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SHOT PEENING

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The purpose of shot peening is to permit more efficient use of structural metals. Just as earlier generations of designers were enabled to reduce the weight and cost of their structures by the substitution of steel for wrought iron, by the introduction of heat treatment, and by the development of modern alloy steels, so prestressing by several processes, including shot peening, increases the net work that may be obtained per unit weight of machine parts.

10. APPLICATION OF SHOT PEENING

Shot peening is coming into extensive use as the most versatile of the several prestressing processes for strengthening metal machine parts against cohesive failure. Cohesive failures that are characterized by brittle fracture are caused only by tensile stresses and result from (1) impact loads on brittle metals in which the tensile stress acting at the surface is greatly magnified by various forms of stress raisers, (2) stress corrosion in which cracks (usually intercrystalline) propagate through metal that is stressed in tension, and (3) fatigue failures in which, because of the magnification of surface tensile stresses, fractures occur from repeated loads that stress the metals less than their nominal yield stress.

Shot peening is effective against these forms of cohesive failure because it induces residual compressive stress in the surface of the metal being peened. The surface tensile stresses from externally applied loads will be reduced by the amount of the residual compressive stress. The quality of the peening is determined by (1) the magnitude of the induced residual stress, which is a function of the yield stress of the peened metal and the state of strain in the metal at the time of peening, (2) the depth of the induced residual stress, which is a function of the hardness and ductility of the peened metal, the state of strain in the metal at the time of peening, and the characteristics of the shot and the shot stream, and (3) the degree of coverage, by which is meant the number of shot impacts per unit of area.

PROCESS. In the process of shot peening, relatively hard particles—usually spherical chilled cast iron or steel shot—are projected against the metal being peened with sufficient velocity to indent the surface. The indentations at each point of impact result from local plastic yielding of the peened metal. The deformed areas tend to expand elastically, but they are restrained by adjacent, deeper metal that was not plastically deformed by the shot impact. Since the plastically deformed surface layer seeks to occupy more space, it is compressively strained; that is, it is residually stressed in compression.

STRESS-CORROSION CRACKING. Since stress-corrosion cracking occurs only in metal that is stressed in tension, it is necessary to protect the surface by only a thin layer of compressively stressed metal to prevent corrosive attack, even though the underlying material is still highly stressed in tension. Thus welded or cold-formed vessels that are residually stressed in tension from the forming operation, or from the localized heat of welding, and/or from the working loads, may be protected against stress corrosion or season cracking by the corrosion-impervious layer produced by shot peening. Surface corrosion will still occur, and may actually be increased by the increased roughness, but the intercrystalline corrosion characteristic of stress-corrosion cracking will be stopped so long as the surface stress remains compressive. Shot peening will become ineffective

against stress-corrosion cracking if the residual compressive stress is lost, as, for example, by applying external tensile loads that exceed the yield strength of the material. When tensile plastic extension has occurred throughout the section, the residual stress induced by peening will have been largely dissipated. Some materials may lose much of the residual stress by slow plastic yielding, usually known as "creep," without the aid of external loads. In such materials, the protection afforded by shot peening will become less effective with time.

IMPACT STRENGTH. The resistance to impact fracture of many brittle materials, such as hard steel, may be increased by shot peening to produce residual compressive stress in a relatively thin surface layer. The hardest steel is still sufficiently plastic to develop residual stress, although the indentations from shot impact may be too shallow to be detected without sensitive instrumentation.

The susceptibility to impact fracture is increased by surface imperfections and discontinuities (often submicroscopic), such as micro-stresses, scratches, minute notches, corroded areas, and similar stress raisers. These stress raisers cannot be eliminated by polishing, but they are rendered ineffective when the surface metal is compressively stressed to a depth equal to the depth of the discontinuities.

The impact strength is increased by an amount somewhat less than the residual compressive stress acting on the "notched" areas. If the effective depth of the notches is greater than the depth of the induced stress, the peening operation will be ineffective. Shot peening will also be ineffective for increasing the resistance to impact failure in metals that are sufficiently plastic to yield under the applied loads. When appreciable plastic yielding occurs, the residual stress induced by the peening operation will be dissipated.

