Shot Peening Technology

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INTRODUCTION

Shot peening is an exclusive mechanical process that is used extensively in applications where the performance of certain components must be enhanced above conventional design limitations.

The shot peening process derives from the same principle that early blacksmiths used when they continued to hammer (peen) a hot forged iron or steel specimen long after it cooled making it a tougher and more durable product.

That art has been refined into a closely controlled manufacturing process that is capable of obtaining results in improving product fatigue life in a way that is not attainable by any other similar production means. It is used successfully on mechanical power transmission and other components for the aeronautical, automotive and industrial fields as well as for many other applications whether constructed of ferrous or non-ferrous materials.

SHOT PEENING PROCESS

Shot peening is a cold working process where certain stressed areas of a specimen are blasted with small spherical elements called shot. Each piece of shot creates a small crater in the area of the part being treated. The depth of the crater may be a few thousandths of an inch deep for steel to .062 of an inch for softer materials.

Each piece of shot impacts and yields a thin surface layer of the crater putting it in tension. At the instant the piece of shot rebounds, the material below attempts to force the surface layer back to its original condition putting the complete surface of the crater in a highly compressed cold worked state.

Subsequent shot will strike areas where there are no craters or where this is an existing crater. Where there is an existing crater, the already cold worked surface prevents any new formation. Where there are no craters, new craters will be formed. This action creates a continuous formation of cold worked craters which put the total area into a layer of compressive stress.

Most failures start at the surface of a part in tension. Since the entire working area of a shot peened part is in compression, the part will experience increased life.

It may seem at first glance that shot peening craters on metallic surfaces will have a destructive effect on the life of a part by acting as stress risers; however, the craters are very shallow and have a smooth spherical surface that is very large compared to its depth. Since the stress rising effect of a crater increases with its depth and decreases with its large area, those made in peening have only slight stress concentration. In addition, it has been shown that a solitary stress riser is much more dangerous than a number of closely spaced stress risers. Closely spaced stress risers seem to share the intensified stress instead of the entire intensified stress being supported by a single stress riser.

A thin sheet of steel when shot peened will bow in both major axes with the peened side bowed up (convex side up). This is due to the internal forces that are generated in the work piece by shot peening. If the thin layer of shot peening is removed, the material will return to its original flat condition. This demonstrates the fact that the internal forces in the work piece causing the curvature were in the thin surface layers only.

One of the uses of this effect of shot peening is in the forming of aircraft wings. Machines have been developed with controls that enable them to shot peen form a number of different aircraft wings and other types of sizes and shapes.

Manufactured parts have residual stresses that can be either compressive or tensile. The surface of an “induction heat treated” part often will have beneficial residual compressive stress while the surface of the heat affected zone of a “welded” part will contain potentially destructive tensile stresses. This makes areas of welded parts good candidates for shot peening.

Figure 1 below has a typical trace of the stress levels in the impact area of a shot peened part. It can be seen on the plot that the compressive stress at the surface follows the known principle that the maximum compressive stress of a part after shot peening is at least equal to one-half the tensile strength of the material itself.

Just below the surface layer, compressive stress increases slightly then rapidly decreases to zero and then reverts to slight tensile stress. This sub-surface tensile stress has to balance the compressive stress for the part to remain in equilibrium. The tensile stress cannot be so high as to create internal cracking, thereby weakening the part. An extreme example of this condition exists where a thin specimen is shot peened with such great intensity that the part can weaken to the point where fracturing can occur.

