Shot Peening

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Shot peening is a cold working process in which the surface of a metal part is bombarded with spherical particles (or shot) formed from cast iron, cast steel, stainless steel, ceramic or glass. Most often, peening is used to create a uniform compressive stress layer on or near the surface of metals that prolongs service life under cyclical loading conditions by resisting fatigue failures. For this purpose, peening is applied to leaf and coil springs, gear fillets, drive shafts, torsion bars, axles, oil well drilling equipment, turbine blade root and foil sections, and many other metal components exposed to cyclical stresses.

Although shot peening is certainly not a new process, many of the finer points related to the effects of peening variables on the performance of metals remain open to continuing scientific investigation and debate. Research published during the 1980s, for instance, places new emphasis on the significance of shot size and questions the traditionally assumed correlation between Almen strip deflection and compressive residual stress. Likewise, test methods, such as X-ray diffraction, have been studied as alternatives to destructive mechanical methods for assessing peening effects and developing optimum peening parameters.

The point here is that the file on theories and test methods used to establish shot peening specifications is definitely not closed. As a consequence, this article will avoid theoretical controversies and will instead focus on the production end of peening, including where and why the process is applied, how processing variables are controlled, and the types of automated peening systems currently available.

FUNCTIONS OF SHOT PEENING

Shot peening is most often employed to increase the stress tolerance and prolong the service of metal components subjected to cyclical loading conditions. (See Fig. 1 and Table I for the metal performance improvements typically achieved.) In essence, shot peening induces a residual compressive stress at or near the surface of metal parts, thereby retarding the migration of cracks toward the core and resultant structural failures. The peening process does, however, have a number of other important, though narrower applications, which include:

- Reducing stress corrosion cracking caused by the complex interaction of environmental attack and sustained tensile stress at the surface of a metal.
- Reducing fret corrosion failures produced by small movements between mating parts.
- Straightening parts that may have been bent during heat treatment or machining.
- Forming of materials, such as aircraft skins, without the use of dies. (An additional benefit of this forming method is the introduction of compressive stresses, which increase fatigue resistance. In most other forming processes, fatigue resistance is reduced.)
- Changing tensile induced by grinding into compressive stress, which increases fatigue resistance.
- Offsetting tensile stresses introduced to metal surfaces during chrome plating.
- Testing electroplated surfaces for adequate bonding prior to final machining.
- Reducing porosity in castings that could lead to hydraulic or pneumatic leakage.
- Expanding undersized parts that are slightly off spec.
- Improving the oil retention properties of pistons, cylinder walls and bearings by creating tiny indentations in their surfaces.
- Reducing the notch sensitivity of higher strength steels so they can be applied more effectively in services subject to dynamic loading conditions.

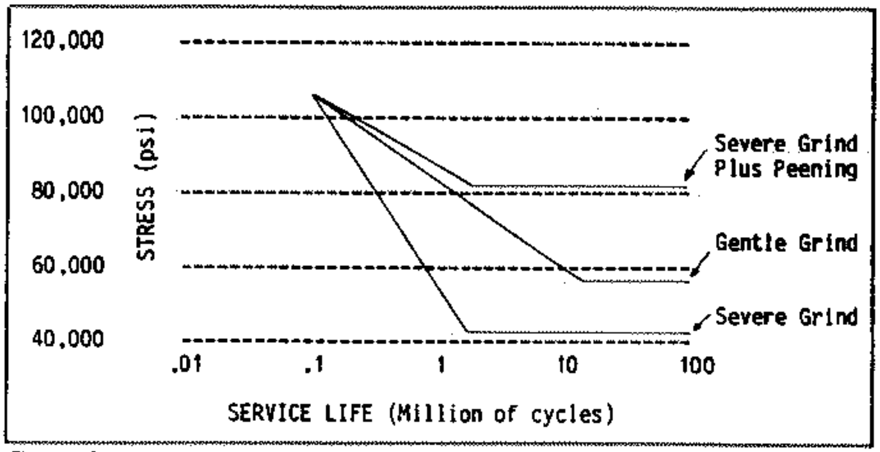

Fig. 1. Representative increase in resistance to cyclical loading produced by peening.

SHOT PEENING VARIABLES

Because shot peening is used to achieve various results on different

Table I. Representative Increases in Permissible Stress

Material	*Unpeened*	*Peened*	*Increase, %*
Carbon spring steel (SAE 1074)	75,000 psi	115,000 psi	54
Alloy spring steel (SAE 6150)	70,000 "	115,000 "	60
Stainless steel (Type 302)	45,000 "	90,000 "	100
Phosphor bronze (SAE 81)	15,000 "	30,000 "	100

types of metal parts destined for a broad range of services, the development of optimum peening specifications for a specific type of workpiece can be a complicated undertaking. Normally, past experience, theory, trial and error, and destructive testing are required to home in on the best peening parameters.

