Shot Peening

*By the ASM Committee on Shot Peening**

SHOT PEENING is a method of cold working in which compressive stresses are induced in the exposed surface layers of metallic objects by the impingement of a stream of shot, directed at the metal surface at high velocity and under controlled conditions. It differs from blast cleaning in primary purpose and in the extent to which it is controlled to yield accurate and reproducible results. Although shot peening cleans the surface being peened, this function is incidental; the major purpose of shot peening is to increase fatigue strength. The process has other useful applications, such as relieving tensile stresses that contribute to stress-corrosion cracking, forming and straightening of metal parts, and testing the adhesion of silver plate on steel.

Peening Action

When individual particles of shot in a high-velocity stream contact a metal surface, they produce slight, rounded depressions in the surface, thus stretching it radially and causing plastic flow of surface metal at the instant of contact. The effect usually extends to about 0.005 to 0.010 in. below the surface; the metal beneath this layer is not plastically deformed. In the equilibrium that results after the shot bounces off, the surface metal is in residual compression parallel to the surface, while the metal beneath is in tension. The surface compressive stress may be several times greater than the tensile stress; this compressive stress offsets an imposed tensile stress, such as that encountered in bending, and markedly improves fatigue life of the parts in service.

The peening action improves the distribution of stresses in surfaces that have been disturbed by grinding, machining or heat treating. It is particularly effective on ground surfaces, because it changes to beneficial compressive stresses the residual tensile stresses that grinding usually imposes in a metal surface. Shot peening is especially effective in reducing the deleterious stress-concentration effects of notches, fillets, forging pits, surface defects, and decarburization.

Strain Peening. The magnitude of residual stress that can be induced by shot peening is limited; in hard metals, it is slightly more than half the yield strength. A higher residual stress, approaching the full yield strength, can be obtained by strain peening, which consists of peening the surface while it is being strained in tension. The effectiveness of strain peening is limited to parts, such as springs, that are subjected to unidirectional service loads.

Table 1. Standard Size Specifications for Cast Shot (SAE J444)

Size No.	Screen tolerances(a)	Screen opening, in.
S1320	All pass No. 4	0.1870
	90% min on No. 6	0.1320
	97% min on No. 7	0.1110
S1110	All pass No. 5	0.1570
	90% min on No. 7	0.1110
	97% min on No. 8	0.0937
S930	All pass No. 6	0.1320
	90% min on No. 8	0.0937
	97% min on No. 10	0.0787
S780	All pass No. 7	0.1110
	85% min on No. 10	0.0787
	97% min on No. 12	0.0661
S660	All pass No. 8	0.0937
	85% min on No. 12	0.0661
	97% min on No. 14	0.0555
S550	All pass No. 10	0.0787
	85% min on No. 14	0.0555
	97% min on No. 16	0.0469
S460	All pass No. 10	0.0787
	5% max on No. 12	0.0661
	85% min on No. 16	0.0469
	96% min on No. 18	0.0394
S390	All pass No. 12	0.0661
	5% max on No. 14	0.0555
	85% min on No. 18	0.0394
	96% min on No. 20	0.0331
S330	All pass No. 14	0.0555
	5% max on No. 16	0.0469
	85% min on No. 20	0.0331
	96% min on No. 25	0.0280
S280	All pass No. 16	0.0469
	5% max on No. 18	0.0394
	85% min on No. 25	0.0280
	96% min on No. 30	0.0232
S230	All pass No. 18	0.0394
	10% max on No. 20	0.0331
	85% min on No. 30	0.0232
	97% min on No. 35	0.0197
S170	All pass No. 20	0.0331
	10% max on No. 25	0.0280
	85% min on No. 40	0.0165
	97% min on No. 45	0.0138
S110	All pass No. 30	0.0232
	10% max on No. 35	0.0197
	80% min on No. 50	0.0117
	90% min on No. 80	0.0070
S70	All pass No. 40	0.0165
	10% max on No. 45	0.0138
	80% min on No. 80	0.0070
	90% min on No. 120	0.0049

(a) Maximum and minimum cumulative percentages (by weight) allowed on screens of numbers and opening sizes as indicated.

Types and Sizes of Shot

Shot used for peening is generally of iron or steel, although some nonferrous and nonmetallic materials also are used. Shot is designated by numbers according to size; shot numbers, as standardized by SAE J444, range from S70 to S1320. The shot number is approximately the same as the diameter of the individual pellets in ten thousandths of an inch. Standard size specifications for cast shot (both iron and steel) are given in Table 1.

Cast steel shot is made by blasting a stream of molten steel with water (often called "atomizing"), and thus forming globules that rapidly solidify into nearly spherical pellets. The pellets are screened for sizing, reheated for hardening, quenched, and tempered to the desired hardness. According to SAE J827, 90% of the hardness measurements made on a representative sample should fall within the range of Rockwell C 40 to 50.

Cast steel shot is now the most widely used peening medium. With suitable heat treatment, cast steel shot has a useful life many times that of cast iron shot. Its improved impact and fatigue properties markedly lower the rate of shot breakage, thereby increasing peening quality and extending the life of components of peening machines.

Cast iron shot (white cast iron or malleable iron) ranges in hardness from Rockwell C 20 to 60 (or higher).

White cast iron (chilled iron) shot may be used in applications that require a peening medium of low initial cost. This type of shot is brittle, with an as-cast hardness of Rockwell C 58 to 65, and breaks down rapidly. However, its inherently high hardness yields higher intensities for a given shot size, in comparison to softer materials. A high rate of shot breakage complicates the control of peening quality and increases the cost of machine maintenance.

Malleable iron shot is used on a limited scale for shot peening. In initial cost and useful life, it ranks between cast steel and chilled iron shot. Usually, its hardness ranges either from Rockwell C 20 to 30 or from 35 to 45. In the annealed condition, malleable iron shot is softer than cast steel shot and leaves a carbon residue on the workpieces.

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Table 11. Vibratory Finishing of Machined Parts (Example 13)

Part		Purpose of treatment	Medium	Load(a)		Vibrations per minute	Cycle time, min
Material	Diameter, in.			No. of parts	Ratio (b)		
Nickel silver	1	Deburr	Steel pins; quartz sand	650	4 to 1	1500	40
Brass	1½	Deburr; radius	Steel wire brads	500	2 to 1	1300	60
Brass	3	Deburr; finish	Arkansas stone(c)	150	10 to 1	1500	35

(a) Capacity of vibrator bowl, 1 cu ft. (b) Parts to medium (by vol). (c) A form of novaculite.

castings 5 by 5 by 1½ in. deep. Fifty of these castings are vibrated simultaneously in a 7½-cu-ft unit.

Size of parts is less critical for symmetrical shapes than for complex shapes. However, as a general rule, a part having a volume equivalent to one-fifth that of the processing container can be satisfactorily finished.

Shape of Part. Although many parts can be processed satisfactorily in either conventional barrel or vibratory units, shielded areas or blind holes are not reached by barrel finishing. Parts such as textile machine needles that are 2½ in. long with delicate 1/32-in. protrusions would be ruined in a conventional barrel but can be processed successfully in a vibratory unit.

Metal tubes with internal piercing burrs are another example of parts that would not respond acceptably to conventional barrel finishing. Small gears that have both external and internal teeth are particularly suited to vibratory finishing, whereas conventional barrel finishing could not produce acceptable results.

Processing Examples. In numerous instances, vibratory finishing is successfully employed to achieve acceptable results when these cannot be obtained by conventional barrel finishing methods. Three such instances, in which a substantial saving in time also was realized, are described in the following examples.

Example 9. Universal-joint yokes (weight, ¼ to ½ lb) that required deburring were barrel tumbled for 8 hr; burrs were merely rolled over, without being removed. In a vibratory unit, however, the burrs were completely removed in 1 hr.

Example 10. Barrel finishing for 6 hr, although successful in removing burrs from ¼-in. wobble cones, caused closing-in of keyways. When the cones were finished in a vibratory unit, deburring was accomplished without effect on the keyways, in 1⅓ hr.

Example 11. Investment cast nozzle diaphragms posed a serious finishing problem because of their intricate design. To attain required results around the airfoil surfaces and adjacent radii, each part required 2 hr of hand work. By fixturing the parts (six parts per load) so that their flat sides were parallel to the ends of a vibrating container and then vibrating for 3 hr, the hand work was reduced to 45 min for each part.