Figure 1

Shot Peening Stress Profile

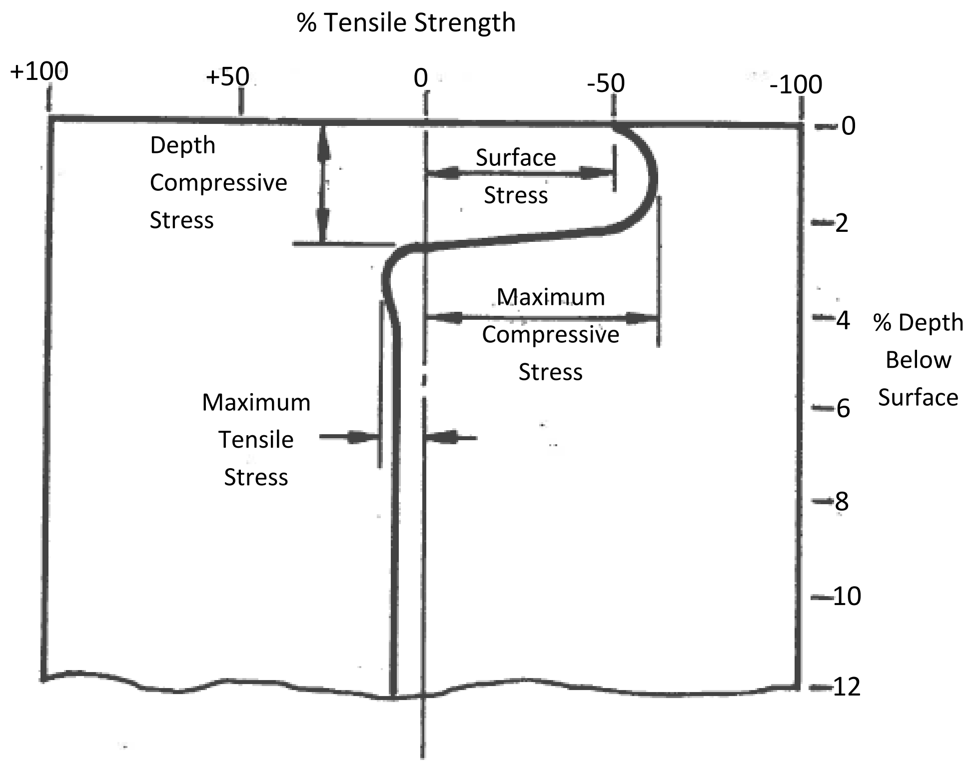
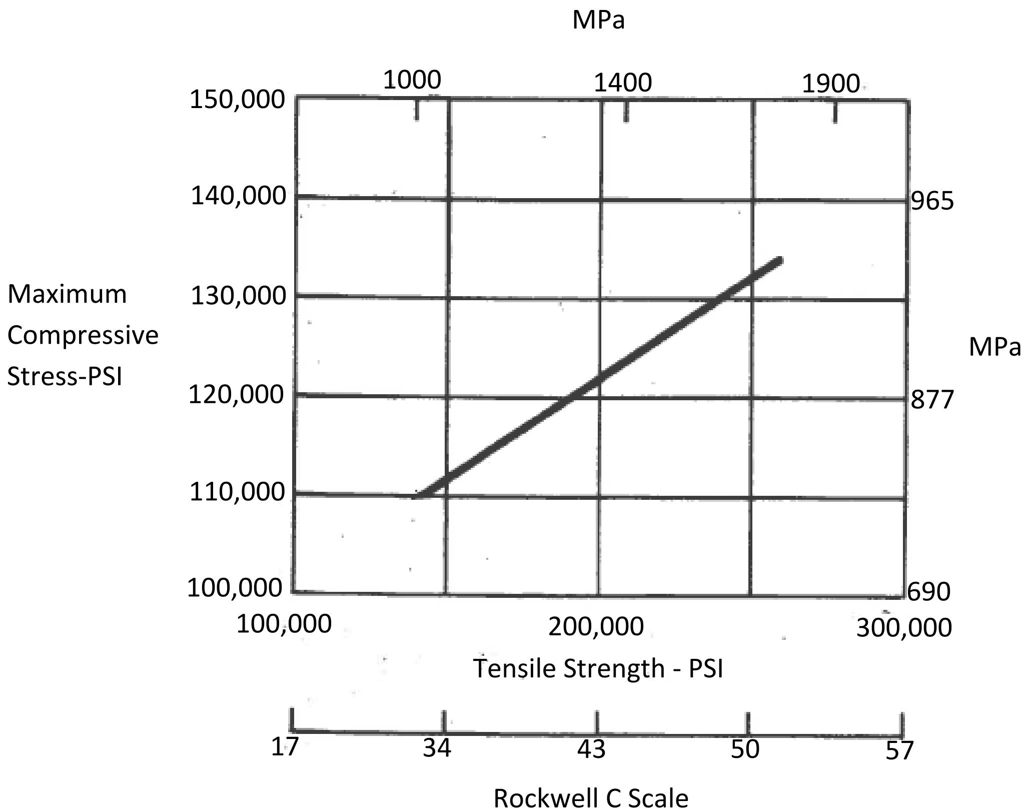


