Shot Peening for Improved Castings

Developed in the 1920s, shot peening is well understood in the automotive, machine tool and aircraft industries. Its ability to increase fatigue life and reduce porosity can also offer foundrymen the ability to produce lighter weight, longer lasting castings.

A. T. DeLitizia
Wheelabrator-Frye, Inc/Materials Cleaning Div
Mishawaka, IN

Every foundryman is familiar with the blast cleaning required for mold and core sand removal and the cleaning and deburring of castings. Most are also familiar with the equipment needed in casting cleaning and finishing, whether it is air nozzle or centrifugal wheel abrasive blast machines. But fewer foundrymen are fully aware of the use, controls and advantages shot peening holds for improving castings.

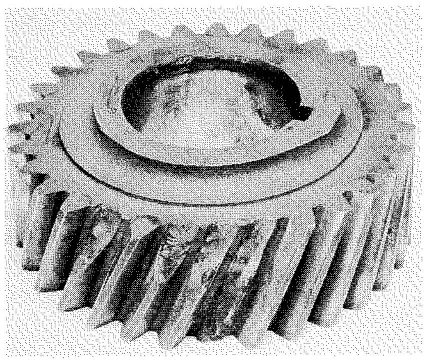
Shot peening has been used for years to eliminate porosity in castings, particularly in castings for high pressure applications. It has also been used on austempered ductile irons where the mechanical surface preparation of shot peening has increased the fatigue strength of the material. This has resulted in several companies reporting success in using austempered ductile iron for gearing applications. The ability of shot peening to increase a component's fatigue life offers the foundryman the advantage of producing longer lasting castings or reducing casting weight.

Historical Perspective

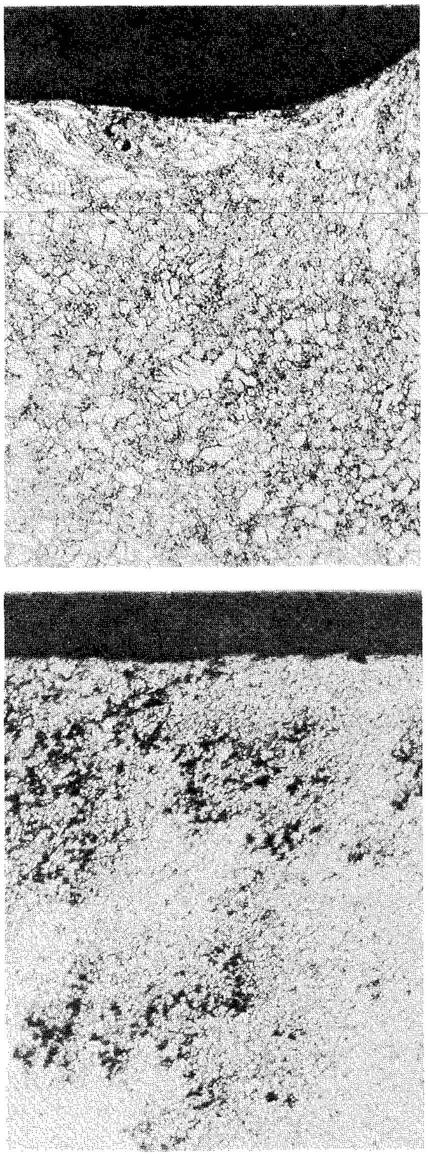
The development of peening in the prestressing of metals by mechanically working the surfaces to obtain improved fatigue strength characteristics has taken place over many centuries. The hammering of copper and gold predates the time of Christ while peening or the hammering with a round-edged hammer was known at the time of the Crusades in about 100 AD. A knight's armor was cold worked to final shape and hardness. Through this repeated hammering, improved metal life was obtained by increasing its fatigue life. From the 1920s, there are reports that European race cars had the fillets of their crankshafts hand peened.

It was also during this period that General Motors Corp engineers were experimenting with ways of increasing fatigue life of valve springs. The increased effectiveness of four wheel brakes, first introduced in the early '20s, enabled cars to reach speeds of 55-60 mph. These higher engine speeds and the stresses of high speed stops resulted in the failure of various components, which had not occurred at the lower speeds.

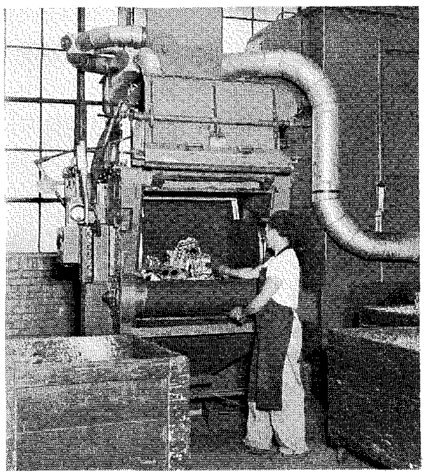
Because of the higher speeds the valve springs were inadequate. GMC



Shot peening has allowed several companies to successfully use austempered ductile iron for gearing applications like the one shown here.



