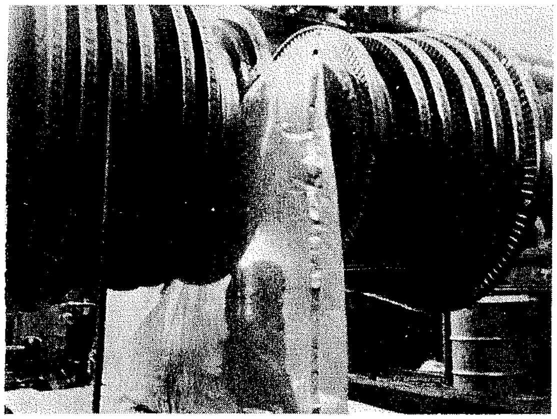

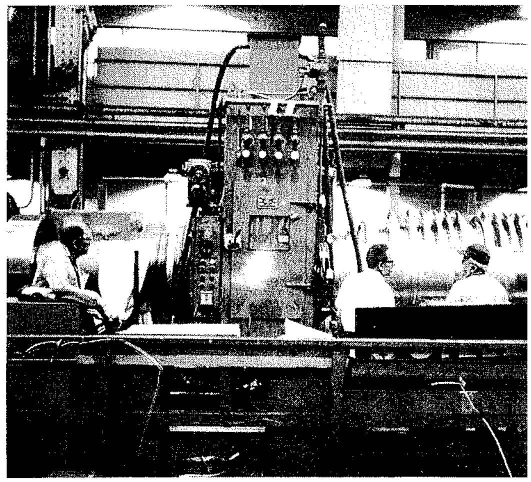

Enclosure for steam-turbine impulse blades (left) and portable machine working on TVA rotor (right) are on-site applications. Gantry (center) peens turbine blades

Maintenance and lubrication

Shot-peening takes expanding role

Originally used primarily to improve fatigue strength, the process, because of the residual compressive stresses it induces, is now being applied increasingly to the prevention of corrosion cracking

By J R Johnston and **J J Daly,** Metal Improvement Co

Shot-peening, as a method of surface treatment of metals, is by no means new: Its origins go back to around 1930. But constant, continual buildup of experience and research findings has made today's closely controlled methods more applicable to maintenance work for utilities and other energy-intensive industries. Steam- and gas-turbine components, heat-exchanger tubes and tube sheets, pump components, preheaters and tanks are some of the elements for which the method prevents metal fatigue and stress-corrosion cracking. To permit the benefits of shot-peening to be extended to large equipment in the field, without the need for dismantling and shipping to a central shop, portable equipment has been developed which can be shipped to remote sites on short notice.

Original application of controlled shot-peening was to small auto and aircraft parts, such as springs. Increased allowable fatigue-stress levels for properly treated parts were the first result. Steel and aluminum were the first metals treated, but bronze,' titanium and magnesium can also benefit from shot-peening. Acceptance of the method was helped by standardization of such variables as size and shape of shot and intensity of the stream. Glass-bead peening also came into use, as a complement to steel shot, for specialized work.

Because of the specialized machinery needed and the close quality control demanded during the actual work, nearly all maintenance shot-peening is done by outside contract services. Parts can be sent to the shot-peening shops, or portable equipment can be set up in a plant. Shot-peening must be done under controlled conditions to prevent actual reduction in fatigue life.

Controlled shot-peening relies for its basic effect on inducing residual compressive stresses in the surface of metal parts. (The process is very different from blast cleaning, which is not a controlled process.) Myriad impacts of carefully sized particles of shot, continuously monitored for size change or degradation, gradually build up a compressive layer a few thousandths of an inch thick. Once this layer is in existence, the initiation of surface cracks becomes difficult. Understandably, stress corrosion is less likely to occur, because the starting crack is prevented. Only if the applied stress at the surface becomes high enough to overcome the shot-peening-induced compressive stress can a starting crack form.

Control of shot-peening means more than control of the shot itself. The length of time needed to achieve results from a given setup of shot type and propulsion device (nozzles or centrifugal wheel) must be determined beforehand. Basis is the Almen gage, as described in box on facing page.

Quality of peening is determined by:

- Magnitude of residual stress induced by shot-peening. This is a function of the material's yield strength.
- Depth of the residual compressive stress, which is a function of the hardness of the material.
- Characteristics of the shot and its velocity.
- Extent of coverage. A properly peened part will be completely covered by overlapping dimples, with an appearance like an orange peel.