FATIGUE STRENGTH. Fatigue failures, like impact failures, result from tensile stress only. Under conditions of repeated load applications, cohesive failures will occur from stresses considerably less than the nominal yield strength of the material. Since there is no apparent yielding, the fracture will be brittle in character, even though the material is quite ductile as measured by the conventional static tensile and bending tests.

Under ordinary conditions of specimen preparation, fatigue fractures will originate very near the surface, because the surface tensile stress is always augmented by micro-stresses and various kinds of stress raisers, or perhaps because a surface is, itself, a discontinuity. The stress increment that is added by surface stress raisers increases as the ductility of the material decreases until, in hard steel, the effective tensile stress may be several times as great as the nominal stress. As the hardness of steel increases, the effective "notch" stress increases at a greater rate than the potential strength of the steel, and there is, therefore, a well-recognized limit of hardness for best fatigue durability. Thus the upper limit of hardness of ordinary springs lies in the range of Rockwell C 40-45 because of surface vulnerability.

However, this hardness limitation does not apply when the hardness is obtained by carburizing or by nitriding, as, for example, in carburized gear teeth, carburized wrist pins, and nitrided crankshafts. The fatigue strength of machine parts that are surface hardened by these processes generally increases as the hardness increases. This deviation from the rule of brittleness is due to the residual compressive stress that is developed in the surface by the volume increase that occurs in the hardened case. It follows that the surface vulnerability (notch sensitivity) of the hardened surface of the steel cannot assert itself until the initial compressive stress is overcome by tensile stresses from external loads. Hence, in most nitrided specimens and in many carburized specimens, the magnitude of the residual compressive stress is of the order of 100,000 to 150,000 psi, the tensile stresses from externally applied loads are often not sufficient to overcome the residual compressive stresses in the hardened case. The surfaces are, therefore, never stressed in tension, and the fatigue failures will originate in the core.

SHOT-PEENING STRESS. The vulnerability to fatigue failure of machine parts and of laboratory specimens is reduced by shot peening because of the layer of uniform residual compressive stress that is induced when the peening process is properly performed. It must be recognized, however, that there are important differences between the protection against fatigue failure that may be gained by the surface-hardening processes previously described and by shot peening. Prestressing by shot peening alone is not so effective as prestressing by several other processes, but it is the most versatile, because it may be applied at relatively low cost to machine parts of all shapes and to metals of all kinds. The magnitude of the residual compressive stress obtainable by shot peening is equal to approximately one half the nominal yield stress of the metal when the peening coverage is adequate and when the peening is performed on the specimen while in an unstrained state. This compressive stress of 50% yield strength is negative to the dangerous tensile stress. It is available to offset surface fatigue vulnerability when, for example, the peening is applied to the tension-stressed side of a beam that is subjected to repeated bending loads

in one direction. However, much or all of the protective residual surface stress may be lost from a shot-peened beam that is subjected to repeated reversed-bending loads.

REVERSED-BENDING LOADS. In reversed loading, one side of the beam will be compressively stressed at each load application. The compressive stress on that side will, then, be the residual stress that was induced by shot peening, plus the compressive stress from the external bending load. If this total exceeds the compressive yield strength of the material, the residual compressive stress will be reduced, and a corresponding part of the protection against surface vulnerability will be lost. The actual yield stress under repeated loading is considerably less than the nominal yield stress as measured by static loading, and it is therefore possible to lose all the residual stress induced by shot peening. If all or most of the residual compressive stress is lost, the fatigue strength of the part may actually be less than before peening, because of the increased notch effects in the roughened surface. Such loss of residual compressive stress under repeated reversed-bending loads does not readily occur in carburized and in nitrided parts because of the greatly increased yield strength of the hardened surfaces.

ONE-WAY BENDING LOADS. The residual compressive stress from shot peening is not lost from the tension side of parts subjected to bending loads that act in one direction only. In such parts, the peening need be applied only to the tension-stressed side, and since this side is not compressively stressed by external loads, the total compressive stress remains that which is induced by peening.