The plastic flow and stretching of the surface fibers of the metal occurs as each pellet causes a slight indentation when it strikes the surface of the part.



From outward appearances, both blast cleaning and shot peening machines look identical. The major difference is in the blast media and control devices needed for shot peening to measure for shot intensity and coverage.

engineers then began experimenting with various types of material and manufacturing techniques to develop an acceptable spring. Springs were typically pickled or barrel cleaned after heat treat. The tumbled springs showed increased fatigue life over pickled springs. It was soon discovered that blast cleaned springs produced the best results and the process was then used on connecting rods, connecting bolts and steering arms and knuckles. The GM engineers had developed the first modern day approach to shot peening.

The use of shot peening to increase the cyclic life and loading of springs, gears, crankshafts, connecting rods and torsion bars spread throughout the automotive industry. It is now used in the aircraft, turbine, machine tool and oil industries. It is used to form aircraft wings, retard stress corrosion cracking and allows components to operate at higher stresses over longer periods of time. The current need for light weight high strength components has renewed interest in the use of shot peening and opened up promising areas for its increased use.

What is Shot Peening?

Shot peening is a mechanical method of imposing a residual compressive stress at the surface of a metal part. This residual compressive stress is produced by striking the metal surface with a blast of spherically shaped pellets which repeatedly hammer the surface of the part. It is not stress relieving as it is sometimes referred to, but the introduction of compressive stresses.

These stresses are relatively shallow, generally in the range of 0.005-0.010 in. for high strength steel and 0.020-0.025 in. for aluminum. The plastic flow and stretching of the surface fibers occurs as each pellet causes a slight indentation when it strikes the surface. The depth of the layer in which the plastic flow takes place in aluminum, for example, will depend upon the impact velocity of the shot, physical properties of the aluminum and size of the shot. Beyond that depth, the fibers are not stretched to the yield point and therefore, retain their elasticity. Since there is a bond between them, the inner fibers pull the outer fibers back to a length which is shorter than that which the stretched fibers would tend to retain. A condition of equilibrium results after peening in which the relatively thick core of material under low unit tensile stress restrains and holds the thin layer of surface fibers in a condition of high unit compressive stress.

It is this compressed layer that prevents surface cracks from propagating into the material core and causing fatigue failures. Since nearly all fatigue and stress corrosion failures originate at the surface of a part, the compressed surface layer produced by shot peening is an economical way for extending the life of a component.

From all outward appearances, the equipment used to shot peen castings is identical to the machine used to shot blast them clean. The major difference is that the shot peening machine uses a more round, uniform media as well as more control devices which measure for correct shot peen intensity and coverage. With these controls, a blast cleaning machine can be used for the shot peening of castings.

Measuring Its Effectiveness

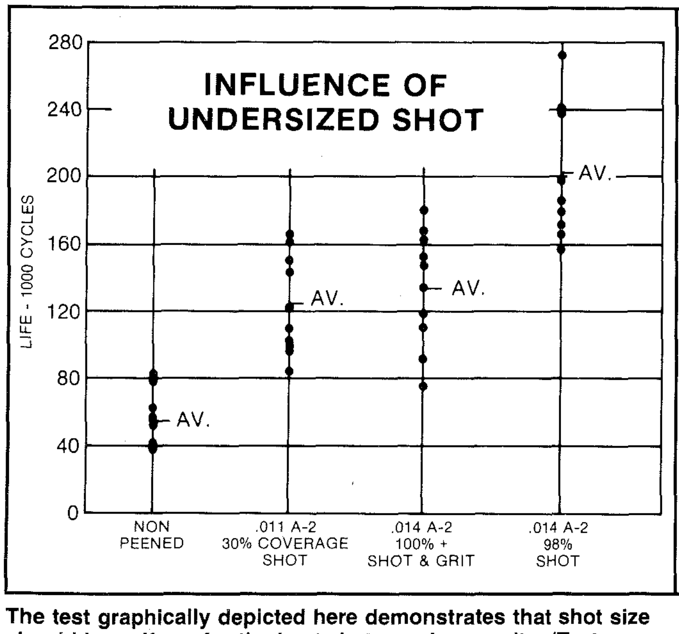
Since the purpose of shot peening is to produce a uniform thin compressed surface layer, it is necessary to measure for these conditions. This is accomplished by the use of an Almen gage, almen strips, shot sizing and machine cycles and conditions. It is important to note the x-ray diffraction method of testing can measure the forces induced into a part by shot peening. The x-ray curve shown in the accompanying figure was generated from shot peened 5160 spring material. Notice the high compressive stress at the surface and the magnitude it obtains 0.009 in. below the surface. The continuation of this curve would eventually bring it to the tension side and the resulting equilibrium generated by the low tensile stress at the material core. The use of Almen strips is then an indirect measurement of the compressive stresses but its use as a standard, which was developed by J. O. Almen, provides a good control over the shot peening process.