The two examples that follow describe typical cycle times and other operating conditions employed in vibratory finishing of nonferrous metal parts.

Example 12. Identical processing conditions, except for the use of different compounds, are employed for cutting down aluminum castings and aluminum cases in a vibratory finishing machine. Castings are 11.687 by 4.531 by 6.000 in., with 0.250-in. side walls; cases are 10.187 by 7.500 by 6.000 in. Castings are processed separately from cases; two parts of each type are finished during each cycle, which is of 15 min duration. Triangular (0.375-in. sides) alumina chips, about 0.125 in. thick, are used as the medium; 550 lb of these chips are used with each load, together with 5 gal of water and 1 lb of compound. For castings, a dry, nonabrasive, water-soluble lubricating compound is used; for the cases, a liquid cleaner. The machine frequency employed is 2800 vibrations per minute.

Example 13 (Table 11) outlines typical conditions employed in performing deburring and other finishing operations on nickel silver and brass machined parts of various diameters, using vibratory methods. A comparison of the vibration frequencies and cycle times indicated in Table 11 with those employed for aluminum parts in Example 12 shows an inverse relationship to exist between these variables.

Causes of Problems. Some common causes of sluggish, ineffective vibratory action are:

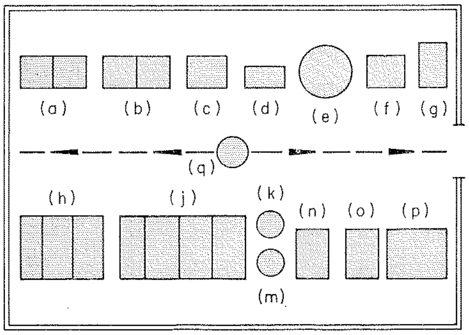
1 Water level is too high, resulting in excessive dampening.
2 Use of wrong type of compound or too much compound, or both; excessive lubrication may cause slippage of mass.
3 Frequency of vibratory action may not be correct or may not be coordinated with other processing variables.
4 Vibratory action is excessive for the volume or mass being processed or for the size of the equipment.
5 Stroke amplitude is too great.
6 Equipment is underpowered and therefore does not develop enough vibratory action for effective performance.

Unacceptable finishes may be the result of:

1 Insufficient cutdown of surface
2 Unsuitable medium for surface hardness of workpieces
3 Dirt load being too great, thus allowing refuse in solution to work back into surface of parts
4 Insufficient flushing and cleaning of medium from processing tub
5 Use of wrong type of finishing compound
6 Vibratory action too harsh
7 Work load too large for amount of medium
8 Careless handling in auxiliary operations.

Finishing Room Layout

The most efficient layout for a finishing room in any specific plant is, of necessity, determined by type, size and flow of work. A typical layout is shown in Fig. 9; this arrangement has proved efficient in a plant that processes a wide variety of parts by both conventional barrel and vibratory methods.



(a) Variable-speed tumbling barrel with two 30-in. compartments. (b) Two-compartment vibratory finishing barrel. (c) 20-in. tumbling barrel. (d) Open vibrating tub. (e) Round vibrating tub. (f) Drying barrel. (g) Scales. (h) Storage for tote pans. (j) Storage for tumbling mediums. (k) Storage for compounds. (m) Storage for compounds. (n) Magnetic separator. (o) Vibrating separator. (p) Rust-inhibitor dip tank. (q) Traveling crane hoist.

Fig. 9. Suggested arrangement of equipment for a barrel (and vibratory) finishing department. Good lighting and drainage are essential services.

Definitions of Terms Relating to Barrel Finishing*

abrasive compound. A compound, usually a dry powder and containing one or more types or sizes of abrasive grain and chemicals, used for *grinding* or deburring with a natural stone *medium* or for self-tumbling.

alkali compound. A chemical compound designed to keep parts clean during *cut-down.*

brightening. Removal of dull or dark surface condition by the use of a *descaler* after extended *cut-down* runs to restore *color.*

burnishing. Polishing to improve *color* and *luster,* usually following *cut-down* runs. Can be applied to operations in any *medium.*

burnishing balls. Balls or other shapes, usually of hardened steel, used with a compound to create a brilliant finish.

burnishing compound. A special chemical compound, usually in powdered form, for producing high *color* and *luster* on parts.

charge. Total amount of work, compound, and medium loaded in a barrel.

color. The actual color of a metal as differentiated from the *luster* of its surface.

cut-down. An abrasive run for deburring, *radiusing,* or removal of heavy tool marks.

descaler. An acid compound used for *descaling* and *brightening.*

descaling. Removal of heat treating scale by processing with an acid compound.

diagonals. Round steel or zinc wire cut at a 45-degree angle into sections as long as the diameter of the wire.

dimensional separator. A mechanical device for separating from the *medium* parts that cannot be separated magnetically or by screening. Also used for grading abrasive mediums and for separating part from part.

fines, abrasive. Fused-alumina abrasive of 120-mesh and finer particle size.

grading. Separation of various sizes of a *medium* into standard size ranges by screening or dimensional separation.

grinding. A term applied to a barrel finishing operation requiring heavy stock removal.

high water. Water several inches above the top of the *charge.*

impinging. Bumping together of parts (resulting in nicks or scratches) while barrel is in operation or during loading or unloading of the *charge.*

layer on layer. Method of loading critical parts and *medium* in alternate layers.

level water. Water level with top of *charge.*

lodging. The wedging of particles of *medium* into holes or crevices.

low water. Water level two or more inches below the level of the *charge.*

luster. The reflective brilliance of the surface.

magnetic separator. A separating device, usually equipped with an automatic demagnetizer, for separating magnetic parts from nonmagnetic *mediums,* or vice versa.

masking. Plugging or covering holes, crevices, and other recesses, to prevent *lodging* or to protect critical areas.

medium. Any material, usually abrasive, used to perform work on the parts and with sufficient bulk to keep the parts from *impinging.*

neutralizer. An alkaline compound used to neutralize the load following operation employing an acid compound.

peen. To pound down or roll over burrs, rather than grinding them off.

radiusing. Breaking sharp edges and creating radii to specifications.

riddle. A hand-screening unit for separating work from *medium* or for grading chips.

rinsing. Flushing residue from the *charge* before proceeding to the next operation or before adding new compound.

screen separator. A separating device employing screens of various-size openings for separating parts from *medium.*

*SOURCE: "Barrel-Finishing", Norton Co., 1961

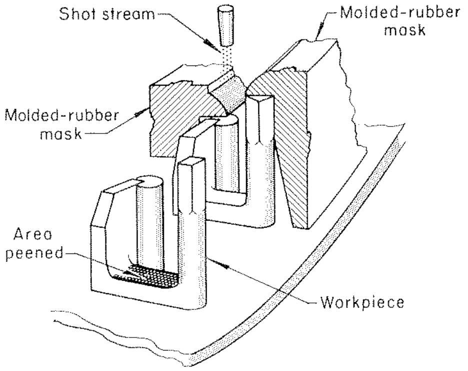


Fig. 3. Example of the use of a special mask, made of molded rubber, for shot peening of a selected area. The mask serves also to hold the work during peening.

Stop-Offs. Various methods and materials have been developed for masking parts that require shot peening on localized areas only. Masking with tape is economical when low production quantities are involved, but its cost is prohibitive on a large-quantity basis.

When fabrication of special masks is warranted, the masks usually are designed to serve as holding fixtures as well as stop-offs. Ordinarily, masks of this type are made of molded rubber (Fig. 3), although large parts sometimes are protected with masks made of steel, carbide or aluminum.

Testing. Control of the shot peening process depends on systematic, periodic testing to determine intensity, coverage, and other important control factors. Standardized equipment for measuring peening intensity is illustrated and described in SAE J442, of which a digest is given in the Appendix to this article.

Dry Peening With Glass Beads. The methods employed for dry peening with glass beads are comparable to the methods that employ dry metallic shot. However, the problem of separating broken particles of glass is quite different and requires special methods of handling.