Figure 2 below has a graph demonstrating the magnitude of the induced compressive stress in shot peened steel. It plots induced compressive stress versus tensile strength of steel. It demonstrates the above-mentioned principle that the compressive stress induced by shot peening is at least one-half the tensile strength of the material being treated. Variations in the shot peening process itself have very little effect as long as the shot is as hard as or harder than the material being treated.

Almen Test: The Almen test is used as a means of duplicating a peening intensity that has previously been established as being optimum on an existing part.

Figure 2

Magnitude of Residual Stress



This is accomplished with an Almen test strip which makes use of the principle mentioned above whereby a thin strip of metal will bow when subjected to shot peening and that more intense peening will result in more bowing of the part being treated.

One very successful treatment that is used occurs when a production part is shot peened at a number of different intensities and fatigue tested. When the shot peening intensity that resulted in the optimum fatigue test life has been determined, an Almen test strip is shot peened at that same intensity and used as a quality control gauge to be able to maintain the shot peening intensity of the part at the correct level throughout production.

The Almen test uses three, 3.00 inch by 0.75 inch test strips; test strip N = .031 inches thick, A = .051 inches thick, and C = .094 inches thick.

The shot peened test strips bow in both the longitudinal and transverse directions.

The following table serves as a guide for determining test strip arc height (bow) in relation to the thickness of the part being shot peened:

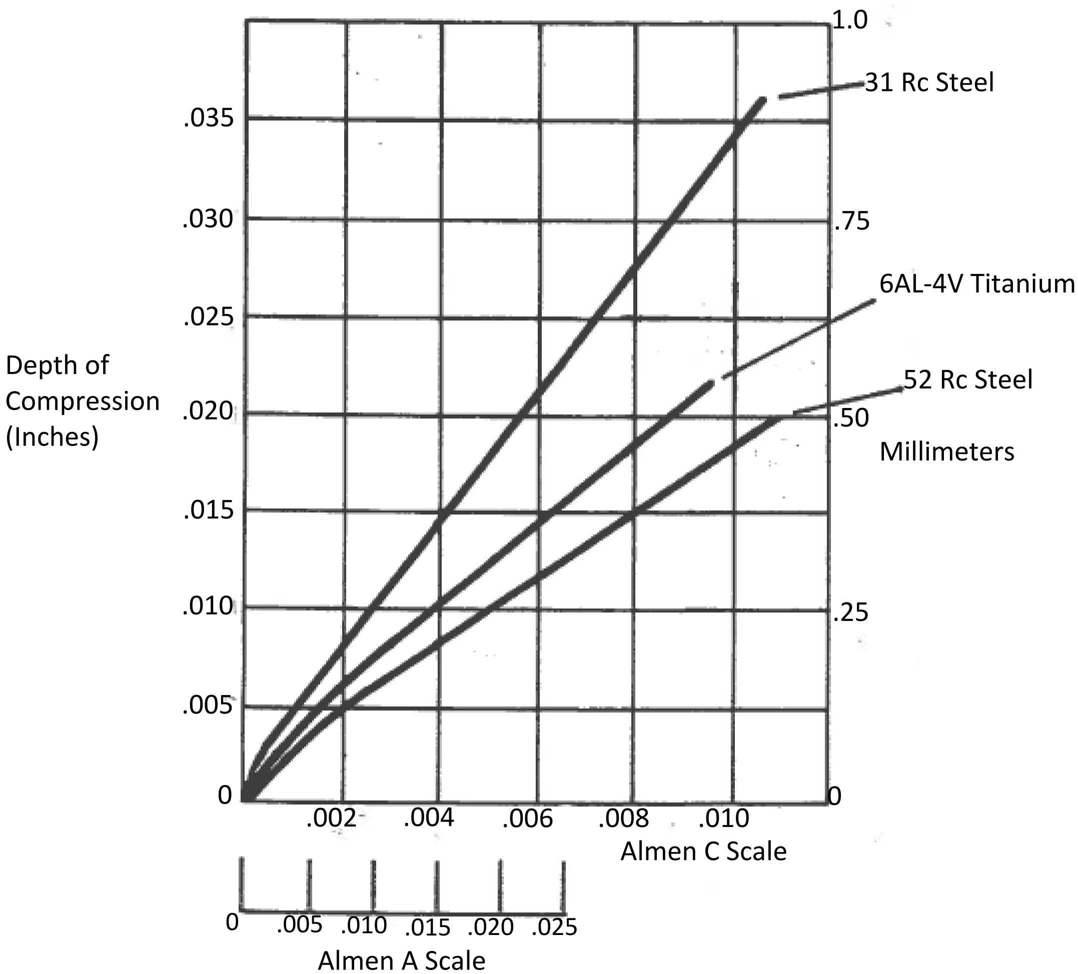
Part Thickness	Arc Height
1/16	.012 N
1/8	.008 A
1/4	.014 A
3/8	.018 A
½	.021 A
5/8	.007 C
¾	.008 C
7/8 (or greater)	.010 C (or greater)

