as the first and second media.

Different velocities

Another practiced technique is to first shot peen under conditions in which the velocity of the abrasive is low, in order to avoid superficial or surface cracks during the peening operation, and then to apply a second shot peening operation at a higher velocity, in order to produce a greater depth of residual compressive stress. The second stage is calculated based on the material and cross-sectional thickness of the particular component to be peened.

Consideration of the conditions under which the component is to operate is also important in the practice of this method. The method is best suited for high notch-sensitive materials in which high radial tensile stresses are likely to occur on the surface of a peened part near the point of impact. In softer ductile steels and aluminum, the metals' compressive stress is set up in the surface before the radial tensile stresses become significant enough to cause microcracks, like the type found on the high notch-sensitive materials. This technique has the effect of sealing the surface by providing a thin, compressed layer of material, which prevents the second, more severe shot peening operation from producing microcracks.

Shot breakdown

In production, shot breaks down as it impacts the work surface. This is typically a fatigue-type failure as the split shot subsequently fractures into successively smaller particles. Generally, steel shot is available in three hardness ranges. The most common is 40 to 50 R_C, which is used for the majority of applications in the range of spring hardness or lower. Another is in the range of 51 to 59 R_C, and the third in the range of 60 to 65 R_C. Shot breakdown tests show that hard shot is subject to a higher rate of breakdown under similar conditions. In the case of shot peening components of high hardness, such as the carburized and hardened gears in the above photo, this increased shot usage can be justified by the fact that higher breakdown is particularly true when the surface being peened is machined with severe cutter marks, such as gear tooth fillets, without the benefit of a rounded hob.

When the work is harder than the shot, permanent deformation of the shot occurs prior to that of the full dimple. Consequently, the depth of penetration of the residual compressive stress is reduced. In the case in which a shot harder than the part is used, higher surface stresses and a deeper compressed layer are possible than if a softer shot were used. Dramatic improvement in surface residual stress and ultimately fatigue life are possible when shot peening with hard shot—shot classified over 50 R_C.

Continued investigation

In an attempt to obtain the best results from the shot peening process, engineers and others continue to explore the standard shot peening approaches as well as the technically advanced, dual shot peening methods. Fatigue tests and tests of components in real-life conditions reveal important component service characteristics under cyclic loading and stressed states. Often a "fingerprint" of the shot peened part is prepared by complete X-ray diffraction measurements below the surface. And, finally, controlling the shot peening process through monitoring shot intensity, coverage, and quality, as well as the machine controls involved, generally proves successful. **ME**

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