Wet Peening With Glass Beads. Wet glass peening is performed with very fine glass particles, usually mixed in water and contained in a suitable hopper. In the automatic machine shown in Fig. 4, a mixer pump maintains a mechanical suspension of glass in water, and a feed pump forces the flow of slurry to the nozzle. The movement of the slurry through the nozzle is accelerated by compressed air. The nozzles are attached to an oscillating bar that directs the flow of slurry at the workpiece. After making contact with the workpiece, the slurry is fed back to the hopper and recycled.

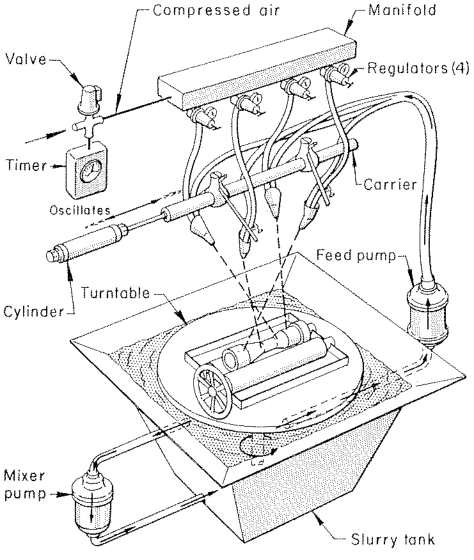


Fig. 4. Automatic machine for wet peening with glass beads. See text for discussion.

The principal controls in wet peening with glass are similar to those used in conventional shot peening. The peening pattern of the slurry is controlled by the oscillating nozzles. Air pressure is controlled at each nozzle by separate regulators. Exposure time for the peening cycle is controlled by automatic timing devices. Because of the high fracture rate of glass particles, the separation of broken glass is particularly important if peening effectiveness is to be properly maintained.

Control of Process Variables

Major variables in the shot peening process are shot size and hardness, shot velocity, peening intensity, surface coverage, angle of impingement, and shot breakdown. The quality and effectiveness of peening depend on the control of each of these interdependent variables.

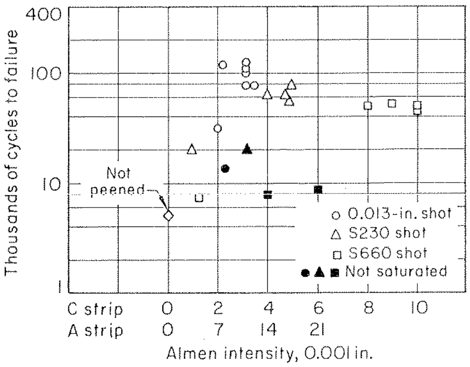


Fig. 5. Effect of shot size and peening intensity on fatigue life of steel leaf springs. Each point on the graph represents the average of four specimens. (R. L. Mattson and W. S. Coleman, Trans SAE, 62, 546; 1954)

Size of Shot. When other factors, such as shot velocity and exposure time, are constant, an increase in shot size will result in an increase in peening intensity and a decrease in coverage. In peening steel leaf springs, moderate variations in shot size do not produce significant differences in peening effectiveness as measured by fatigue strength (Fig. 5). Thus, it is common practice to select the minimum shot size capable of producing the required intensity in order to take advantage of the more rapid rate of coverage obtained with smaller shot.

The selection of a particular shot size may be dictated by the configuration of the part to be peened. In shot peening the fir-tree serrations of steel compressor blades, for example, complete coverage can be obtained only if the radius of the shot does not exceed the radius of the serrations. The same principle applies to the selection of shot size for peening the root radius of threads.

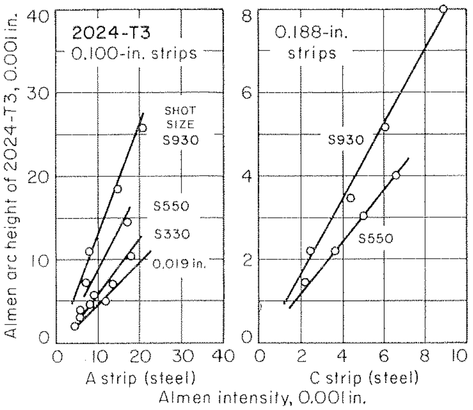


Fig. 6. Relation of standard peening intensity to curvature produced on aluminum strips with shot of different sizes (H. O. Fuchs, ASTM STP 196; 1957)

In peening aluminum, a larger shot size than that required to achieve the desired intensity may be used to enhance surface appearance and to increase depth of penetration. When surface appearance is significant, it is customary to specify a minimum shot size for aluminum parts. At the same intensity, the peening effect on aluminum increases with an increase in shot size. Figure 6 shows the relationship between intensity (as measured using standard steel Almen test strips) and the curvatures (Almen arc heights) produced on 2024-T3 aluminum strips with different shot sizes.

Hardness of Shot. Variations in the hardness of shot do not affect peening intensity, provided the shot is harder than the workpiece. If the shot is softer than the workpiece, a decrease in shot hardness will result in a decrease in intensity.

Velocity of Shot. Peening intensity, as measured by arc height, increases with velocity. However, when velocity is increased, the increase in rate of shot breakdown usually offsets the increase in peening intensity obtained.

Peening intensity is governed by the velocity, hardness, size and weight of the shot pellets and by the angle at which the stream of shot impinges against the surface of the workpiece. Intensity is expressed as the arc height of an Almen test strip (see Appendix) at full coverage. Arc height is a measure of the curvature of a test strip that has been peened on one side only. Assuming full coverage (saturation) of the Almen strip, it follows that arc height is a measure of the effectiveness of the peening operation on a specific part on a day-to-day basis. The Almen strip is the primary standard of quality control and should be used at regular intervals and in the same location in the peening machine. Used correctly, it will quickly indicate a reduction in intensity (lower arc height) caused by a reduction in wheel speed or a drop in air pressure, by excessive breakdown of shot, or by other operational faults, such as nonremoval of undersize shot.

Selection of Intensity. The lowest peening intensity capable of producing

Glass beads are used for peening stainless steel, titanium, aluminum, magnesium and other metals that might be contaminated by iron or steel shot. They are used also for peening thin sections. Relatively low intensities (seldom exceeding 0.006 A) are employed. Glass beads can be used in either wet or dry peening processes.

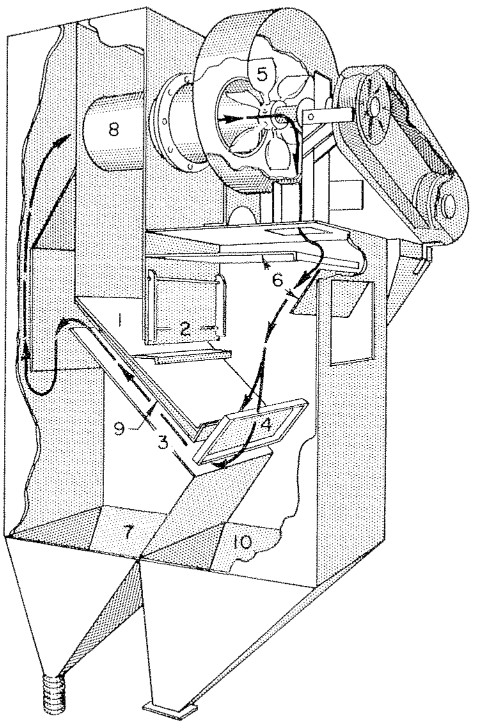
Equipment

The equipment used in shot peening is essentially the same as that used in abrasive blast cleaning, except for certain auxiliary equipment made necessary by the more stringent controls imposed in the shot peening process. For a description of basic blasting equipment, such as blast cabinets, wheels, nozzles and conveyors, see "Abrasive Blast Cleaning", page 364.

The principal components of shot peening equipment are a shot-propelling device, shot-cycling arrangements, and a work-handling conveyor. All portions of the equipment that are exposed to the stream of shot are enclosed, to confine the shot and permit it to be recycled.

Propulsion of Shot. Two methods of propelling the shot are widely used in shot peening: one employs a motor-driven bladed wheel rotating at high speed; the other, a continuous stream of compressed air.

In the wheel method, the shot is propelled by a bladed wheel that employs a combination of radial and tangential forces to impart the necessary peening velocity to the shot. The position on the wheel from which the shot is projected is controlled to concentrate the blast in the desired direction. Among the advantages of the wheel method of propulsion are easy control of shot velocity, high production capacity, and freedom from the moisture problem encountered with compressed air.



