

The Merits of Shot Peening

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Metal peening has had a long history—the ball peen hammer was used to improve the quality of the gentleman's sword. And manufacturing engineers and production managers generally are acquainted with some aspects of the shot peening process. But there is a scarcity of adequate literature and instructional material relating to present-day shot peening techniques, potential uses, and economic advantages. This comprehensive review of the state of the art, by a recognized authority in the field, is presented on the premise that the spread of its applications in production operations bears a direct relationship to the spread of the knowledge about what it can do, and why

● Shot peening can make a dramatic improvement in the service life of highly stressed members subject to cyclic loading. For instance, life increases of several hundred per cent are commonly achieved in such objects as springs, connecting rods, machine parts, aircraft components, and other parts subject to vibration and reverse loading or shock loads.

But while the shot peening process offers a powerful tool to the design engineer, from a production standpoint it also involves subtle factors which must be applied with a considerable degree of finesse. In exploring potential applications for radical improvements in service life, the key factor to recognize is that shot peening is normally beneficial when the design objective is to obtain long service life under conditions of severe dynamic loading at stress levels approaching those which are maximum limits under simple static loading.

Plastic Deformation

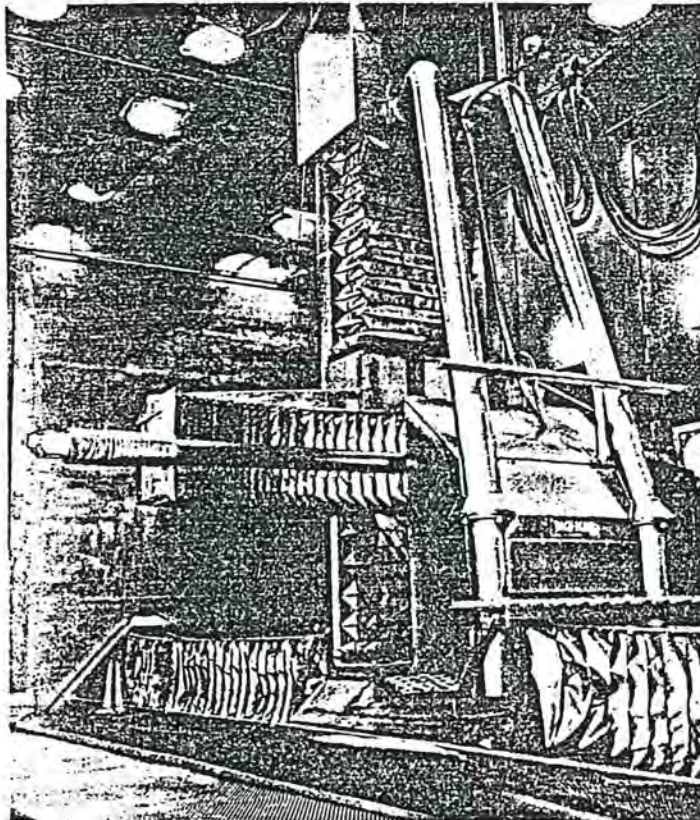
In production, the process uses a high velocity stream of hard, spherical particles such as steel shot to hammer the surface of the workpiece, causing the surface region to deform plastically. The objective is to impart a residual compressive stress in surface regions of the workpiece, as distinguished from cold working for purposes of hardening. The compressively stressed "skin" is highly effective in preventing premature failure under conditions of cyclic loading, since the failure-causing fatigue cracks generally propagate from the surface of the workpiece and start in a zone subject to tensile stress during at least a part of the dynamic load cycle. By introducing compressive stresses which reduce the extreme fibre stresses when under load, the shot peening effectively blocks the formation of such cracks.

The desired surface compression is achieved by plastic deformation of the surface. Forces which would tend to make the surface expand as a result of this deformation are balanced by tensile stresses induced in the unpeened core of the workpiece, resulting in a permanent residual compressive stress in a thin shell surrounding a relatively massive core which has low unit tensile stress. The thickness of the compressively stressed surface shell varies with the nature of the workpiece material and the intensity of the shot peening process, with a penetration of .010 to .030 inches being representative of much of the work done, even on quite massive parts.