Any plastic yielding that may occur on the tension side will increase the residual compressive stress and will therefore tend to increase the fatigue strength of the part. In fact, such yielding actually does occur in nonpeened, as well as in peened specimens, and is one reason—perhaps the principal reason—for the greater fatigue strength of specimens subjected to one-direction loading. The effect usually referred to as "understressing" is also explained by such yielding.

Plastic yielding also occurs on the side of fatigue specimens that are loaded in compression. Such compressive yielding results in residual tensile stresses, which occasionally become great enough to cause fatigue failures to originate on the side nominally stressed in compression. The maximum tensile stress occurs, of course, when the external load is removed. From such occurrences arises the erroneous belief that fatigue failures can be caused by compressive stress.

Because of the greater protection against surface vulnerability that is given to fatigue specimens subjected to one-way bending loads, it is often desirable to increase the compressive stress induced by shot peening. This may be accomplished by performing the peening on the tension side while the part is statically loaded, in the direction of the normal service load, to approximately one-half the yield stress of the material. The peening will then superimpose upon the static tensile stress, compressive stress equal to about 50% yield stress, which will be increased to approximately 100% yield stress when the static load is removed. The static load to be applied during peening should not exceed 50% yield stress because, upon relaxing the external load, the compressive stress will exceed the yield strength, and plastic deformation will occur. This plastic deformation will be in the opposite sense to the plastic deformation that occurred during shot peening. Also the surface layer might be damaged by being excessively cold worked.

FATIGUE TESTS MAY BE MISLEADING. From the foregoing, it will be seen that it is not possible to evaluate the effect of shot peening or to measure the fatigue strength of parts that, in normal use, are to be loaded in one-direction bending, by subjecting them to reversed-bending fatigue tests. This is also true of specimens in which favorable residual stresses have been developed by understressing and by such processes as surface rolling or overloading to cause yielding, and quenching from tempering temperature.

MEMBERS LOADED IN TORSION. It is usually convenient to consider members that are loaded in torsion to be stressed in shear. However, to understand the effects of prestressing, it is necessary to apply a stress pattern that may be expressed in terms of having positive and negative values. Therefore, instead of shear, the tensile and compressive stress components of the shear stress are used. These stresses act at angles of 45 degrees to the shear plane and at right angles to one another; that is, when the tensile stress acts in the direction of a right-hand helix, the compressive stress will act in the direction of a left-hand helix.

In repeated reversed-torsional loading, the tensile and compressive stresses are reversed at each load application, and therefore the residual compressive stress induced by shot peening may be lost, wholly or in part, in the same manner as in specimens subjected to reversed-bending loads.

For torsional loads that are applied in one direction only, the residual compressive stress acting in the direction of the tensile stress component remains fully effective. Much of all of the residual compressive stress acting in the direction of the compressive stress

component may be lost by plastic yielding, but this loss does no harm unless the yielding is so extensive as to induce dangerous residual tensile stress when the external load is at its minimum.

For greater protection against fatigue in one-way torsional loading, the magnitude of the residual compressive stress induced by shot peening may be increased by performing the peening while the specimen is statically loaded, in the normal direction of twist, to approximately half the yield stress of the material. The surface stress prior to peening will then be one-half the tension yield stress in the direction of the tensile stress component and one-half the compressive yield stress in the direction of the compressive stress component. After peening, while still statically loaded, the surface stress in both directions will be compressive and equal to one-half the yield stress of the metal. The peening will not have altered the surface stress in the direction of the compressive component, but in the direction of the tension component the surface stress will have been changed from one-half the yield stress in tension to one-half the yield stress in compression, a plastic flow representing 100% of the yield stress of the metal.