For other than flat parts, the above values are to be modified depending on the exact shape to be shot peened. For instance, when shot peening the exterior of a tubular part, the arc height will be much higher than the arc height of the wall section itself.

Figure 3 has a plot of the depth of the compressive stress layer versus the Almen test strip deflection for three different materials. It shows that the depth of compressive stress is higher for lower hardness 31Rc steel than for 52Rc steel with titanium falling between the two.

Figure 3

Depth of Residual Stress



For parts having a thickness of 1/16 inch or less, a slurry of very small glass beads and water, propelled by pressurized air, has been found to create the best results. The results, similar to those using air-propelled dry metal shot, create small craters of cold worked material. Since the glass beads are smaller than metal shots, the craters are smaller, creating a very thin layer of compressed stress established in the work piece.

In general, shot peening will increase the life of a part if it is subject to a bending or twisting stress; however, it has little effect on the life of a part that is subject to axial (push-pull) stress, since such stresses are reacted by the entire cross-section of the part rather than principally on the outer fibers.

Parts such as bolts or other types of conventional fasteners that are under axial stress only may not benefit from shot peening; however, if excessive bending or twisting occurs during installation (torqueing), or if certain types of loads or vibrations are encountered that put the part in bending or twisting, shot peening may be of value. A partial list of parts and products where it has been reported that shot peening has been successfully implemented in production is as follows:

- rocker arms: 1400% life increase
- leaf springs: 600% life increase
- connecting rods: 1000% life increase
- coil springs: 1370% life increase
- gears: 1500% life increase
- steering knuckles: 475% life increase
- rocker arms: 1400% life increase

It has been found that with increase in fatigue life, costs can be reduced as shot peened parts can be made smaller and lighter, and in some cases, be made of less expensive material.

Shot peening has been found to replace production processes such as polishing and honing. It has also been found to improve the resistance to stress corrosion of a magnesium alloy, eliminate porosity in aluminum die castings, and improve the lubrication of crankshafts because of oil collecting in the craters.