The machines developed for shot-peening hold and rotate small parts so that either air nozzles at closely maintained air pressure or rapidly rotating wheels can propel the shot at the workpiece. Masking of areas not to be treated confines the effect. On a crankshaft, for example, only the fillets re-

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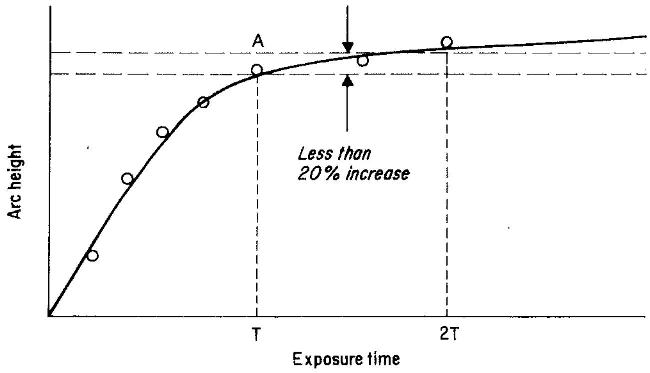
Test strip, exposed to blast, is clue to process settings

Shot-peening's effect depends on the intensity of the blast, which in turn depends on time, nozzle distance, wheel speed, impingement angle and other factors. In practice, the actual measure of intensity of the blast is the amount of curvature that a small flat metal specimen, exposed to the blast, assumes after removal from its solid mounting block. An Almen gage measures the curvature as arc height over a 1¼-in. chord. Because the measurement should fall in certain ranges, three strip thicknesses are available. The "A" strip, 0.051 in. thick, is most common.

Bending of the strip, convex toward the blast, clearly shows that the surface is in compression. Not all the bend-induced compression is at the exact surface; instead, it tapers off inwardly, reaching zero at a few thousandths of an inch below. Progressively longer exposure will increase the arc height up to a certain value, with little subsequent increase. The arc height for several test strips, each for a different time, can be plotted, as below, to give a saturation curve. At some time value, the arc height will increase by no more than 20% for doubled exposure time. This value, beyond the knee of the curve, is called *intensity*. Exposure time to achieve intensity is, then, an indication for the actual job. If the part differs greatly in hardness from the 44-50 Rockwell C of the test strip, the time needed for saturation will differ.

If shot-peening effects depend on creation of compressive stress, then raising the metal temperature later above a threshold value should relieve the stress and destroy the benefits. This actually happens, as the chart below shows. Cryogenic temperatures, on the other hand, have no effect.

Full coverage or saturation of a surface can be determined by an inspector who views the surface through a 10X magnifier to see if the surface is fully covered by dimpled shot marks. Another inspection that is made constantly during shot-peening is for shape of shot. Excessive broken, elongated or hollow shot means that the metal surface will be torn or otherwise harmed by the process. Modern machines classify the shot continuously, removing broken and defective shot. This equipment, however, is operated back in the shop rather than transported to the field.



Saturation on the test strip is reached at A (left). The strip is exposed to the same automatic processing as the workpiece.

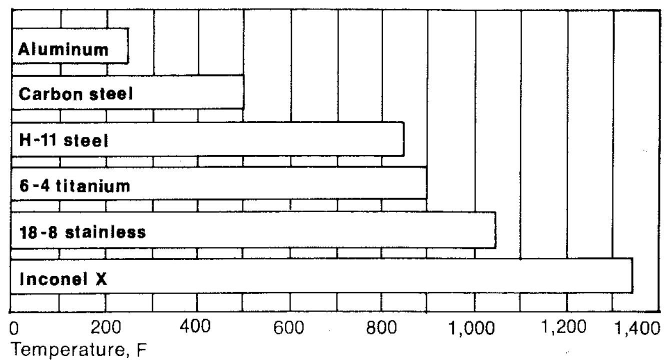


Chart above shows temperature for initial loss of effect. Surface-metal removal after shot-peening also cuts benefit

quire shot-peening, and other areas are masked off. Where only welds are to be shot-peened, masking may be optional.

Surface treatment can be critical for shot-peened areas. Grinding after shot-peening is not permitted, because it raises surface temperature enough to relieve the compressive stress. Thus, any grinding must be done beforehand. Shot-peening after grinding is often specified because grinding induces residual tensile stresses near the surface, with consequent loss in fatigue life. This is especially important for high-strength steel parts.