Most peening is done with hardened steel shot, graded by size to achieve the effect desired. For delicate workpieces, such as some aircraft engine parts, spherical glass beads may be substituted for the heavier steel shot. Stainless steel shot is also used for a few specialized applications where ferrous contamination of the workpiece must be avoided, but the vast majority of the shot peening work currently being done in industry employs steel shot, with glass bead peening assuming an increasingly important secondary role.



A five-axis controlled shot peening machine developed by Vacu-Blast for General Dynamics, Fort Worth, blasts the underside section of a wing support assembly to increase fatigue-resistant strength with absolute uniformity. With tape control "... we can depend on the 100th or 1000th assembly being peened to exactly the same strength as the first," says E. L. Minch, GD manufacturing research and development engineer. Designed with a 25-ft travel along the X axis, 5-ft along the Y axis, and 5½-ft along the Z axis, the machine also processes 30 other components. The boom on which the nozzle is mounted rotates 360 degrees, while the nozzle scans 135 degrees, including 45 degrees in a backward direction



Permissible Stress Levels

The stress level to which a particular workpiece can be subjected under fatigue conditions is subject to many variables, a number of which are influenced by the design or environment of the particular workpiece rather than being solely a function of the material of construction. It is misleading, except under well-defined circumstances, to speak in terms of an increase in fatigue life from shot peening. A more revealing approach is a statement of the increase in stress level which may be tolerated for a predetermined number of cycles chosen to correspond with the design life of the workpiece. For most purposes, a design life of ten million cycles is considered the equivalent of unlimited service life, as the stress/life curve is essentially flat at this point unless other factors, such as a corrosive atmosphere, are introduced.

The pattern of compressive stresses produced within the workpiece seldom needs to be analyzed in application of the process to a manufacturing design, but it is of value in visualizing the effect produced. The magnitude of the stress increases in proportion to the strength of the material, and the compressively stressed zone extends deeper into the softer materials under a given peening exposure. However, undue emphasis should not be placed on thickness of the compressed layer, such as by a broad assumption equating protection with thickness under all conditions.

In pieces free of abnormal surface defects, it is not necessary to use high intensities, since all that is necessary is to provide a compressively stressed layer to surround surface irregularities that may act as stress risers. Rough forged parts, on the other hand, which may be heavily scaled, should be peened with sufficient intensity to reach uniform metal. The distinction is obviously due to the fact that protective surface compression must not merely relate to the smooth plane defining the boundary of the workpiece but rather to the micro-surface. It must include the innermost penetration of any hairline crack or inclusion to assure an effect which may be visualized as a force tending to keep the cracks pushed closed.

Shot Peening Equipment

Two broad types of equipment — compressed air and centrifugal wheel — are used in shot peening operations. The choice is usually a function of workpiece design, peening requirements, and production volume.

A wide variety of work is done with compressed air equipment, which is similar in principle to abrasive blasting equipment, but with controls to regulate the shot stream velocity, and reclaiming equipment to remove damaged shot from the circulating shot charge. This type of equipment is most versatile, and must be used for applications where peening is required in deep cavities or on selective surfaces of complex workpieces. This method is also used to peen certain critical areas of a workpiece which is part of a machine or

sembly without dismantling the entire assembly to move the workpiece to an enclosure. An example of this is the Vacu-Blast vacuum recovery gun for shot peening critical areas of aircraft landing gear without removing the aircraft from the flight line.