(1) Inclined shed. (2) Hinged, weighted gate. (3) Outlet for spent shot. (4) End baffle. (5) Fan. (6) Air baffles. (7) Settling hopper for spent shot. (8) Fan inlet. (9) Adjustable baffle. (10) Storage hopper for usable shot.

Fig. 1. Shot separator for use with a shot peening machine. See text for description.

The air-blast method introduces the shot, either by gravity or by direct pressure, into a stream of compressed air directed through a nozzle onto the work to be peened. Aside from being more economical for limited production quantities, the air-blast method can develop higher intensities with small shot sizes, permits the peening of deep holes and cavities (using a long nozzle), consumes less shot in peening small areas on intricate parts, and has lower initial cost — especially when a source of compressed air is already available.

Cycling of Shot. Equipment for shot cycling consists of devices for the separation and removal of fines and spent (broken or undersize) shot and for the addition of new shot.

The shot separator shown in Fig. 1 employs a closed air system, which maintains a constant velocity and volume of air throughout the separator and uniformly removes spent shot and fines. This unit operates as follows:

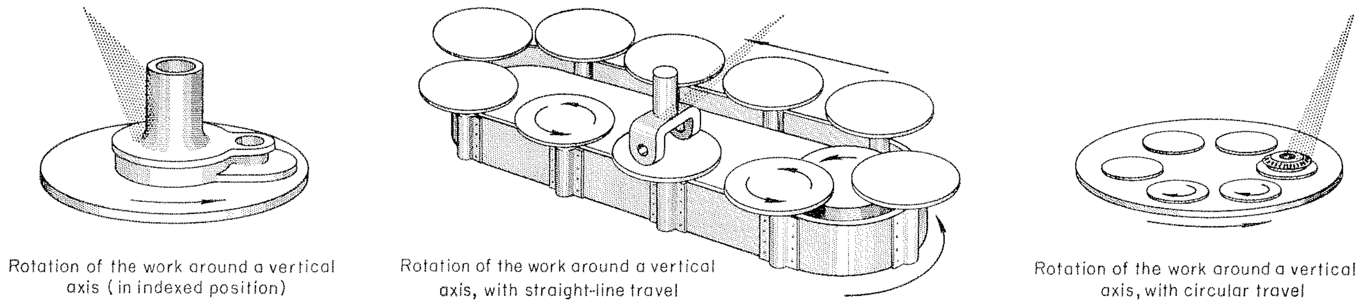
Incoming shot flows down the inclined shed (1). The hinged, weighted gate (2) insures an even distribution of shot across the shed and permits the flow of shot to vary according to the quantity being recirculated. The end baffle (4) forces all shot to pass directly past the opening (3).

An air current from the fan (5) passes through the baffles (6) and carries all particles of less than a predetermined mass through the opening and up the incline at (3) to hopper (7), where these particles settle out as a result of impingement on baffles and of the decrease in air velocity. The relatively clean air then passes upward to the fan inlet (8) and is recirculated. Usable shot is unaffected by the airstream and drops by gravity into the storage hopper (10) for re-use.

The effectiveness of the separator depends on careful control of the velocity of the air as it passes upward through the opening at (3). Velocity control is affected by two adjustments: the adjustable baffle (9), which changes the size of the opening at (3); and the variable-speed drive on the fan, which controls the pressure differential between hoppers (7) and (10).

Shot-adding devices automatically replenish and maintain an adequate quantity of shot in the machine at all times. They are equipped with a capacitance-type switch, or similar device, to control the level of shot in the storage hopper and to add shot, as required, from a supply hopper.

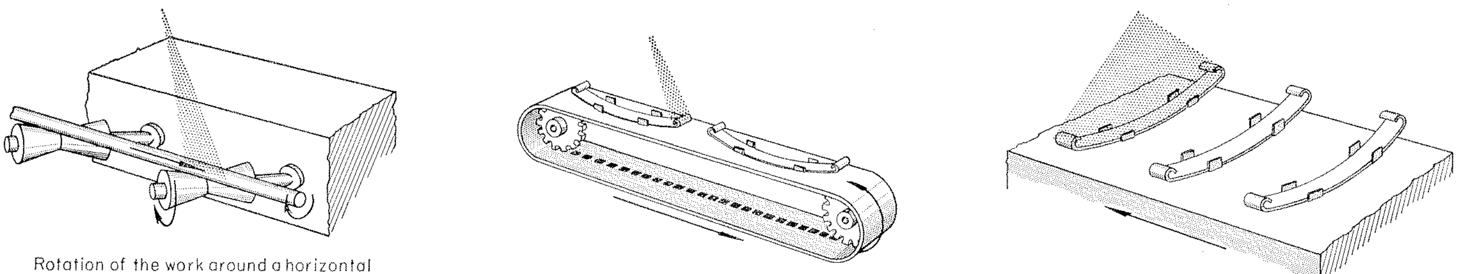
Work Handling. The effectiveness of shot peening depends largely on peening intensity, and it is essential that all critical areas of a part be adequately exposed to the blast stream. Proper exposure is facilitated by the use of efficient work-handling fixtures, conveyors and mechanisms. Figure 2 shows six types of work-handling mechanisms, which incorporate several basic motions for effective exposure of parts of a variety of shapes.



Rotation of the work around a vertical axis (in indexed position)

Rotation of the work around a vertical axis, with straight-line travel

Rotation of the work around a vertical axis, with circular travel



Rotation of the work around a horizontal axis, with straight-line travel parallel to the axis of rotation

Straight-line travel of the work, with no rotation

Straight-line travel of the work, in a transverse direction

Fig. 2. Examples of motion and fixturing used in work-handling equipment for shot peening

the use of hot forming; cold forming produced surface tensile stresses of 20,000 psi or more, which were alleviated by shot peening the panels on the tension side. Proper curvature of the panels could be obtained by shot peening alone, with careful control of intensity. The need for conventional cold forming methods was thereby avoided, and the high compressive stresses induced by peening virtually eliminated the possibility of fatigue failures.

Other parts that have been successfully formed by peening techniques include precision collets, honeycomb panels, and large aluminum tubes that were pre-formed in halves in a press brake and peened to the desired diameter.

Straightening and the correction of distortion by peening have been employed in salvaging expensive parts.

Example 2. Large ring gears (36-in. OD by ¾ in. thick) developed ⅛-in. out-of-roundness as a result of heat treating; shot peening restored the gears to within 0.005 in. of perfect roundness.

Example 3. Shafts 2-in. OD by 80 in. long developed a ¾-in. bow, which was straightened to within 1/32 in. by shot peening.

Improving Resistance to Stress Corrosion. Stress corrosion is a complex interaction of sustained tensile stress at the surface and corrosive attack that can result in brittle failure of a ductile material. Cracking due to stress corrosion has been associated with several metals, including brass, stainless steel, aluminum, zinc and magnesium. The surface tensile stresses that give rise to stress corrosion can be effectively overcome by the compressive stresses induced by shot peening.

Table 3. Effects of Shot Peening on Stress-Corrosion Life of Various Alloys (Example 7)

Material	Type of solution to which exposed	Time to failure: Unpeened	Time to failure: Peened
Magnesium (AZ31B-H)	Potassium chromate and sodium chloride	110 sec	>10 days
Magnesium (AZ61A-H)	Potassium chromate and sodium chloride	9¼ min	430 hr
Brass cups, cold drawn	Ammonia	2½ hr	19 & 47 hr
Stainless steel (type 309)	Hydrated magnesium chloride	270 hr	>3000 hr

Example 4. A large 7079-T6 aluminum alloy die forging had a deep, moisture-retaining pocket machined in on the flash plane. The machining exposed grain flow normal to the surface, at which a residual tensile stress of about 50% of the yield strength was present.

In salt spray tests (MIL-Std-151) of four unpeened forgings, cracks were obtained in two forgings in 35 and 81 days; the other two forgings lasted 43 and 81 days without cracking. Two specimens peened at an intensity of 0.012 to 0.015 A with S230 cast steel shot each endured 81 days without cracks. When exposed to MIL-C-5410, a complex solution containing acids and organic solvents, an unpeened specimen cracked in 35 days, while a specimen peened as above endured 78 days with no cracks.