Shot-peening before plating is often specified as a help in preventing loss in fatigue life. The compressive stress at the base-metal surface resists inward propagation of fine cracks that develop in the plating layer.

Changing the shape of thin or flat parts by shot-peening is also possible. There are advantages here compared with conventional methods, because the finished part has surface compressive stress rather than the tensile stress caused by other methods. Rods, shafts and disks are not the only shapes that benefit from this treatment, either. Ring gears that are out-of-round can be brought back to circularity. Large panels have been formed for airplane wings, and the result is a panel with compressive stress on both faces.

On very thin panels, the effect of shot-peening can be harmful, however. The compressive stress may extend down into a large fraction of the cross-section, and therefore the internal tensile stress will be high at the core. Distortion is also a danger in these thin panels.

The temperature at which the compressive stress begins to dissipate must be interpreted properly in each case. For example, a stack or duct carrying gases at temperature above the top temperatures shown in chart at right above may still be improved in resistance to fatigue if the sensitive parts, such as flanges, are at a lower temperature than the gas. Shot-peening is confined to these areas in manifolds and ducts.

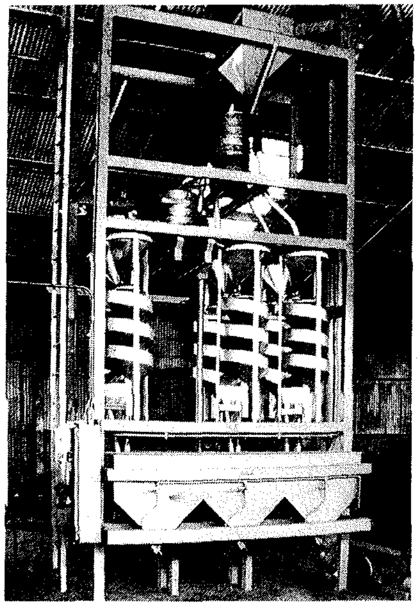
Let's look at actual applications in utilities and industrial plants. Turbines, gears, springs, weldments and highly stressed rotating parts are examples. Some of the shot-peening work is done on parts before the machines are assembled at the factory, of course, but in other cases the work becomes necessary for replacement parts or after field repairs.

Equipment required for this work is of several types, ranging from small, high-production units designed to handle small parts, to machines for peening large turbine components or other large parts. Portable equipment is available for quick movement to field sites where large components cannot be easily moved to the shop.

In every case, the basic idea is to avoid manual shot-peening, which is much more difficult to control and check than is shot-peening with automatic machines specifically designed for the purpose and operated under controlled conditions. Manual shot-peening should be performed only by certified peening operators.

In steam and gas turbines, shot-peening on the roots of buckets and blades not only improves fatigue life but also helps prevent fretting and galling of the high-performance alloy steels. Broaching can leave tears, pits or scores, which are stress-raisers. Shot-peening will correct this detrimental effect.

Out in the airfoil section, shot-peening will retard pitting along with improving fatigue life. And if the blades



Circular chutes of this shop machine reclassify shot by size and condition

are to be plated, shot-peening before plating is important.

Jet-engine turbine disks that are subjected to stress corrosion will benefit from shot-peening, too. Stress corrosion can occur in nearly any atmosphere if the surface is in tension for long periods. Stresses that lead to stress-corrosion cracking come from press fits or fasteners, or they may be residual from heat treatment or machining.

For maintenance work on site, there are many opportunities to improve machine and equipment life and reduce downtime. Some of the symptoms that suggest use of shot-peening are:

- Short fatigue life of stressed parts.
- Cracks originating from holes or other stress concentrations.
- Scoring and galling of gears and cams.
- Porosity in castings.
- Leakage of oil from seals.

Replacement springs are a good application for shot-peening. If a spring has failed because of breakage in fatigue, the replacement spring should be shot-peened.

Failures in shafts may indicate a need for shot-peening. Examination of the failure can give clues. The treatment may be needed only at fillets or keyways, of course.

Gears are another possibility. If the fillets at the roots of teeth are found to be highly stressed, shot-peening of these areas can increase the fatigue strength of the gear. Shot-peening after carburizing is also often specified.