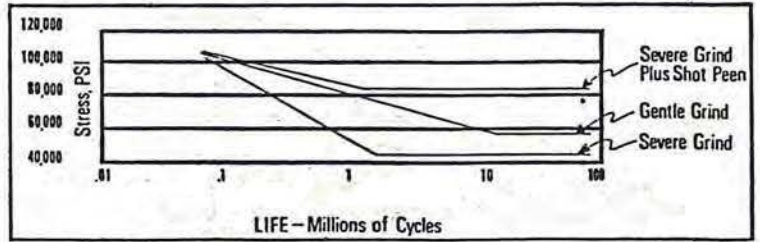
Centrifugal wheel equipment, similar to that used for cleaning castings in foundries, is used for large quantity peening where precise control of coverage in confined areas is not required, and where production volume justifies the large installations this method requires. The process is well suited to many of the high production peening applications found in the auto industry, such as the peening of springs.

While shot peening can be done in a simple, manually operated cabinet, substantial mechanization is usually employed, often to reduce process costs, but more often to obtain a degree of uniformity and control not possible by manual means. This mechanization takes many forms to suit different job requirements, ranging from simple oscillating devices which sweep a cluster of peening nozzles back and forth over a moving workpiece, to conveyORIZED pass-through systems for high volume work, to five-axis numerically controlled contouring systems which move a peening nozzle over a complex structural member and achieve a degree of process control not possible by any other means.

Shot size and type may or may not be specified. In the absence of a specific designation, the peening shop will select a fairly hard steel shot of a size large enough to achieve the desired effect and small enough to reach critical areas such as small-radius fillets. Unless unusual conditions exist, it is preferable to avoid imposing limitations on factors such as shot feed rate, peening air pressure, and coverage speed over the surface. These may be easily selected by a production group skilled in performing the peening operation, the final effect on the workpiece being adequately controlled by the other specified variables.

Controlling Variables

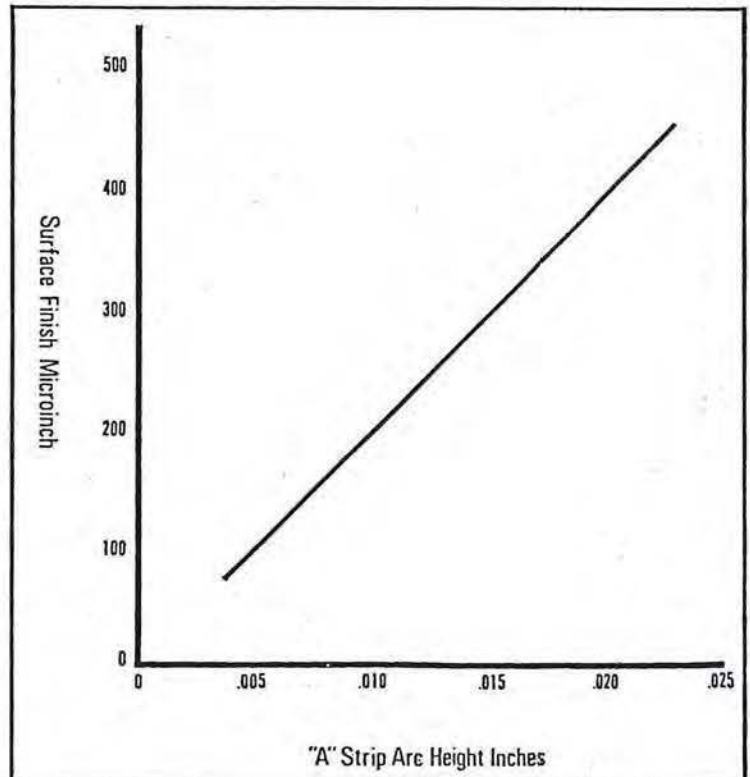
Among the several variables which determine the final effect achieved in the workpiece are size and hardness of the shot used, the velocity of the shot stream, the angle of impact, and the duration of exposure to the shot stream. With so many variables, and with several of them so difficult to measure and control as independent factors, a unique production control technique has been uniformly adopted throughout industry to control the process. This technique is the Almen strip system, in which a standardized metal test strip is subjected to the peening process intended for a given workpiece and the effect is analyzed by subsequently measuring the amount or distortion of the strip. The compressive stresses induced by shot peening one side only, bend the strip in an arc, and the height of the arc so produced is directly proportional to the intensity of the shot stream. The height of the arc is measured with a standardized Almen indica-