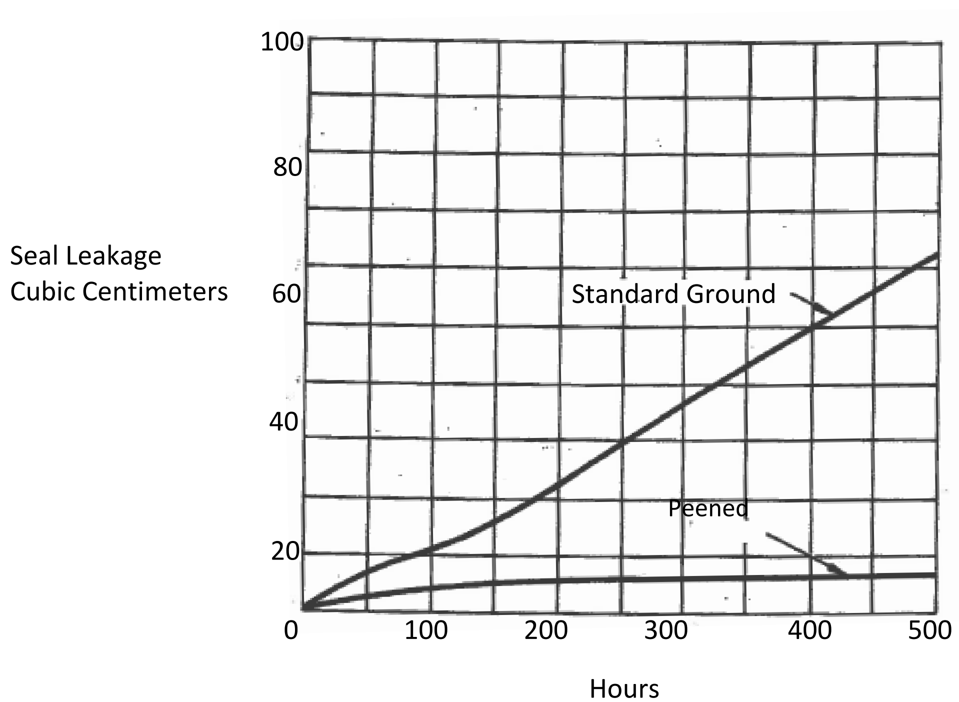
Shot peening springs while being statically loaded under bending (leaf springs) or torsion (coil springs or torsion bars), called stress peening, produces even greater life expectancies than shot peening unloaded springs.

An interesting application of shot peening is on the seal lip contact surfaces of rotating shafts. With increasing speeds and higher pressures, seal leakage becomes a challenge to the mechanical designer. Many times the sealing lip surface of rotating shafts has microscopic random sharp edges that wear away much softer seal lips, usually constructed of a form of rubber. Sometimes the sharp edges are not random but occur in parallel forming a hydrodynamic pumping action causing leakage. These microscopic surface deformities are difficult to eliminate or control. It has been found that the much smoother and random surface produced by shot peening eliminates both problems resulting in improved sealing.

Figure 4 depicts a graph of seal leakage versus operating time for both standard ground and shot-peened shaft sealing surfaces. It can be seen there is a marked improvement with peened shafts over ground shafts.

Figure 4

Ground vs. Shot Peened Sealing Surface



Shot peening isn't the only method by which the fatigue life of a part can be increased. Others include cold working by rolling, stretching, compressing, twisting; heat treating including induction hardening and flame treatment; and altering the surface composition by "carburizing", "nitriding", etc. However, shot peening possesses advantages over all of the above such as improved flexibility, control, safety and cost.

<u>Peening Shot</u>: Shot peening shot consists of spherical particles obtained by the dispersion of a molten stream of metal immersed in water, air or other media. The earliest shot used for commercial purposes was made from chilled cast iron. High carbon content cast iron, melted in a cupola (smelting furnace), is immersed in water where the metal is quenched and broken up into small spherical particles of hardness ranging from 55 to 66 Rockwell C.

Another form of cast iron shot material is malleable cast iron. Malleable cast iron shot is formed by heat treating (annealing) chilled cast iron shot down to a hardness of 22 to 40 Rockwell C. This makes it not as hard as chilled cast iron shot and not recommended for higher hardness materials, but less brittle and longer lasting for lower hardness materials.

An advancement in peening applications is steel shot; either cast steel which has been heat treated to the proper hardness, or cut wire which has been cold worked by a drawing operation. Steel shot has a hardness range of 40 to 65 Rockwell C which gives it good peening action and the toughness to resist fracture better than any of the common ferrous shot materials used. It has been shown that steel shot of Rockwell 42 to 50C hardness will effectively peen Rockwell 60C hardness work comparable to chilled iron shot of Rockwell 55 to 60C hardness.

Tests have shown steel shot to be more effective than iron shot in performance and durability of use, and have become the standard. Tests have also shown steel shot to be more effective in increasing the fatigue life of Rockwell 60C work better than any other ferrous material. Besides having great resistance to fracture, steel shot has been found to create less wear on peening equipment and greater economics of operation making it an important achievement in shot peening advancement.