Example 5. Test bars 0.437 in. in diameter were cut in the short transverse direction from a 7075-T6 aluminum alloy hand forging and stressed to 75% of the yield strength. During alternate-immersion tests in 3½% NaCl solution, unpeened specimens failed in 1, 5, 5, 17, and 28 days, respectively. Specimens peened (in the unstressed condition) with S230 cast steel shot lasted 365 and 730 days — when failure occurred in the unpeened grip outside the test area.

During exposure to an industrial atmosphere, unpeened similar test bars failed in 20, 37, 120, and 161 days, respectively, while a peened specimen (same conditions as above) was uncracked when it was removed from testing after an exposure of 3111 days.

Example 6. Salt-fog tests on axial tension-test specimens of martensitic stainless steel showed that failure could be expected in a few days at stresses between 40,000 and 140,000 psi. Shot peened specimens stressed at 100,000 psi lasted 14 to 21 days, as compared to 2 to 4 days for unpeened specimens. At a stress of 60,000 psi, no failure of a peened specimen had occurred in 75 days, at which point the test was discontinued. It was concluded that peening was beneficial, but that it could not prevent stress corrosion at high stress levels.

Example 7. Table 3 presents stress-corrosion data indicating the life in various corrosive mediums of peened and unpeened specimens of magnesium alloys, brass and stainless steel. All these materials showed a high degree of improvement in resistance to stress corrosion as a result of peening.

Testing Adhesion of Silver Plate. The successful use of silver as a heavy-duty bearing material depends on a uniformly high-strength bond between the silver plate and the steel substrate. Controlling the integrity of the bond

Table 2. Effect of Shot Peening on Fatigue Strength of Aluminum Alloys and Carbon and Low-Alloy Steels

Metal tested	Type of specimen	Stress cycle	Surface condition as received	Peening conditions: Shot: Type	Peening conditions: Shot: Size No.	Peening conditions: Intensity, 0.001 in.	Fatigue strength, 1000 psi: As received	Fatigue strength, 1000 psi: Polished	Fatigue strength, 1000 psi: Peened	Strength gain by peening, %: Over as recd	Strength gain by peening, %: Over polished	Reference
Aluminum Alloys												
2014-T6	Plain, 1.5-in. diam	Reversed bending	Smooth turned(a)	Cast steel	S70	6 A	31(b)	....	38(b)	23	...	[1]
					S230	30 A	31(b)	....	38(b)	23	...	
					S550	13 A	31(b)	....	38(b)	23	...	
2024-T4	Plain, 1.5-in. diam	Reversed bending	Turned(a)	Cast steel	S230	10 A	26(b)	....	35(b)	34	...	[1]
7079-T6	Plain, 1.5-in. diam	Reversed bending	Turned(a)	Cast steel	S230	10 A	28(b)	....	36.5(b)	30	...	[1]
Carbon and Low-Alloy Steels												
5160 spring steel(c)	Flat leaf, 1.5 in. wide, 0.192 in. thick	Unidirectional bending	Machined before heat treatment(d)	Chilled iron	S230(e)	6 C(f)	128(g)	....	194(g)	51	...	[2]
					S230(e)	6 C(h)	128(g)	....	176(g)	37	...	
					S230(e)	6 C(j)	128(g)	....	141(g)	10	...	
1045 steel (165 Bhn)	Plain (R. R. Moore)	Rotating bending	Machined	Chilled iron	(k)	(m)	....	39.5(n)	43.8(n)	..	10	[3]
1045 steel (285 Bhn)	Plain (R. R. Moore)	Rotating bending	Machined	Chilled iron	(k)	(m)	....	80.7(n)	75(n)	..	—7	[3]
9260 steel (526 Bhn)	Plain (R. R. Moore)	Rotating bending	Machined	Chilled iron	(k)	(m)(p)	....	108.6(n)	106(n)	..	—2	[3]
Ingot iron (121 Bhn)	Plain (R. R. Moore)	Rotating bending	Machined	Chilled iron	(k)	(m)(p)	....	26.8(n)	27(n)	..	0.7	[3]
4340 steel (277 Bhn)	Plain (R. R. Moore)	Rotating bending	Machined	Chilled iron	(k)	(m)	....	66(n)	78(n)	..	18	[3]
4118 steel (R_C 60)	Single gear tooth	Unidirec. bending	Machined	Cast steel	S110	8 to 10A	2350(q)	....	3025(q)	29	...	[4]
8620 steel (R_C 58)	Single gear tooth	Unidirec. bending	Machined	Cast steel	S230	16 A	12,500(q)	....	15,250(q)	22	...	[4]
S-11 steel(r)	Grooved, 0.3-in. D(s)	Rotating bending	Machined	......	S280	(t)	38	....	61	62	...	[5]
0.54% C steel(u)	Plain, 0.315-in. diam	Rotating bending	Decarburized	Chilled iron	S460	19 A	44.5	....	68.5	54	...	[6]
	Plain, 0.236-in. diam	Reversed torsion	Decarburized	Chilled iron	S460	19 A	32.5	....	47	43	...	
0.54% C steel(u)	0.394-in.-diam bars:											
	Smooth	Rotating bending	Polished	Chilled iron	S460	19 A	84.5	....	87	3	...	[6]
	Round-notched(v)	Rotating bending	Machined	Chilled iron	S460	19 A	43	....	57	33	...	
	V-notched(w)	Rotating bending	Machined(x)	Chilled iron	S460	19 A	27	....	47	73	...	
Music wire(y)	Coil spring	Not reversed	....	......	S110	....	120(z)	....	190(z)	58	...	[7]
4340 steel(aa)	0.560-in. diam(bb)	Reversed torsion	Smooth turned	Cast steel	S170	8 A	40(g)	....	75(g)(cc)	87	...	[8]
4340 steel(dd)	0.250-in. diam(bb)	Rotating bending	Highly polished	......	....	10 A	83	39(ee)	98(ff)	..	150	[9]
4340 steel(gg)	0.250-in. diam(bb)	Rotating bending	Highly polished	......	....	10 A	105	55(ee)	103(ff)	..	87	[9]

Lettered Footnotes for Table 2

(a) 20 micro-in. (b) Typical values at 1,000,000 cycles. (c) Oil quenched and tempered at 770 F; hardness, Rockwell C 46 to 50. (d) 7 to 12 micro-in. (e) Shot peened only on side subjected to tension in fatigue test. (f) Peened under a strain of +0.60 (180,000 psi). (g) Fatigue limit based on 5,000,000 cycles. (h) Peened under a strain of +0.30 (90,000 psi). (j) Peened under zero strain.

(k) Equal parts of S170 and S280. (m) Depth of cold work (peening), 6 mils. (n) Fatigue limit based on 10,000,000 cycles. (p) Stress relieved at 400 F for 20 min after peening. (q) Fatigue limit in pounds load based on 5,000,000 cycles. (r) 3% Ni – Cr steel, oil quenched from 1525 F, tempered at 1110 F; tensile strength, 135,000 psi. (s) 0.031-in. semicircular groove. (t) Air pressure, 50 psi. (u) Tensile strength, 205,000 psi. (v) Notch depth and radius, 0.040 in. (w) Notch depth, 0.040 in.; radius, 0.002 in. (x) Root of notch not hit by shot. (y) 0.039-in. diam. (z) For 400,000-cycle life. (aa) Tensile strength, 270,000 psi. (bb) Chromium plated. (cc) Same value obtained for peened and chromium plated; not peened and plated, less than 40,000 psi. (dd) Tensile strength, 220,000 psi. (ee) Fatigue limit for chromium plated and baked. (ff) Fatigue limit for peened, chromium plated, and baked. (gg) Tensile strength, 288,000 psi.

Numbered References for Table 2

[1] G. A. Butz, unpublished data. [2] R. L. Mattson and J. G. Roberts, "The Effect of Residual Stresses Induced by Strain-Peening Upon Fatigue Strength", Internal Stresses and Fatigue in Metals; Elsevier, Amsterdam, 1958. [3] J. M. Lessells and W. M. Murray, Proc ASTM, 41, 659 (1941). [4] J. A. Halgren and D. J. Wulpi, Trans SAE, 65, 452 (1957). [5] W. J. Harris, "Metallic Fatigue", Pergamon, 1961.