Upon release of the external load, the bar will untwist to nearly its original angle of zero stress. In so doing, however, the strain in the direction of the tensile component will increase the compressive stress and the strain in the direction of the compressive component will reduce the compressive stress. The residual compressive stress will then be, roughly, 100% of the compressive yield stress in the direction of the tensile component and zero stress in the direction of the compressive component. Since, under ordinary test load range from zero to maximum, slow yielding will occur under repeated loading, the residual compressive stress in the direction of the tensile component may decrease slightly to equal the dynamic compressive yield stress. In the direction of the compressive component, tensile residual stress will be induced by slow yielding. Extensive plastic yielding by creep, added to the plastic deformation that occurred during peening, may damage the material sufficiently to cause fatigue failure from the induced tensile residual stress, which acts in the direction of the nominal compressive stress. Being residual, the maximum tensile stress, which may cause fatigue fracture, occurs when the external load is removed. Since the fatigue fracture will originate on a line at right angles to the tensile stress causing the failure, it is possible, by observing the direction of the initial fracture, to determine whether the failure was caused by the tensile component of the external load or by induced residual tensile stress acting in the direction of the compressive stress component. Fracture from induced tensile stress cannot occur from a test in which the load is varied from the same maximum, but to a lesser minimum; for example, in a test in which the load range is plus 25% to plus 100%. This again demonstrates that the effect of shot peening cannot be evaluated by an arbitrary test procedure based on nominal stress or nominal stress range.

AXIAL-LOADED SPECIMENS. A few machine parts, and occasional fatigue specimens, are loaded in tension or in combinations of tension and compression. Shot peening will increase the fatigue strength of specimens repeatedly loaded in tension by reducing the subsequent tensile stress in the vulnerable surface layer. However, since the residual compressive stress in the surface layer must be balanced by tensile stress in the core to maintain force equilibrium, the total tensile stress in the core will be the tensile stress from the external load, plus the residual tensile stress. If the area of the specimen is small in relation to the depth of the peened layer, the residual tensile stress may become so great as to require only a small external tensile load to cause subsurface fatigue failure. Slight peening may be very beneficial from the standpoint of fatigue, and heavy peening may be very harmful.

Under push-pull fatigue loading, the residual compressive stress from shot peening may be lost, in whole or in part, depending on the magnitude of the external compressive load. When the residual compressive stress is lost, the specimen will have been damaged by shot peening because of the increased stress raisers created by the peening.

CARBURIZED AND SHOT-PEENED METALS. The residual stress that results from carburizing can be made much more effective by shot peening as a final operation. The residual stress from carburizing extends to the depth of the hardened case, and the compressive stress is of the order of 100,000 psi. However, the maximum stress occurs at some depth, with considerable loss of stress near the surface. Shot peening effectively increases the maximum compressive stress, and, since the compressive yield stress in the hardened case is great, there will be little loss of residual compressive stress during fatigue testing in normal service. The fatigue fracture will often originate in the core in carburized and shot-peened specimens, for the reason that the surface stress does not become tensile. For a given specimen, a close approach to the best possible treatment will have been obtained when fatigue fractures in successive specimens originate with equal frequency at the surface and in the core. This must not be taken as "best," however, because the relative areas of core and case may be such as to stress the core in tension unduly.

An effect similar to carburizing may be obtained by other case-hardening processes. In steel sections of adequate diameter, low-hardenable steel, such as severely quenched SAE 1010-1050, will harden only in a relatively thin case. This hardened case will be readily stressed in compression because of the volume increase upon hardening, just as occurs in a carburized case. The fatigue strength of such specimens in bending and in torsion may be further increased by shot peening.

TREATMENT FOR BEST FATIGUE STRENGTH. For repeated reversed loading in bending and in torsion, the best fatigue strength from prestressing of steel is obtained by case hardening followed by shot peening. The deep, and relatively great, residual compressive stress reduces the tensile stress from external loads, and the high yield strength of the case prevents serious loss of the protective stress. Shot peening is not required for nitrided parts, because the residual stress is sufficiently great as heat treated.

For one-way bending or one-way torsion, the best fatigue strength may be obtained from parts that are deep hardened. The material may be in the hardness range Rockwell C 50-55; it should be overloaded to produce plastic yielding in the same direction as the normal load; and, finally, it should be shot peened while statically loaded to approximately half the yield strain.

Because of the suggested hardness of the specimen, the operation of prestressing by overloading is hazardous, particularly since the plastic deformation should be extensive enough to extend to approximately 15 to 20% of the specimen thickness. Unless suitable precautions are observed, this extensive cold setting may damage the material and may even cause immediate fracture. The overloading should therefore be applied at an elevated temperature to reduce the yield stress temporarily and to increase the ductility of the steel. Shot peening at one-half yield strain prior to presetting will also aid in preventing fracture or other damage during the presetting operation. Finally, the shot-peening operation should be applied while the part is statically loaded in the direction of the normal load to approximately half the yield strain.