Shot is classified in sizes normally ranging from .016 to .094 inches in diameter although standards have been established for shot .005 to .111 inches in diameter. Shot must be of uniform size, shape and hardness and be durable in order for peening to be effective. Broken, out-of-round, or undersized shot must be automatically removed from the system to ensure proper peening action. Shot hardness determines the amount and depth of compressive stress. In most cases, shot hardness should be equal to or harder than the part being treated unless surface finish is a concern.

Peening intensity depends on the mass of individual shot; therefore, it is important that shot used be of uniform size in order to obtain uniform peening action. Shot hardness must be uniform and shot shape must be spherical and uniform and without surface defects. The use of durable shot usually overcomes its extra cost resulting in greater overall savings.

Shot size has a different effect on the depth of the compressive layer on aluminum alloys than it does on any other metals. In steel and titanium, the depth of compression remains fairly constant with peening intensity regardless of shot size. An aluminum part, peened to a given Almen intensity, will have a deeper layer of compression stress when peened with larger shot than when peened with smaller shot at the same intensity.

Shot Peening Machines: Shot peening is generally carried out in a cabinet in order to confine the shot and the dust that occurs as a result of the process and to facilitate the collection and reuse of the shot. In full mass production mode, the work is automatically carried in and out of the enclosure by mechanical means with the area to be peened positioned in an easily accessible location.

Shot may be propelled by air, water, or by a wheel with velocities in the order of 200 fps. Air or water systems propel the shot through a nozzle while the wheel method slings the shot using a rotating vaned device.

The area impacted by the shot stream is called the shot pattern. In the case of a pneumatic delivery machine, shot is sprayed by a nozzle covering a circular target area of about 2 or 3 inches in diameter depending on nozzle size and distance to the work. The shot pattern from a wheel is fan shaped with the included angle of about 40 degrees, and width somewhat greater than the wheel width. The length and width of the pattern is governed by the distance of the work to the wheel.

A typical peening machine is made up of the following major systems:

- A cabinet to contain the work piece including various shot delivery and recovery as well as dust and debris removable systems
- Conveyer system to transport the work in and out of the cabinet and/or a mounting device to position the work to be shot peened
- A shot handling system for delivering shot and accurately propelling it to the target
- A device to return the shot that has been used in the peening process to be recycled
- Separator to remove broken or undersized recycled shot
- Device to replace broken or undersized shot with new material
- System to collect and remove dust and debris from the cabinet

Shot peening machines may be classified into two major categories depending on the system used to deliver and propel the blast to the target area. They are:

- Air Blast Machines
- Centrifugal Blast Machines

<u>Air Blast Machines</u>: There are three different types of air blast machines depending on the method used to introduce the shot into the air stream:

1. Suction Induction Air Blast Machine: In this type of machine, a gun is used which has two inlet ports and one outlet nozzle. One inlet port receives and sends compressed air out the nozzle. At the same time, the pressurized air draws shot through the second inlet port from a lower storage bin and propels it to the target. This is the simplest type and is used to peen small parts or small quantities, or when the required intensity is low. It is used for laboratory work or for other applications where the shot size is changed frequently.

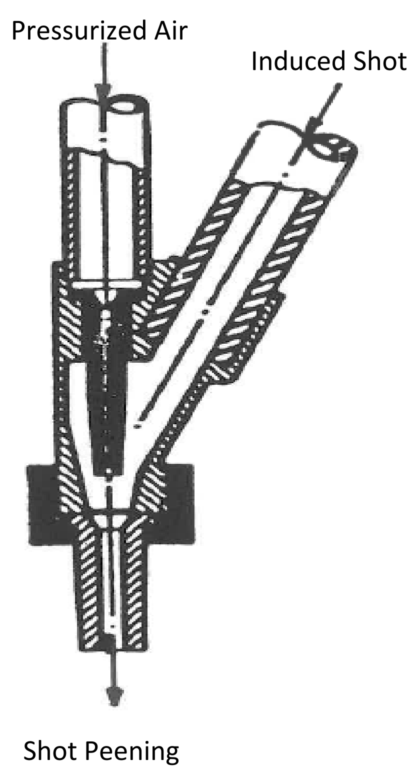
2. Gravity Induction Air Blast Machine: In this type of machine, the same nozzle is used; however, the shot is delivered to the nozzle by means of

gravity from an upper storage bin. This results in better control of the shot velocity and flow rate. These machines are used when the vacuum through the nozzle created by the flow of pressurized air is not great enough to lift the shot from a lower storage bin.