What often makes the development of a shot peening specification difficult is the number of variables involved in the process. Factors that typically have to be considered include:

- The workpiece (its thickness, configuration, metallurgical properties and intended service).
- Other treatments that have been or will be performed on the workpiece before or after peening.
- The shot material (its type, hardness, shape, size, uniformity, impact velocity, impact angle and the degree to which it covers the work surface).

Fortunately, for the shot-peening practitioner, all these variables need not be considered individually in the course of performing a job to specifications. Typically, shot peening requirements specify the shot size and type, the area of the part to be peened, peening intensity, and coverage percentage. Frequently, additional stipulations related to shot sampling are included to prevent processing with degraded shot—too high a proportion of oversized, undersized, cracked or out of round shot will adversely affect peening results.

While meeting a peening specification related to shot size and type might seem to be a relatively straightforward undertaking, it is, in fact, often one of the more difficult aspects of the process to control. For starters, no class of shot is ever perfectly uniform in terms of roundness, size, density and hardness, but the initial condition of the shot presents a relatively insignificant problem. Even if the condition of the fresh shot were perfect, it would be impossible to maintain during the peening process unless, of course, all shot were discarded after a single use—a cost prohibitive proposition, to say the least. In practice, shot breaks down during peening and provisions must be made to extract the degraded shot during media recycling. Otherwise, peening quality will be compromised, mainly because larger shot delivers higher peening intensity and less coverage than smaller shot when all other factors are held constant. Thus, two aspects of the peening specification, "peening intensity" and "coverage percentage", will drift farther off-spec as the shot degrades, and peening results could be seriously jeopardized.

Concerning types of shot material, most peening is done with cast steel shot sized to SAE recommended practice AMS 2430K with a hardness range of 40 to 50 Rockwell C. The US military and aerospace industries have developed shot specifications (ML-S-13165B) for this same material that require closer control of size, hardness and allowable nonrounds.

Cast iron shot, another alternative, is relatively inexpensive and, because of its hardness, delivers high peening intensities. At the same time, cast iron shot is brittle and breaks down rapidly, thereby increasing media replacement costs and complicating quality control.

As a peening medium, glass beads have grown in popularity during recent years. Normally, they are used to process thin metal sections requiring low peening intensity and to avoid ferric contamination of nonferrous parts. In addition, glass beads are used to remove ferrous residues from nonferrous metals previously worked with cast steel or cast iron shot.

Ceramic beads, a newer nonferrous peening medium, offer a number of advantages over glass including greater durability, higher density, improved spherical uniformity and better breakdown characteristics; however, the higher cost of ceramic beads, combined with the need to change existing peening specifications calling for glass beads, has slowed the acceptance of ceramics in certain industries.

Stainless steel shot, produced by cold beading, provides another option for preventing ferric contamination and, at the same time, offers excellent consistency in terms of size and hardness. Offsetting these benefits is the very high cost of stainless steel when compared to other types of shot.

Regarding the second part of a peening specification, "the area of the part to be peened", hands on work, such as masking, and the design of the peening machine play important roles. The types and capabilities of currently available peening systems will be covered in a later section.

PEENING INTENSITY

Shot peening intensity is normally measured through an empirical method involving Almen strips, which are mounted on specially designed blocks in positions that accurately simulate the surface of the part to be peened. Developed many years ago by J. O. Almen of the Laboratory Research Division of General Motors Corp., the Almen strip is still used today as the standard measure of shot peening intensity.

Following test peening of an Almen strip, the side of the specimen which has been struck by a shot will assume a convex curvature when removed from its mounting, a specially designed block that holds the test strip securely in place. This bowing toward the shot stream is an expression of the residual compressive stress induced by the peening process, and the extent to which the test strip bends is inferred to be a measure of peening intensity when coverage of the test strip is held constant. "Saturation", the goal in most peening operations aimed at resisting metal fatigue, is achieved when the desired Almen strip deflection occurs at 100% coverage. In other words, striking the entire surface of the specimen strip with shot should produce the prescribed curvature or arc height. If the arc height is too small, peening intensity is too low, it it's too large, peening intensity is too high.

The Almen test method uses different strips of standard thicknesses and consistency to measure ranges of peening intensity: an "N" strip for low intensity, an "A" strip for average intensity and a "C" strip for high intensity.