It is important at this time to define some of the terms used in shot peening:

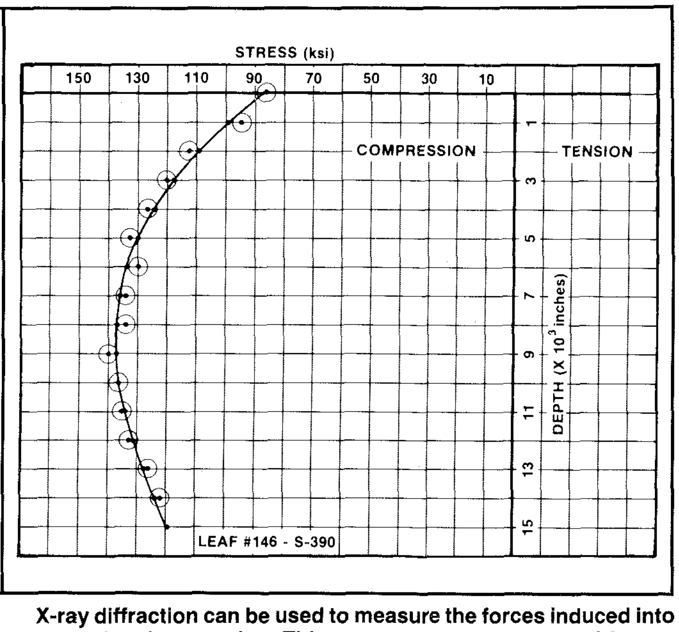
Intensity is the resulting impact force that is absorbed on an Almen strip which is measured as arc height at full coverage. It is dependent on shot size, shot velocity and angle of impact of the shot on the work.

Impact Angle is the angle of impact between the work surface and the direction of the blast. The peening intensity varies directly as the size of the angle of impact.

Arc Height is a measure of the curvature of a test strip which has been peened on one side only. The arc height is measured by the use of Almen test equipment. The arc-height is expressed as a reading in inches, followed by the suffix letter, (N, A or C) to designate the type of strip used. Thus, 0.013A represents an arc height of 0.013 in. measured



The test graphically depicted here demonstrates that shot size should be uniform for the best shot peening results. (Test conducted by John Straub in the Wheelabrator-Frye laboratories.)



X-ray diffraction can be used to measure the forces induced into a part by shot peening. This x-ray curve was generated from a shot peened 5160 material.

on an "A" strip by using the Almen gauge (the number 2 Almen Gauge is now strictly used).

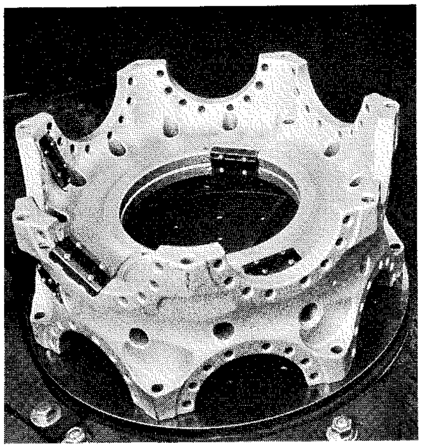
Coverage is a measure of the denting of the original surface and should be 100% minimum. Many applications require 200% or more coverage. Coverage is measured usually by 10 × magnification, the Straub method, the Valentine method or by the saturation curve method.

Shot peening specifications accept the saturation curve method, which establishes full coverage by plotting intensity versus time and assuring that the correct intensity (determined by the arc height of the test strip) falls on the right side of the knee of the curve.

Saturation is that point on the saturation curve where the arc height does not increase by 10-20% after doubling the time of exposure and is understood to be at the intensity required for the application.

In specifying media for shot peening, it is necessary to have a minimum of 85% full size shot. While in cleaning applications, on the other hand, a good mix might have only 30% full size shot and the balance distributed over a series of smaller sizes which actually do the final cleaning.