3. Direct Pressure Air Blast Machine: In this type of machine, the shot is stored in a vessel at the same pressure that air is sent to the nozzle in the above induction machines. The air-shot mixture is delivered to the nozzle which directs it to the target. This system allows greater freedom of movement of the nozzle and is used to peen smaller areas such as fillets at higher intensities. The nozzle in the gun used in all three air blast machines experiences wear from the abrasive action of the shot and has to be replaced periodically. Air blast guns have been developed with improved nozzles that provide a uniform shot stream for longer periods of time than previously used nozzles (See Figure 5).

Figure 5

Shot Peening Gun

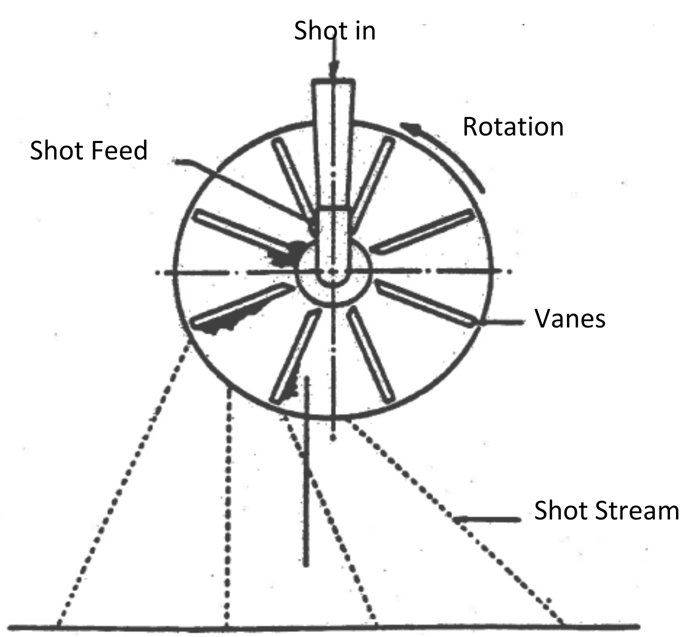


Centrifugal Blast Machines: In this class of machine, the shot is propelled by centrifugal force. The shot is gravity fed to the hub of a rotating wheel which has radial vanes or blades where it is propelled to the target. The spray pattern, instead of being circular like that of air blast nozzles, is somewhat rectangular for covering different shaped targets (See Figure 6).

High Frequency Impact Treatment (HiFIT): HiFIT involves using an air-operated handgun with a 3 millimeter (0.118 inch) hardened ball attached at the end to impact the work piece at an adjustable frequency rate of 180 to 300 Hertz (cps). Many times the durability and life of structures are determined by the strength of the welds. HiFIT has found exceptional use on welded structures, both new and existing, by strengthening the critically stressed extreme edges (toe) where the weld thins out and meets the parent material. HiFIT creates a track of local deformations plastically deforming and bonding the toe to the parent metal creating an area of induced compressive stress. At institutional testing, it was shown that HiFIT increases the fatigue strength of welds by 80 to 100 percent and an increase in weld life of 5 to 15 fold. The advantages of HiFIT are that it is simple, portable, effective, reliable and economical.

Figure 6

Shot Peening Wheel



Laser Shock Peening: The Laser Shock Peening system produces compression with minimum cold working using shock waves to yield the material. High speed, high powered lasers are used to focus a short duration energy pulse on a coating applied to the work piece, usually black tape, to absorb the energy of the laser beam. A transparent layer, usually water flowing over the tape, allows the laser beam to pass through but acts as a barrier to the resultant shock wave. When the laser is fired, the beam passes through the water exploding the tape and creating a shock wave that is confined by the water barrier and directed into the work piece, thereby cold working an indentation of approximately one millimeter (.039 inches). The procedure is continued across the surface of the work piece creating a serious of computer controlled slight depressions resulting in a region of subsurface compressive stress. Laser shock peening has been applied to a variety of alloys used in aircraft engines and airframes as well as other engineering applications. Although limited by cost, quality control and logistics, laser peening has been applied successfully to improve the damage tolerance to compressor blade leading edges.