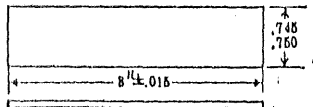


Fig. 1. Almen shot-peening test strip. Specifications are: Hardness, Rockwell C 44-50; flatness, ± 0.0015 in. on Almen gage; A strip thickness, 0.051 ± 0.001 in.; C strip thickness, 0.004 ± 0.001 in. Ends only may be shear finish, burrs must be removed and corners broken.

The principal instrument that is used for measuring, and thereby controlling, shot peening consists of a standard steel strip (Fig. 1) that is shot peened on one side while attached by screws to a heavy hardened steel base (Fig. 2). When the test strip is removed from the heavy base after peening, the residual compressive stress that was induced causes convex curvature of the strip on the peened side. The curvature is measured on the unpeened side in terms of arc height over a standard chord by a special indicator (Fig. 3).

The amount of curvature, that is, the measured arc height of the strip, is called *peening intensity*. The peening intensity is the overall effect of the magnitude of the induced stress, the depth of the stressed layer, and the uniformity of the stress, in magnitude and in depth, over the surface of the strip—hereafter called the *coverage*. Since the peening intensity measurement is made on a steel strip of standard dimensions and standard physical properties, the magnitude and depth of the induced stress are those of the test strip and not of the metal being peened.

Two thicknesses of test strips have been standardized to meet the needs of sensitivity for light and for severe peening. The dimensions of the two strips, designated as A strips

11. SHOT-PEENING INSTRUMENTATION

To specify that a machine part is to be shot peened without stating how much, in measurable quantities, is equivalent to specifying "heat treat" without mentioning temperature or time. To meet this need, instrumentation is available that is sufficient for the purpose in accuracy, cost, and simplicity.

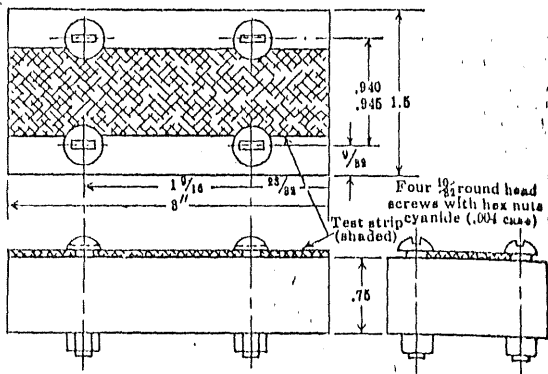


Fig. 2. Holding fixture for shot-peening test strip.

and C strips, are given in Fig. 1. A chart correlating peening intensity readings from A strips and C strips is shown in Fig. 4.

In production use, the hardened holding fixture (Fig. 2), with attached test strip, is passed through the peening machine in the same manner as the parts being peened. The surface of the holding fixture, to which the test strip is attached, is located in such a way as to represent a critical area of the work, in order that the peening received by the test strip will be substantially the same as is received by the work. Usually, the holding fixture is welded or bolted to a dummy machine part that has been prepared for the purpose. Complex machine

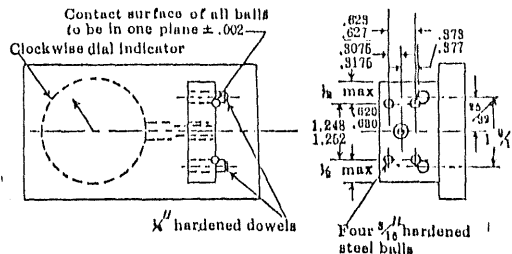


FIG. 3. Almen gage.

parts having many angles and planes may require a number of holding blocks, each representing a different plane or critical area of the work. Peening intensity measurements are made several times each working day. New test strips are used for each location every time the measurements are made.