The chart indicates the pattern of improvement of a typical operation, such as a ground steel shaft. If grinding is done very gently, there is a minimum of local heat build-up at the wheel contact point and the performance curve shown for "gentle grind" will result. A severe grind, however, can result in thermally induced superficial tensile stresses, or even a minute crack pattern, which severely lowers the safe stress level for cyclic loads. Shot peening will reverse the stress distribution and produce a part capable of being cycled repeatedly at levels above even those which could be achieved by the gentle grind. Note that all three curves converge, this being the design point usable for static loading

| Material | Unpeened | Peened | Per Cent Increase |
|--------------------------------|------------|-------------|-------------------|
| Carbon Spring Steel - SAE 1074 | 75,000 psi | 115,000 psi | 54% |
| Alloy Spring Steel - SAE 6150 | 70,000 psi | 115,000 psi | 60% |
| Stainless Steel - Type 302 | 45,000 psi | 90,000 psi | 100% |
| Phosphor Bronze - SAE 81 | 15,000 psi | 30,000 psi | 100% |

The increase of permissible stress for long service life in general amounts to 50 to 100%. In one test series, increased life of coil springs in sections less than 3/8 in. thick produced the values shown above



The amount the surface finish of a workpiece is altered by shot peening is primarily a function of shot size, shot velocity, and material and shot hardness. Note that a single straight line curve may be used to approximate the relationship of surface finish to shot peening specification. Variations in shot

Two standard test strips, designated A and C respectively, are most commonly used. The two strips differ only in thickness, with the relatively thin A strip of a thickness which causes it to bend with exactly 350 per cent of the deflection of the thicker and more rigid C strip, under any peening exposure within the useful range. This fixed relationship allows the two strips to cover a wide range of peening conditions, with the thinner A strip being used up to intensities which result in .024 in. deflection, beyond which the C strip is used.

When a shot peening specification is required it is shown, for example, as .008 - .010 C. This means that the height of the arc produced in a C strip exposed to the peening process desired for a workpiece should be between .008 and .010 inches high as measured on the commonly used Almen gage.

As a guide to practical peening, the following Almen gage intensities represent good general practice, to be modified by special considerations such as distortion of delicate sections:

| Part Thickness | Almen Gage Reading |
|----------------|--------------------|
| 1/16-in. | .004 A |
| 1/8-in. | .008 A |
| 1/4-in. | .014 A |
| 3/8-in. | .018 A |
| 1/2-in. | .021 A |
| 3/4-in. | .008 C |
| 1-in. | .010 C |

Since the introduction of the comparatively delicate glass bead shot peening in recent years, a third test strip known as the Almen N strip has come into use. Like the others in the series, it is identical in all respects except thickness, and is the thinnest of the set. Just as the A strip will deflect 350 per cent as much as the C strip, the N strip will deflect 350 per cent as much as the A strip under a given bombardment, thus extending the practical measurement range toward more delicate peening.

In practice, the vast majority of peening work is done in the range of .008 A to .018 A, even in the case of fairly massive parts.