[6] S. Takeuchi and M. Honma, "Effect of Shot Peening on Fatigue Strength of Metals", Reports of the Research Institute for Iron, Steel and Other Metals, Tohoku University, Sendai, Japan, 1959. [7] H. C. Burnett, Proc ASTM, 58, 515 (1958). [8] "Effect of Chromium Plate on Torsion Fatigue Life of Shot Peened 4340 Steel", Douglas Aircraft Co. Report No. MP 20,005 (Sept 13, 1960); available through SAE. [9] B. Cohen, "Effect of Shot Peening Prior to Chrome Plate on the Fatigue Strength of High Strength Steel", WADC Technical Note 57-178, U. S. Air Force, June 1957.

the desired effect is the most efficient and least costly, because it can be achieved with the minimum shot size in the minimum exposure time. Conversely, an intensity may be considered excessive if, as with very thin parts, it produces a condition in which the tensile stresses of the core material outweigh the beneficial compressive stresses induced at the surface. Figure 7 presents data, representative of current practice, that indicate the relation of peening intensity to cross-sectional thickness.

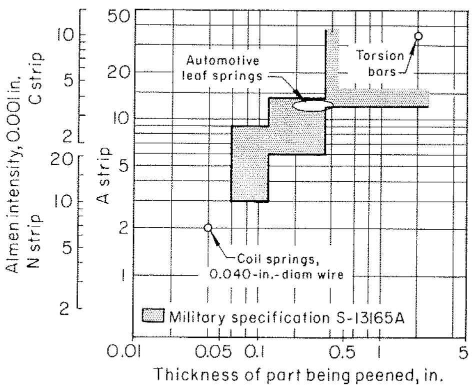


Fig. 7. Relation of peening intensity to cross-sectional thickness of parts peened

The depth of compressed layer produced by peening also may be a factor in the selection of peening intensity. For instance, a heavy steel component with a partially decarburized skin requires a peening intensity high enough to induce a compressive stress beneath the decarburized layer. The relation between peening intensity and depth of compressed layer for steel hardened to Rockwell C 31 and 52 is shown in Fig. 8.

Surface coverage (saturation) is a measure of how completely an area has been hit by the myriad of impinging shot particles. Without adequate coverage, the improvement in fatigue characteristics normally produced by shot peening (see Fig. 5 and Table 2) will not be obtained.

As stated in SAE J443, there is a definite and quantitative relationship between coverage and exposure time, which may be expressed as follows:

$$C_n = 1 - (1 - C_1)^n$$

where C_1 = % coverage (decimal) after 1 cycle, C_n = % coverage (decimal) after n cycles, and n = number of cycles.

This relationship indicates that coverage approaches 100% as a limit. It is difficult to obtain accurate measurements of coverage above 98%, but a measurement at a lower degree of coverage will serve as a means of determining the exposure time or equivalent required to obtain any desired coverage. Because accurate measurement can be made up to 98% coverage, this value is arbitrarily chosen to represent full coverage. Beyond this value, the coverage is expressed as a multiple of the exposure time required to produce 98%. For example, 1.5 coverage represents a condition in which the specimen or workpiece has been exposed to the blast 1.5 times the exposure required to obtain 98% coverage. Figure 9 shows the relationship between exposure time and coverage and indicates that after a measurement of a low percentage of coverage has been established, the correct exposure time for any percentage of coverage can be readily determined.

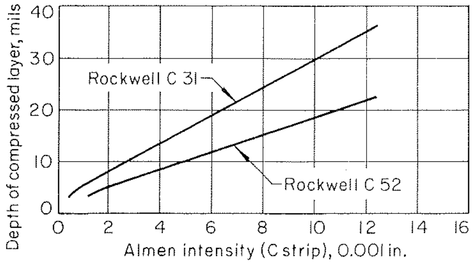


Fig. 8. Relation of depth of compressed layer to peening intensity for steel of two different hardnesses (Brodrick and Lessells, SAE Division 20, 1956)

Measurement of Coverage. Direct methods for measuring coverage include visual methods and the Straub method. Among the indirect methods are the Valentine method and methods (such as layer removal and x-ray diffraction) for determining the magnitude of residual stress, which can be related to peening coverage.

Visual methods, although not quantitative, are almost universally employed. The simplest of these consists of visual inspection, with or without the aid of optical magnification, of the surface of the peened part; this method may be supplemented by a series of reference photographs illustrating various percentages of coverage.

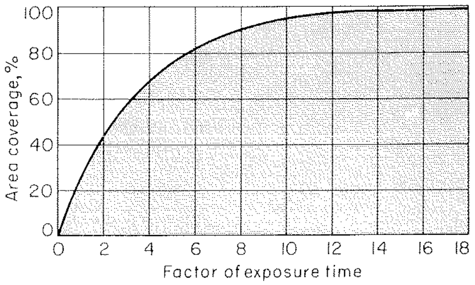


Fig. 9. Area coverage as a function of exposure time in shot peening

Another visual method consists of preparing a transparent plastic replica of the peened surface and comparing it, by means of photographic projection, with reference replicas having various percentages of coverage.

The Straub method consists of exposing a polished surface to the shot stream, projecting the surface at a magnification of 50 diameters on the ground glass of a metallographic camera, tracing the images of the indented areas on translucent paper, and measuring the total area and the indented area with a planimeter. Percentage of coverage is expressed as the ratio of indented area to total area multiplied by 100. About 15 minutes is required to make one measurement.

The Valentine method (Trans ASM, **40**, 420; 1948) consists of making a duplicate of the part from low-carbon steel, peening the part, annealing it for several hours to promote recrystallization and grain growth, and, by metallographic examination of cross-sectional areas, relating peening coverage to the amount and continuity of grain growth.

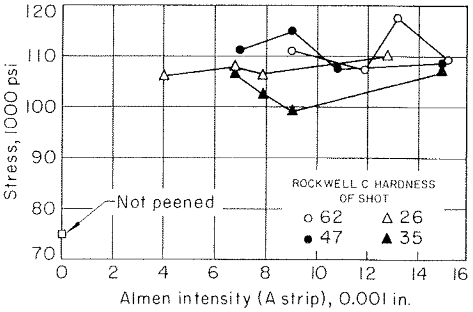


Fig. 10. Effect of hardness of shot on fatigue strength of coil springs of 0.148-in.-diam steel wire (F. P. Zimmerli, *Steel,* Oct 19, 1948)

Angle of Impingement. By definition, the angle of impingement is the angle (90° or less) between the surface of the workpiece and the direction of the blast. As this angle is decreased from 90°, peening intensity is reduced. Peening intensity varies directly as the sine of the angle of impingement. Therefore, when a low impingement angle is unavoidable, increases in shot size and velocity may be required to attain a desired intensity.

Breakdown of Shot. To maintain the required intensity and provide consistent peening results, a production peening unit must be equipped with a separator that will continuously remove broken or undersize shot from the system (see Fig. 1 and related text). Rate of removal should approximate the rate of wear and breakdown; the percentage of full-size shot in the system should never fall below 85%, and higher percentages are preferred.

Applications

Although the major application of shot peening is related to improvement of fatigue characteristics, other useful applications have been developed, such as metal forming, straightening, improving resistance to stress corrosion, and testing the adhesion of plated deposits of silver on steel.

Improving Fatigue Properties. The improvement in fatigue strength obtained on several aluminum alloys and carbon and low-alloy steels is indicated in Table 2, which lists the type and size of shot and the peening intensity employed on most of the materials and provides data on the fatigue test specimens, the type of fatigue test, and the surface condition of specimens.

Figure 10 shows the effect of peening on the fatigue strength of coil springs made of 0.148-in.-diam steel wire that were peened with shot of four different hardnesses and at various intensities.

Forming. Shot peening is well suited for certain operations in the forming of thin sections. It has been used to form (as well as strengthen) structural components of aircraft.