The accompanying figure shows the results of fatigue tests run to determine the influence of undersized shot. The test points at the left show an average life of about 50,000 cycles on non-peened specimens. The next group was peened with uniformly sized shot to an arc height of 0.011A and a coverage of only 30%. This showed a life increase of about 2½ to 1. The third group was peened under the same conditions as the second group and was then re-peened with five times as much additional undersized shot, simulating the size analysis which was discovered in a production peening machine with a high percentage of undersized shot due to lack of proper separation. It is interesting to note that the life of these two groups is almost identical in spite of the fact that six times as much shot struck the third group. Even though the coverage had been increased from 30% to over 100% and the arc height had been increased from 0.011A to 0.014A, the influence of the additional coverage with undersized shot was negligible.



In tests conducted by a parts supplier to the automotive industry, Almen blocks were mounted to a sample casting to measure for a thin uniform compressed surface layer on the part. Shown here is a typical example of a sample casting with Almen strips attached.

The group at the right was peened to the same arc height as that in group three and to a coverage of 98% with uniformly sized shot. This resulted in almost double the average life of the second group.

The above test demonstrates that shot size should be uniform for the best shot peening results. This presents a dilemma for the foundryman who wants clean castings as well as longer lasting castings. But his questions can be quickly answered if the foundryman performs a simple series of tests which were conducted by a parts supplier to the automotive industry. It consisted of:

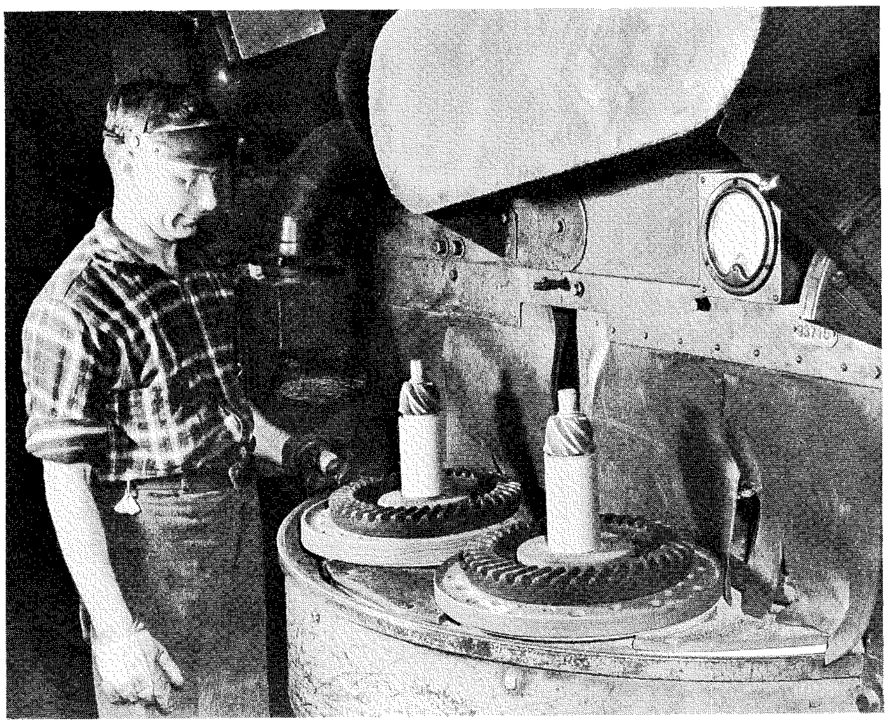
- Placing a uniform shot size in the cleaning machine.
- Mounting Almen blocks to a sample piece part as an example.
- Plotting a saturation curve.
- Fatigue testing of samples.

The results showed an improvement of six times over unpeened parts and three times over parts that were cleaned but not control peened. They experienced a one and one-half times increase in machine cycle times because of the lower cleaning rates with shot peening sized media and the time required before saturation occurred.

Since the compressive forces induced by shot peening forms a thin layer at the surface, any machining that removes this layer will, of course, remove the benefits of shot peening. Also, processes that heat the part like grinding or heat treating will remove the compressive stresses. Therefore, those areas where failure occurs, which are not machined, ground or heat treated after shot peening are those that can benefit from shot peening. Castings that are currently shot peened include; camshafts, crankshafts, gears, railroad wheels and suspension brackets.

Another example of where shot peening proved beneficial to castings is the use of ductil iron gears for weight savings over steel gears. Ductile iron has a density of approximately 90% that of steel. It has been found that shot peened ductile iron gears are acceptable while unshot peened were not in tests conducted for light weight trucks. Shot peened ductile iron gears showed a five times life increase over ductile gears that were not.

The foundryman who closely controls his cleaning operation and whose manufacturing sequence allows the opportunity to obtain the benefits of shot peening can expect improved castings. He will experience castings that are uniform in fatigue life, thus longer lasting and castings that potentially weigh less.



One example of where shot peening has played an important role in casting production is in the use of ductile iron gears which provide weight savings over steel gears.

For a free copy of this article circle No. 315 on Reader Action Card.