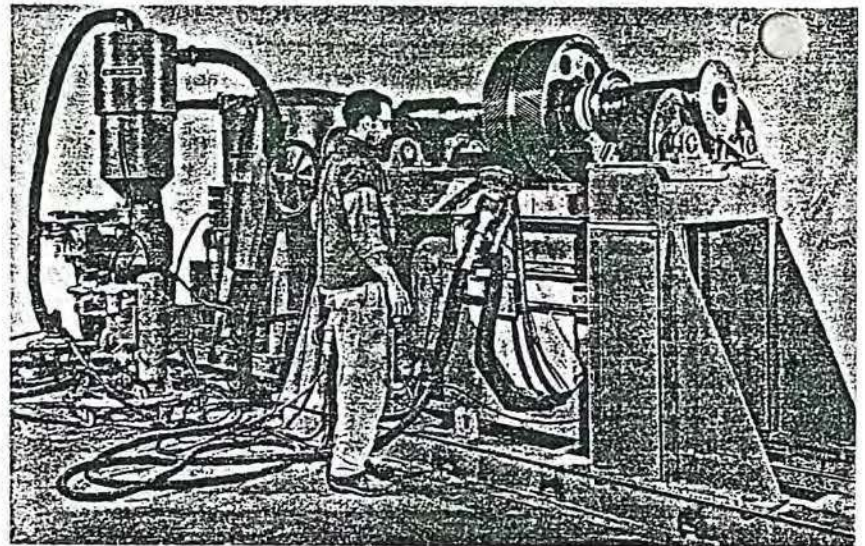
Surface Finish and Tolerances

The surface finish of a workpiece will be altered by the shot peening process, the exact amount being primarily a function of shot size, shot velocity, and material or shot hardness. A single straight line curve (see chart, p. 109) may be used to approximate the relationship of the A strip arc height to surface finish. Variations in shot size used to obtain a specific A strip arc height do not cause substantial departure from the curve, as larger shot particles are propelled at lower velocities to obtain the given arc height, thus limiting the surface penetration which otherwise might be expected.

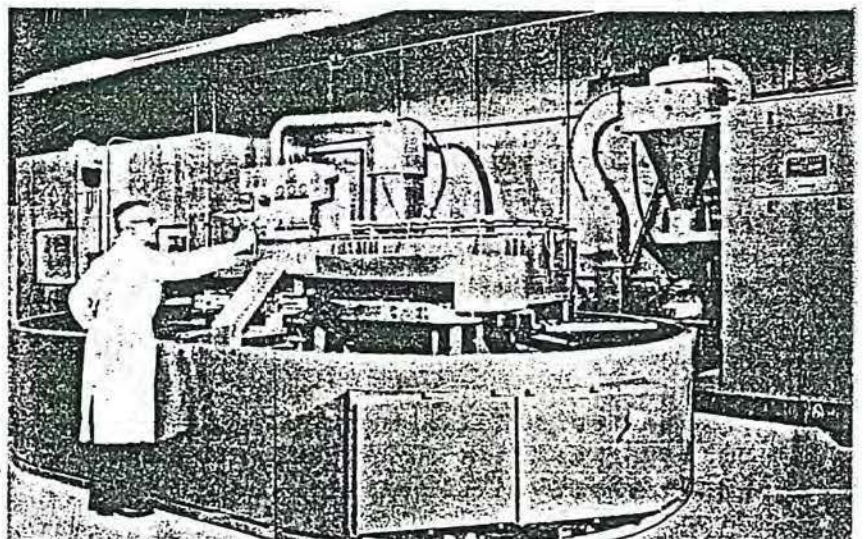
Tolerances are affected by shot peening, but in a predictable and correctable manner. The shot particles indent the surface, causing the displaced material



(Above) Distortion of Almen test strips is directly read on a standard gage. (Below) A double helical reduction gear for a large steam turbine is being shot peened to increase fatigue life of the gear teeth. The gear rotates as the blast gun automatically indexes across the front. The machine is a standard Senior Model Vacu-Blaster equipped with a special work table



Automatic blast cleaning and shot blasting of jet engine blades was made possible by this new machine developed by Vacu-Blast for United Airlines maintenance headquarters in San Francisco. An automatic transfer line moves the blades from a blast cleaning station into a shot peening area where an automatic adjustment mechanism compensates for different sizes of blades and provides different peening intensities on different sections of each blade. All variables are pre-set at a central control



the indented zone. This is a true plastic displacement, not an erosion action in which metal is removed to a significant degree.