Example 1. Integrally stiffened aircraft wing panels machined from slabs of aluminum alloy 7075-T6 had to be curved for aerodynamic reasons. The large size of these panels (32 ft by 46 in.) precluded

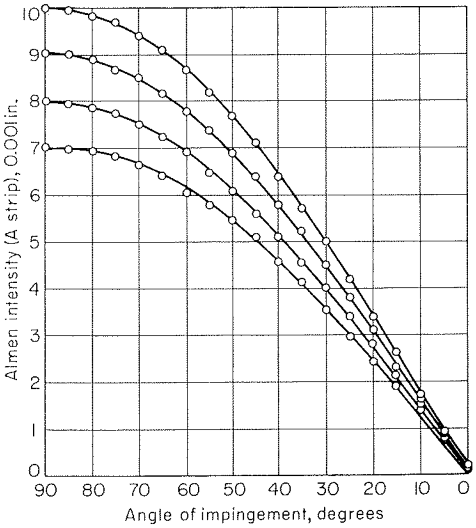


Fig. 14. Peening intensity as a function of angle of impingement (Example 11)

intensity indicated was measured at an impingement angle of 90°; the true intensity on various portions of the butt serrations was considerably less, depending on impingement angle. However, maximum intensity was obtained at the critical root radius, and the selection of an 83° impingement angle was calculated to have this effect. The relation between impingement angle and intensity is shown in Fig. 14.

Peening was performed in a gravity-feed, continuous-conveyor, production-type cabinet, using a ⅝-in. (bore diameter) nozzle, a 5/32-in. aspirator, 92-psi air-line pressure, and a shot flow of 7¼ lb per min. The distance from the nozzle to the work was set at 4 in. The cabinet conveyor moved at a fixed speed that exposed the work to the blast for a period of 5 sec.

The peening operation required two passes under the nozzle, one for each side of the blade butt. The airfoil sections of the blade were protected from the blast by a sheet rubber covering.

Costs

The cost of shot peening on a production basis depends on several factors, including the size, shape and hardness of parts, the total area to be peened, and required intensity and coverage. Shot type, size and velocity also influence costs, because they affect peening intensity, rate of shot breakdown, and the rate at which the desired coverage is obtained.

With an increase in shot velocity, the rate of shot breakdown increases far more rapidly than the intensity of the blast. However, the weight of a shot pellet varies directly, while the number of pellets per pound of shot varies inversely, with the cube of the diameter of the pellet. Consequently, for a given intensity, coverage is obtained much more rapidly with smaller shot and higher velocity. Because of these opposing factors, the number of pounds of shot used per part is virtually the same for various shot sizes, assuming similar intensity and coverage and good control of uniformity of shot size. The use of small shot at high velocity increases production rate and reduces labor costs.

Example 12 (Table 5) presents an analysis of the costs in one plant for shot peening forged gears of 8620 steel carburized (0.030-in. case depth) and hardened to Rockwell C 57. Peening was performed in a machine with two 30-hp wheels, which was equipped with an automatic system for handling and reclaiming shot and with a dust collector. Mounted on mandrels, the gears were automatically rotated and conveyed through the peening blast, which provided an intensity of 0.017 A and 98% coverage. Cast steel shot (size S230) with a hardness of Rockwell C 54 to 60 was used.

The cost data given in Table 5 are based on peening for 23 hr per day, 6 days per week, 50 weeks (6900 hr) per year. The high percentage of total cost represented by production labor cost is accounted for by the fact that the gears had to be loaded and unloaded individually by hand.

Example 13 (Table 6) shows the costs in one plant for peening automotive coil springs made of hot rolled 5160 steel rod 0.450 to 0.900 in. in diameter. These springs were 5¼ in. in diameter and up to 18 in. long. After being heat treated, they were peened with cut steel wire shot (which must be "preconditioned" to round off sharp edges, before use in peening) at an intensity of 0.016 A and 85% coverage.

The peening machine contained two 20-hp wheels, and was equipped with an automatic shot handling and reclaiming system and a dust collector. The springs were automatically rotated and conveyed through the peening blast. Loading and unloading of parts was automatic, also. One operator supervised three machines (hence the lower labor costs in comparison to those for the manual loading of gears described in Example 12). Cost data given in Table 6 are based on peening for 8 hr per day, 5 days per week, 5 weeks (2000 hr) per year.

Processing After Peening

Shot peening itself is a finishing treatment, and usually no further processing of peened work is required, except for the application of a rust preventive on low-alloy steels. The as-peened surfaces of these steels are clean and chemically active, and therefore highly susceptible to corrosion due to fingerprints and other contaminants. However, such surfaces are also highly receptive to oils for rust-prevention and lubrication and provide an excellent base for organic or inorganic coatings that do not require thermal treatment other than low-temperature baking. Temperatures high enough to relieve the beneficial compressive stresses imposed by peening should be avoided.

It is good practice to passivate stainless steel that has been peened with iron or steel shot, thus preventing contamination by iron particles, which causes rusting. Passivation is not required on superalloys intended for use at elevated temperature.

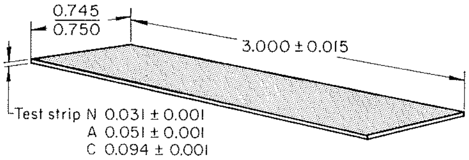


Fig. 15. Designations and dimensions of standard test strips used in measuring shot peening intensity

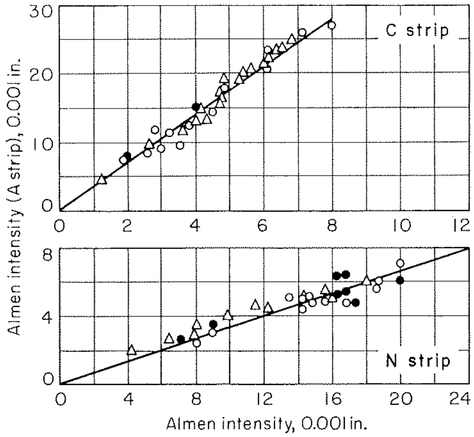


Fig. 16. Correlation of intensities as indicated by arc heights of A, C and N strips peened under identical blast and exposure conditions (SAE J442)

Because the compressive layer induced by peening is relatively superficial, subsequent grinding or machining of peened surfaces should be avoided, except for aluminum or magnesium alloys that have been peened to a greater depth. As much as 0.005 in. may be removed from the surface of these alloys without deleterious effect to the pre-stressed layer, and the improved surface finish may prove beneficial to fatigue properties. However, a knowledge of stress gradients must be available before stock removal is undertaken.

Steels may be lightly honed or lapped after peening. There is limited evidence that these operations (or fine-particle abrasive blasting) may have a beneficial effect where maximum fatigue resistance is desired. After peening, straightening or cold forming by conventional methods should be avoided; these operations may result in a complete reversal of the residual-stress pattern. Peen straightening and forming, however, are permissible, because they do not introduce harmful residual tensile stresses.

Table 5. Cost of Shot Peening Carburized and Hardened 8620 Steel Gears (Example 12) (a)

	Cost	
Cost factor	Per year	Per hour
Original investment . . . $80,000		
Amortization (over 8 years) . .	$ 10,000	$ 1.45
Maintenance materials	6,900	1.00
Maintenance labor ($2 per hr)	1,200	0.17
Shot (at $220 per ton) (b)	36,000	5.22
Power (67 hp, 1¢ per hp-hr) . .	4,630	0.67
Production labor (c)	41,400	6.00
Total	$100,130	$14.51
Peening cost per gear $0.063		

(a) Based on peening for 23 hr per day, 6 days per week, 50 weeks (6900 hr) per year. Production rate, 230 gears per hour (1,587,000 per year). (b) Cast steel shot (size, S230; hardness, Rockwell C 54 to 60). (c) Two men for loading and one for unloading, at $2 per hr.

Table 6. Cost of Shot Peening Hardened 5160 Steel Coil Springs (Example 13) (a)

	Cost	
Cost factor	Per year	Per hour
Original investment $70,500		
Amortization (over 8 years) . . .	$ 8,812	$ 4.41
Maintenance materials	6,000	3.00
Maintenance labor ($2 per hr) .	1,500	0.75
Shot (at $315 per ton) (b)	33,264	16.63
Power (135 hp, 1¢ per hp-hr) .	2,700	1.35
Production labor ($2 per hr) . . .	4,000	2.00
Total	$56,276	$28.14
Peening cost per spring $0.013		

(a) Based on peening for 8 hr per day, 5 days per week, 50 weeks (2000 hr) per year, using three machines. Production rate, 12 springs per minute per machine (totals, 36 springs per minute, 2160 per hour, 4,320,000 per year). (b) Cut steel wire shot.

by peening has been accomplished with a high degree of reliability. There is no known use of this technique on other electrodeposits.