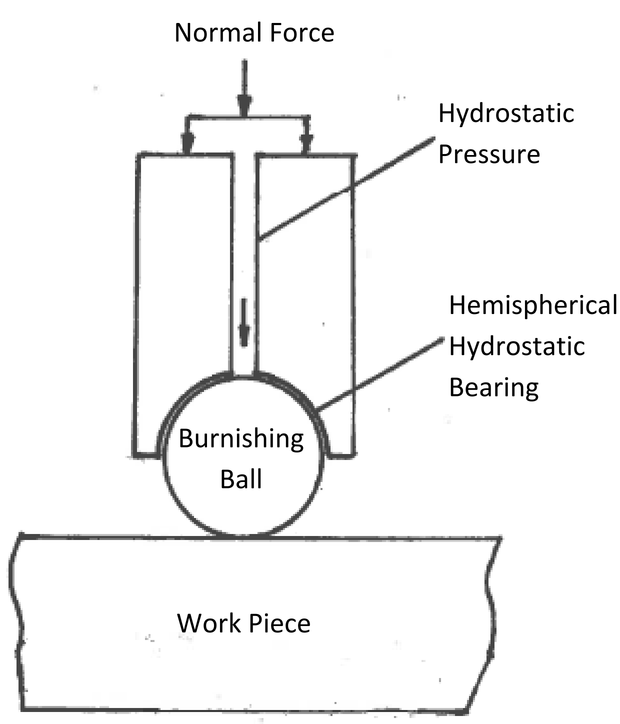
One advantage of laser peening is that the depth of compressive stress exceeds that of shot peening with less cold working (i.e., shallower indents). Also the compressive stress tends to be maximum at the surface and diminishes nearly linear with depth. The minimum of cold working provides thermal and mechanical stability in high temperature applications or where there may be momentary overload due to impact (birds drawn into aircraft turbine engines).

Disadvantages with laser peening include a clean room environment and a one million dollar equipment installation. Laser peening requires repeated operations with newly applied tape to obtain the correct compressive stress depth. Laser peening can cost multiple times the cost of shot peening.

Low Plasticity Burnishing (LPB): LPB encompasses applying pressure to a rolling ball (or roller) over the surface to be treated with sufficient normal force to deform the surface layers. The basic LPB tool is a ball supported in an overhead hemispherical hydrostatic bearing. The tool can be mounted in a lathe or a Computer Numerical Control (CNC) machine where a machine tool coolant is used to pressurize the hydrostatic bearing, thereby preventing the ball from contacting the metal bearing seat (See Figure 7). The ball is loaded in a normal direction down on the surface of the work piece with a hydraulic cylinder which is in the body of the tool. The ball rolls across the surface of the work piece in a pattern established by the CNC or any other machine being used. Since the lateral force being applied to the ball is through a thin layer of hydrostatic fluid, the ball is free to roll in any direction. As the ball rolls over the work piece, the normal force applied by the ball causes plastic deformation to occur in the surface of the work piece underneath. Since the surrounding material in the work piece tend to return the plastically deformed material back to its original configuration, the deformed area is put in a state of compressive stress. The pattern of the residual stress is designed to increase the performance of a part against the effects of fatigue failure and stress corrosion. LPB removes no material, smooth's asperities, and leaves the work piece with an almost mirror-like finish.

Figure 7

Low Plasticity Burnishing Tool



The cold working produced by LPB is minimal compared to shot peening, laser peening or deep rolling. A minimal amount of cold working results in improved performance at elevated temperatures and mechanical overload conditions, both which tend to relieve compressive stress that is cold worked into components by the other above-mentioned surface treatments. LPB has been used on turbine engines, piston engines, propellers, landing gear, biomedical implants (knee replacements) and welded joints. The applications involve titanium, iron, nickel and steel-based components.