COVERAGE PERCENTAGE

With the Almen strips, it is also possible to make a fairly accurate and quick determination of "coverage percentage", another standard in most peening specifications. Defined as the area of the work surface that has been peened, coverage is expressed in terms of percentages. For instance, 100% coverage occurs when the entire surface has been struck by shot. (In practice, a value of 98% is normally used to express complete coverage because coverage rates decline dramatically as the 100% mark is approached. (See Fig. 2). Likewise, 50% coverage occurs when half of the work surface has been struck by an evenly distributed pattern of shot. (As can be seen from Fig. 2, the exposure time required for 100% coverage is approximately seven times greater than the time required to produce 50% coverage, reflecting the fact that an in-

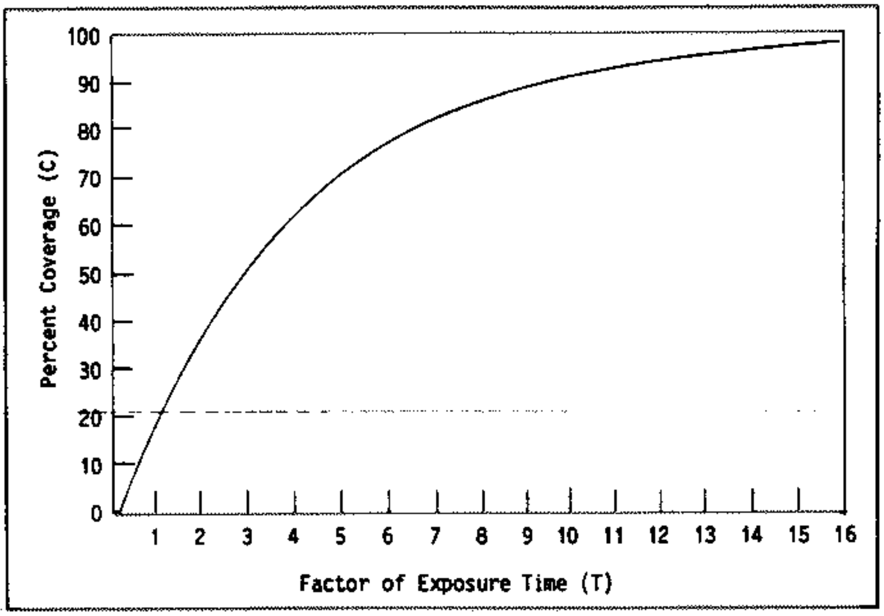

Fig. 2. Coverage versus exposure time.

creasing proportion of the surface is struck multiple times before all areas are struck at least once as coverage increases. Coverage requirements in excess of 100% are expressed as multiples of the time required to reach 100%).

Almen strips are used to estimate coverage by adjusting exposure times, with all other variables held constant, and then comparing arc heights. It's important to note here that arc heights do not increase significantly after 100% coverage has been reached. Doubling or tripling the exposure time after complete coverage has been attained, for instance, will normally result in no more than a 15% increase in arc height on the Almen test strip.

As a first step in assessing coverage with Almen strips, two specimens should be peened: one for four times the duration expected to produce 100% coverage, and the other for twice the time expected to achieve 100%. If the arc heights of both strips are nearly equal (within 10 to 15% of each other), it can be concluded that 100% coverage or more was obtained with the strip exposed for the shorter period of time. By continuing to shorten exposure times in this manner until a substantial difference in arc heights (15% or more) occurs, it is possible to make a fairly accurate assessment of the minimum exposure time required for 100% coverage.

Although Almen strip behavior can be used as a test of coverage, other methods are generally considered more practical. Visual inspection with optical magnification is by far the most popular. In another technique for measuring coverage, a test strip is magnified approximately forty diameters in the field of a metallurgical camera and, using a piece of transparent paper as a ground glass, the indented areas are traced with a sharp pencil. The area of all the indentations is then measured with a planimeter and the ratio of the indented areas to the total area determined. This method is rather time consuming and assumes that the area selected for magnification is typical. As a result, several areas on each test strip should be calculated and the average used as a probable coverage.

A newer approach for assuring that 100% coverage is attained employs an ultraviolet light sensitive liquid that remains on the work surface until it is removed by the impact of shot.

SHOT PEENING LIMITATIONS

Shot peening has a number of limitations, the most obvious being recessed and other hard to reach work areas that cannot be effectively hit with shot.

Another limitation is restrictions on post peening processing. Although polishing, lapping, honing, grit blasting and hand sanding can normally be performed after peening, other processes that induce tensile stress or remove 10% or more of the peened layer are generally unacceptable, unless the surface is subsequently repeened.

Thin metals can also present problems in that they tend to deform when peened. In some cases, this obstacle can be overcome by using low density shot or by peening both sides of the critical surfaces simultaneously.