Very hard steel parts can profit from shot-peening. With some alloys, the highest strength levels are accompanied by an actual reduction in fatigue strength, because of notch sensitivity and brittleness of the metal. Shot-peening allows the high strength of the harder alloy steels to be retained without loss in fatigue strength. Important in this case, too, is the fact that controlled shot-peening eliminates the effect of shallow scratches that would cause early failure in unpeened parts. The surface compressive stresses are high enough and extend deeply enough into the surface to prevent the scratches from becoming progressing cracks.

Shot-peening of holes should not be overlooked. Small size of a hole is no major deterrent, because holes as small as 0.087 in. in diameter have been shot-peened under controlled conditions.

Surface changes caused by shot-peening can help in other ways beside strength improvement. The shallow indentations visible under low magnification have been found to improve lubricating properties and act as oil reservoirs. This is a plus with gears, tappet faces and cams. Smoother action, lower temperature and less scoring and galling are the result.

Porosity in castings may be a problem that apparently only impregnation or extensive weld repair would correct. In many cases, shot-peening will close up the porosity satisfactorily and is faster and less expensive than other methods.

Seal leakage is another maintenance problem on which shot-peening can help. Seal manufacturers specify the finish to be provided under the seal. But sometimes, even if a surface meets basic roughness limits, the directional marks left by grinding can allow excess leakage. Careful lapping or honing will improve conditions, but shot-peening, usually with glass beads, gives a superior result. The slightly roughened surface, with no directional marks to aid leakage, does not wear seals excessively.

In a different area of industry, a heat exchanger had a problem with polymers clinging to the inside surface of the tubes. The tubes were glass-bead-peened to solve the problem. Tests showed that the polymers would not stick to the nondirectional finish generated by the glass beads.

Welding for maintenance reasons can cause residual tensile stresses that decrease fatigue life. With shot-peening on site, such harmful residual stresses can be changed to residual compressive stresses. Welds in large fans, such as forced-draft and induced-draft, can be shot-peened on-site. Grinding before shot-peening will improve fatigue life over that obtained by shot-peening alone. Piping welds, in alloys such as stainless, have been shot-peened for improved life. Pipe in wall thickness as low as 0.047 in. in ¾-in. OD has been shot-peened.

What does an on-site shot-peening job entail? On a turbine, the work could include lashing lugs, welds and areas under shroud welds. This can require several days, even with crews working 24 hours, so scheduling to coordinate with other repairs is necessary. Shipment of shot-peening equipment may even have to be by air to save time. An enclosure around the shot-peening machine is a must, so a large tent is usually put up. When needed, dust-collection equipment prevents hazards to nearby workers or machinery. In operation, intensity tests are made before peening, and at intervals during the work. The shot is also checked periodically for deterioration.

Recent developments in controlled shot-peening have used more fully the possibilities of enhancing stress-corrosion resistance through shot-peening. In addition, the problem of intergranular cracking has been attacked successfully in some cases. This is one of the most promising areas for future expansion of the method. For example, intergranular cracking of austenitic stainless steels has been shown by recent test findings to be helped by shot-peening. In Ni-Cr-Fe alloys heated to the 900-1500 F (482-816 C) range and slowly cooled, chromium carbides can precipitate, with subsequent depletion of chromium near grain boundaries. Reduction in chromium content leaves the steel susceptible to attack, and intergranular cracking can follow.

Shot-peening can break up surface grains to form nucleation sites for carbide precipitation below the surface, thus protecting the surface metal. Ceramic beads can be used instead of hardened steel for this application. Peening times are long compared with ordinary applications in the maintenance field.

Problems remain to be solved before shot-peening will be fully useful against intergranular cracking. For example, nondestructive examination becomes more difficult. Also, a method is needed for quickly judging the effect as a function of peening time. Code views of shot-peening are not uniform, and some codes at present may prohibit, perhaps inadvertently, the application of shot-peening for this purpose. Future development must take this into account for some types of equipment in steam and power generation.

Tangential cleaning of cylindrical shapes with glass beads instead of the customary alumina grit is another development. Heretofore, magnetic-particle or dye-penetrant inspection had to be done before this cleaning, just as it must be done before shot-peening. In the case of cleaning, the gentle action of the glass beads allows effective magnetic-particle inspection afterward, because fine cracks are not smeared over. This cleaning technique is similar to shot-peening with glass beads. ***WOK***

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