Shot peening has been used as a method of detecting poorly bonded silver plate on steel since the second World War. In the poorly bonded areas, the silver deforms plastically under the peening action of the shot and forms wrinkles or blisters.

Shot peening intensities required for revealing defectively bonded areas may be determined experimentally using the data in Fig. 11 as a guide. Figure 11(a) shows the minimum shot peening intensity required to blister poorly bonded silver plate in relation to the thickness of the plate. In practice, it is customary to plate the silver at least 60% thicker than the finished dimensions require. The plate is then machined to an oversize diameter to a uniform thickness for peen testing. The intensity is adjusted to +0.004, −0 of that indicated in Fig. 11(a). Uniform coverage and exposure time should be maintained. Masking is generally applied to the unplated areas. After peening, the surface is again machined to final dimensions. This gives rise to the data in Fig. 11(b), which show the relation between the minimum thickness of silver for peen testing and the maximum finished thickness of silver.

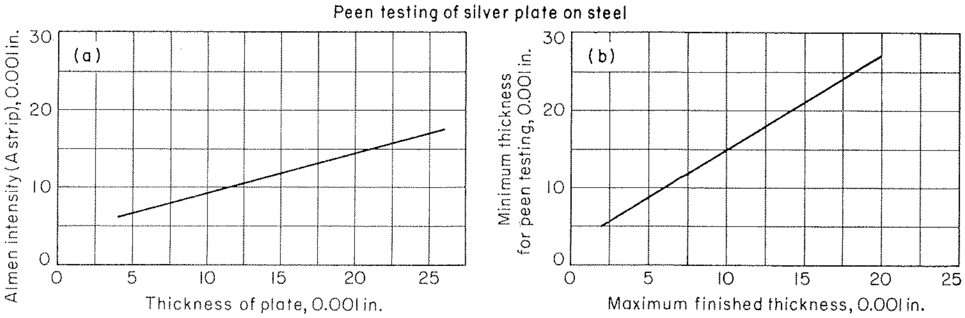


Fig. 11. (a) Minimum shot peening intensity required to blister poorly bonded silver plate, shown as a function of plate thickness. (b) Relation between minimum thickness of silver plate for peen testing and maximum finished thickness of plate.

Limitations

Shot peening has few practical limitations in terms of the materials or of the size, shape, quantity, surface condition, and surface hardness of parts that can be peened. In general, major limitations are not related to the mechanical aspects of the peening process but to certain effects that can nullify the beneficial results of shot peening, such as the effects of elevated temperature and of machining.

Size and Shape of Workpiece. The size of the peening cabinet is normally the only limitation on the size of workpiece that can be peened. To some extent, even this limitation can be overcome by the use of portable peening equipment.

Provided the surface to be peened is accessible to the blast, the shape of the workpiece is seldom a limitation. The peening of small radii in fillets and thread roots is obviously limited by the smallest available shot size. Sharp edges that must retain their sharpness should not be peened.

Surface condition, provided the workpiece surface is free of gross contaminants is seldom a limitation in shot peening. Water, oil and grease will seriously contaminate the shot and interfere with peening quality and effectiveness. An as-forged surface usually will realize a greater improvement in fatigue strength as a result of peening than a polished surface. Cast surfaces respond as well to peening as wrought surfaces. Aluminum parts, however, should be peened *before* being anodized.

Temperature Limitations. Low tempering temperatures, such as those normally employed for carburized parts, have no adverse effect on peening stresses. Low-alloy steels can be heated to about 550 or 600 F for a relatively short time before encountering a significant decrease in compressive stress induced by shot peening. Steels intended for elevated-temperature application will usually withstand temperatures of 800 to 850 F without undergoing a significant stress-relieving effect. However, exposure at 1000 F or above will relieve induced stresses in all high-temperature alloys.

Problems in Production Peening

The examples that follow describe problems that were encountered in the shot peening of production parts to enable them to meet performance requirements, and the measures that were adopted to correct the problems.

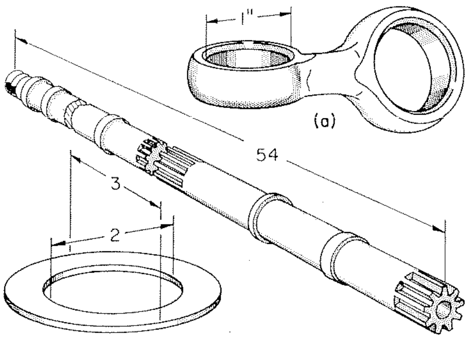


Fig. 12. Production parts that presented unusual problems in shot peening (Examples 8, 9 and 10)

Example 8. A small forging (Fig. 12a) contained two holes with thin wall sections; the inner bearing surfaces had to be held to a tolerance of 0.0005 in. Normally, in shot peening a hole with a heavy wall section, the size of the hole is reduced by the peening action. With the thin wall section here, however, the size of the hole was not reduced but the hole became oval-shaped. The solution to this problem required the establishment of new dimensions prior to shot peening that would permit a light honing operation after shot peening to bring the hole size to within dimensional requirements.

Example 9. A flat ring (Fig. 12b) failed in fatigue either by cracking from the inside diameter to the outside diameter or by "chip-out". Shot peening eliminated the fatigue failures but caused the parts to dish as well as warp. (These parts were required to retain flatness to within a tolerance of 0.0005 in.) After various intensities were tried, the distortion problem was solved by peening one side of the ring at a higher intensity than that used on the other side, depending on warpage direction.

Example 10. Specifications for a splined shaft (Fig. 12c) imposed a runout tolerance of 0.001 in. over its length. It was at first thought that, to satisfy this requirement, the shaft would have to be peened during one continuous pass of the blast nozzle, and that a short pass, requiring the repeening of a portion of the shaft, would result in excessive distortion. However, after the internal and external surfaces of the shaft were peened under supposedly ideal conditions, warpage over the length of the shaft ranged from 0.030 to 0.200 in. The problem was solved by selectively peening portions of the shaft at higher intensities.

Table 4. Peening Intensity as Affected by Sizes of Nozzle and Aspirator and Distance From Nozzle to Work (Example 11) (a)

Test No.	Nozzle size, in.	Aspirator size, in.	Almen intensity (A strip), 0.001 in. Distance from nozzle to work, in. 8	7	6	5	4
1	3/8	5/32	5.5	4	5	5.5	5
2	3/8	7/32	4	5.5	5	5.5	5
3	1/2	5/32	3	2.5	3	3	3.5
4	1/2	7/32	5	6	7	7	7
5	5/8	5/32	7	6	5.5	7	7 to 8
6	5/8	9/32	6	6.5	7	7	7.5

(a) Tests made using suction-type shot peening test cabinet, S70 steel shot; pressure, 92 psi; flow of shot to nozzle, 7¼ lb per min.

Example 11. In shot peening the fir-tree serrations of type 410 stainless steel compressor blades used in a jet-aircraft engine, it was determined that a maximum improvement of 26% in the fatigue life of serrated blade butts could be obtained only if a closely controlled peening procedure was followed. Certain variations from this procedure actually proved harmful to blade life. An alteration in peening intensity, for example, had a marked effect on fatigue characteristics. Variations in intensity that could be obtained by changing nozzle size, aspirator size, or the distance from the nozzle to the work are given in Table 4.

The procedure adopted consisted of peening the butt serrations (Fig. 13) with S70 steel shot at an intensity of 0.007 to 0.008 A and an impingement angle of 83°. The

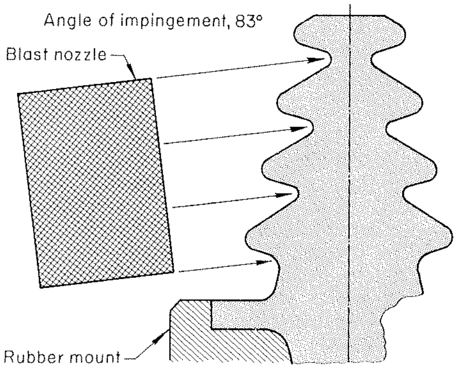


Fig. 13. Relation of nozzle angle, angle of load face, and resulting angle of impingement, in peening butt serrations of compressor blades (Example 11)