Ferric contamination of nonferrous and corrosion resistant parts also causes difficulties. Often, the only solution here is to peen with nonferrous shot or to remove ferric residues subsequent to peening by acid dipping or over peening with glass beads.

PEENING SYSTEMS

The two types of peening approaches applied most widely today are mechanical systems and pneumatic systems. Gravity type and wet pneumatic systems are also employed for peening, but both are limited to narrow applications. Wet pneumatic systems are typically reserved for low intensity peening and removal of ferric contamination, and gravity powered systems, though highly energy efficient, lack versatility.

In many high production peening jobs, mechanical systems offer a number of major advantages. Through the use of a bladed wheel rotating at high velocity, these devices impart momentum directly to the shot. Therefore, energy transfer is very efficient. These machines are also capable of delivering a large volume of shot at high velocity.

Because the shot stream is unidirectional with this type of equipment, accessory machinery is normally required to turn or roll workpieces in order to gain the prescribed exposure. In addition, adjustments must be made for the "hot spot" characteristics of centrifugal wheels. Due to the fact that they "fling" shot, these machines produce a wide pattern in comparison to their actual working focus. Nevertheless, the "hot spot" or working area can be easily controlled by adjusting the distance between the delivery mechanism and the workpiece. Also, because shot "thrown" by a centrifugal wheel does not vary significantly in velocity, controlling shot momentum is a simple matter of choosing the correct wheel speed.

Within the realm of pneumatic peening, two basic approaches are used: pressure systems and suction systems. In the pressure system, shot is contained in a pressure vessel so that it drips by gravity through a metering orifice into a high pressure air line leading to a blast nozzle or nozzles located within an enclosure. Shot flow is regulated with a fixed orifice or adjustable valve. When continuous operation is desired, the pressure vessel is equipped with an upper chamber that can be vented to the atmosphere while being filled and then pressurized again before shot is dropped into the continually pressurized lower chamber.

Desired shot flow rates, velocities and exposure times are determined empirically with Almen strips and one of the methods for measuring coverage discussed earlier. Normally, shot flow rates and velocities are set to achieve desired peening results within the shortest feasible exposure time.

Because a pressure system produces higher shot velocity than a suction system, it can move shot through long lances and side shooting nozzles to peen hard to reach areas such as interior bearing surfaces. Pressure systems also offer more precise control than suction systems, making them better suited for both heavy and light peening.

The fundamental difference of a suction system is that it relies on pressure differential to draw shot into a blast gun. Two hoses are involved in this arrangement: one hose provides compressed air to the blast gun to propel shot and the other supplies shot to the gun from a storage hopper. As compressed air passes through the gun, a vacuum is created, inducing an air flow which draws shot into the gun. In this process, some energy is lost in moving shot from the storage hopper. As a result, the suction system is less efficient than a pressure system. The benefits of suction are lower initial cost and easier maintenance. These systems also simplify continuous operation and the use of multiple blast guns.

The primary advantage of either type of pneumatic system is versatility. Because the blast nozzles are relatively small and attached to flexible hose, they can be oriented to cover specified areas on a workpiece. Also, shot velocity and flow rate can be varied from one nozzle to the next in certain types of equipment employing multiple nozzles.

With both mechanical and pneumatic peening systems, equipment should be provided for collection and recycling of shot. Normally, this is accomplished with an air wash separator or cyclone reclaimer that removes extreme fines, a coarse screen that catches debris and foreign objects, and a screening arrangement that maintains correct shot size. With larger systems, a shot replenisher can be provided to introduce new media in place of degraded shot that has been extracted from the process.

Part handling techniques used with peening machines range from simple turntables to sophisticated material handling systems. Accessory equipment is also available to remove dust and maintain adequate ventilation in the work area.

PEENING CONTROLS

In most peening operations, the equipment can be controlled manually or automatically; however, because of the many variables involved in peening and the importance of meeting specifications, automation offers major advantages in terms of its ability to deliver improved consistency and repeatability. If precision peening is required, automation is a virtual must.