When it is necessary to hold a close dimension in the shot peened zone, proper practice is to specify a final machining operation to re-level the surface and restore the desired tolerance. This can be done by honing or very gentle grinding, carried out to minimize contact point temperature rise. As the compressively stressed zone extends somewhat beneath the indented region, protection will be retained if the final finish is carried out in such a way as to retain a visible pattern of indented areas.

One approach representing conservative good practice is the military specification MIL-S-13165 A Amendment 1 governing shot peening of ferrous metal parts. It states in part: "It is permissible to improve the surface finish after peening by lapping, honing, or blasting, provided such operations do not generate temperatures exceeding 475 degrees Fahrenheit, and do not remove material layers thicker than 10 per cent of A intensity arc height (for example, up to .0007 inches may be removed from a part peened to .007 A intensity)."

The term "coverage" as applied to shot peening refers to the percentage of the peened area which is actually indented by the shot particles, as determined by a visual examination after peening. While the coverage percentage may be specified by the designer, it is commonly omitted and virtually complete coverage is assumed. Surfaces for which peening is neither required or indicated as optional may be masked to protect them from the shot stream, or may be peened and then have the effects removed by subsequent machining.

When a process specification calls for shot peening of parts without indicating the specific areas to be peened, it is understood that the parts shall be peened on all areas except small holes and other sections which cannot be readily reached by the shot stream. If it is desired to limit peening to certain designated portions of the part, the portions to be peened should be designated by arrows pointing to the surface to be treated.

Quality Control

Quality control of the process is unique in that there are no nondestructive test methods to determine whether a completed piece has been properly peened. Control tests must be made at the time of shot peening by measurement of the effect of the shot stream on Almen strips, supplemented by such controls as visual inspection of the workpiece for uniform indentation.

Mechanization for quality control purposes is necessary for most work of a critical nature because all standards depend on the shot stream duplicating the effect that is first checked on the Almen strip. The requirement for mechanization must, therefore, be

as a cost reduction factor. While a design specification seldom indicates the mechanization technique to be used, it is considered good practice to specifically exclude manual peening when the necessary reliability requires that repeatability be rigidly controlled.

Secondary Applications

In addition to the highly effective use of shot peening in treating high strength members subject to cyclic loading, another application involves the protection it offers under conditions of static loading.

It has been found that peening of a surface which is stressed in tension in a corrosive environment will inhibit growth of corrosion cracks. This principle has been applied to treat inner and outer surfaces of aircraft landing gear members which are stressed by internal hydraulic pressure while the aircraft rests on the ground, and also to treatment of the inner surfaces of thin, highly stressed propellant tanks.

Another special application of shot peening is to shape a workpiece by warping it, just as the Almen strip will bend into a gentle arc when peened on one side only. In most shot peening applications this effect is specifically avoided by uniform peening of opposite surfaces of a workpiece or by limiting the peening intensity in proportion to the stiffness of the workpiece. The bending effect may be used to advantage, however, to compensate for distortions induced in heat treatment or to produce a controlled twist in milled aircraft wing skins which may be milled from a flat slab and then twisted much more economically than if originally produced in the complex configuration.

Economic Factors

From an economic standpoint, the primary justification for shot peening is that it permits operation at high stress levels under conditions subject to fatigue considerations. In the case of aircraft, this means reduction in structural weight for a specified reliability level. In ordnance and automotive applications, it means that relatively small, low-cost components can be upgraded for conservative operation at stress levels that would represent poor practice without shot peening. Springs, torsion bars, connecting rods, and gears are examples of components that are upgraded without the use of costly alloys or increased sections.

The ability to upgrade a component by shot peening offers obvious opportunities in the correction of undersized components, when fatigue failures occur after a product is standardized or in field service. In the automotive industry, for example, this technique has been used to increase the effective strength of components of the power transmission train of an automobile when horsepower is increased from year to year, thus eliminating the high cost of introducing dimensional changes in these components. In a related manner, shot peening often allows a cost savings through substitution of a low-cost material for a more