One of the most important recent developments in the area of automated peening has been the application of increasingly sophisticated programmable controllers to pneumatic equipment. With these controls, processing instructions related to nozzle and workpiece movements, peening duration, shot flow and shot velocity are entered into the system via a control panel. If the system includes multiple work stations, information for each station as it relates to the processing of a particular part is stored. Some systems capable of classifying different types and sizes of shot even make it possible to program shot selection. After processing parameters for a specific part have been stored, the data can be accessed and put into action by recalling information assigned to that part. Key peening variables can also be printed out with this type of equipment to support the fact that peening was performed to specifications and

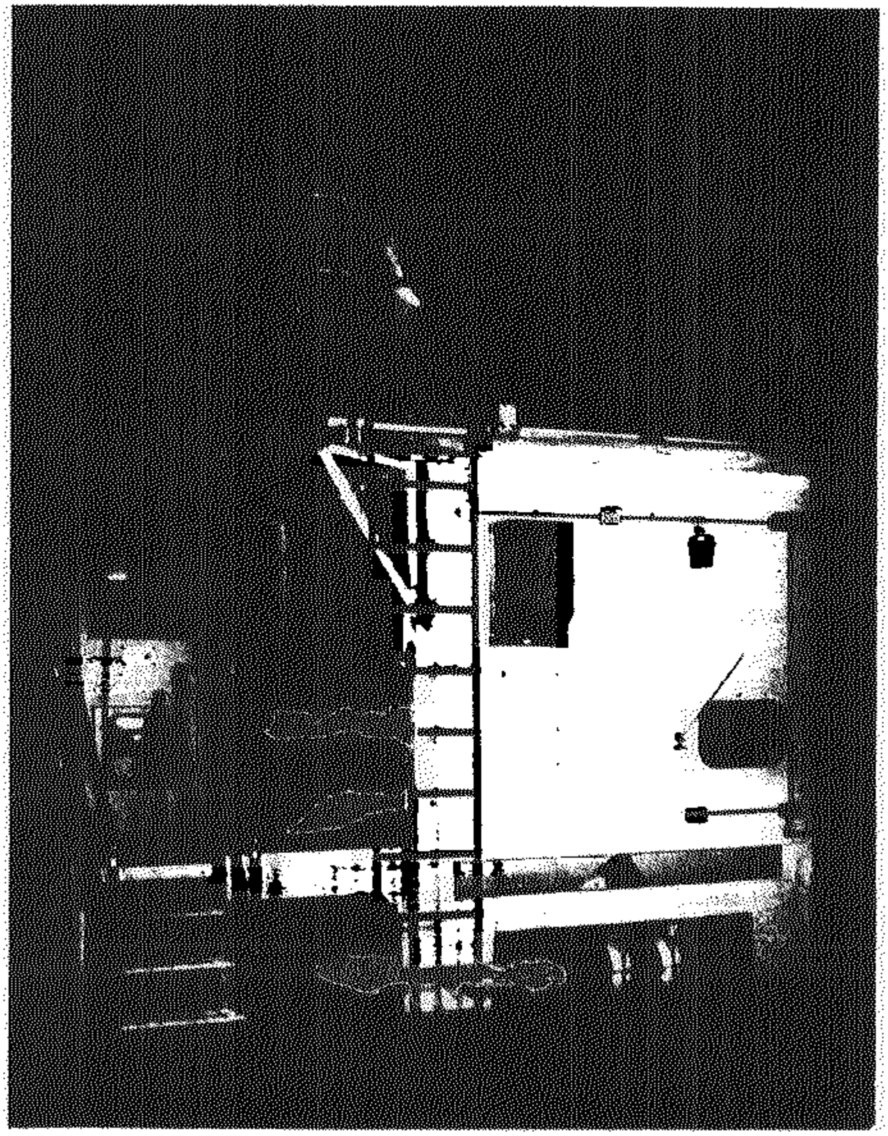

Fig. 3. Programmable CNC peening machine capable of classifying different types of shot.

quality standards maintained.

When additional flexibility is required in terms of defining and recalling multi-axis nozzle and workpiece movements, CNC technology is employed. (See Fig. 3). As has been demonstrated in the area of machine tooling, CNC often simplifies the programming and control of automated equipment. In pneumatic peening systems, CNC is now used in applications where a part, or portion of a part, must be traced precisely during processing. With a CNC controlled peening machine, a teach pendant and keyboard allow the operator to input dwell times, nozzle movements, workpiece positioning and other peening variables. Once programmed, this data can be retrieved, thereby permitting an operator to process any one of many previously programmed workpieces to required specifications.

One major result of the improved machine versatility provided by programmable controllers and related electronic hardware now used in peening is that more manufacturers and rebuilders are peening in-house rather than sending work out to peening specialists. With the development of automated machines capable of performing a variety of controlled peening operations, in-house peening has become more reliable and more affordable. **MF**

Biography

Robert B. Heaton is chief engineer/shot peening systems at Empire Abrasive Equipment Corp., Langhorne, PA. During the last 10 years, he has worked closely with a number of major US aircraft component manufacturers and airlines in the development of peening specifications, operator training programs and automated shot peening systems.