Peening intensity is a measure of the quality of the shot stream which may be likened to the measurement of temperature in a heat-treating operation. The temperature of the metal being heat treated is usually arrived at indirectly by measuring the temperature

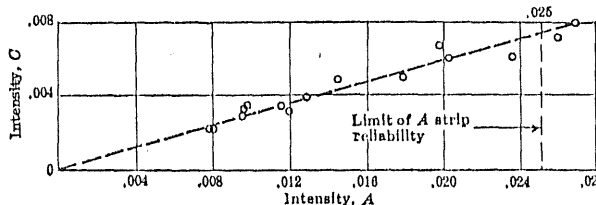


FIG. 4. Correlation of gage readings for Almen A and C strips.

of the furnace in the vicinity of the work and exposing the work to that temperature for a sufficient time to saturate the metal. Unless both temperature and time are correctly specified, and unless the specifications are followed, the heat-treating operation cannot be successful.

12. PEENING SPECIFICATIONS

A shot-peening specification consists of the indicator reading for the test strip, which is the arc height in inches, followed by the letter designating the strip size.

Shot-peening specifications must take into account the dimensions and physical properties of the peening shot, the characteristics of the shot stream, and the physical properties and manner of loading of the machine part being peened. The factors affecting peening intensity are shot size, shot velocity, coverage (quantity of shot per unit area), shot cleanliness, direction of shot relative to work, and shot quality (hardness, mass, shape, etc.).

SHOT SIZE. A system of peening shot sizes has been adopted by the Society of Automotive Engineers and accepted by shot manufacturers. This standard designates shot size by a number which is the nominal shot diameter in mills, preceded by the letter "P" to distinguish peening shot from shot intended for other purposes. Table 1 is a reproduction of the shot-size specifications included in the SAE Recommended Practice.

The selection of shot size depends on (1) the radii of fillets and of surface irregularities such as indentations and cutter marks, (2) the section thickness of the work, (3) the appearance desired, (4) the abrasion desired, and (5) the manner of loading the peened part.

Radii of Fillets. The radius of the shot should be approximately half, or less than half, the radius of the smallest fillet or surface irregularity in the critical area. This rule does not apply to shallow cutter marks or scratches, the depth of which is small with respect to the depth of the compressively stressed layer. If the radii of the shot are large with respect to the radii of deep cutter marks or of fillets, the compressive stress induced in these regions will be too small to afford effective protection.

Section Thickness. When the thickness of the work being peened is small compared to the size of the shot, there is danger that the induced compressive stress will extend too

Table 1. Peening Shot Numbers and Screening Tolerances
 Per cent of total sample by weight retained on each pertinent screen
 (Reprinted by permission from the *SAE Handbook*)

Peening Shot Number	High-limit Screen		Oversize Screen		Nominal Screen		Low-limit Screen	
	Shot Retained, % max	Screen Number and Aperture	Shot Retained, % max	Screen Number and Aperture	Shot Retained, % min	Screen Number and Aperture	Shot Retained, % max	Screen Number and Aperture
P 157	0	3 1/2(. 223)	2	4(. 187)	90	5(. 157)	5	6(. 132)
P 132	0	4(. 187)	2	5(. 157)	90	6(. 132)	5	7(. 111)
P 111	0	5(. 157)	2	6(. 132)	90	7(. 111)	5	8(. 0937)
P 93	0	6(. 132)	2	7(. 111)	90	8(. 0937)	5	10(. 0787)
P 78	0	7(. 111)	2	8(. 0937)	90	10(. 0787)	5	12(. 0661)
P 66	0	8(. 0937)	2	10(. 0787)	90	12(. 0661)	5	14(. 0555)
P 55	0	10(. 0787)	5	12(. 0661)	85	14(. 0555)	7	16(. 0469)
P 46	0	12(. 0661)	5	14(. 0555)	85	16(. 0469)	7	18(. 0394)
P 39	0	14(. 0555)	5	16(. 0469)	85	18(. 0394)	7	20(. 0331)
P 33	0	16(. 0469)	5	18(. 0394)	85	20(. 0331)	7	25(. 0280)
P 28	0	18(. 0394)	5	20(. 0331)	80	25(. 0280)	12	30(. 0232)
P 23	0	20(. 0331)	5	25(. 0280)	80	30(. 0232)	12	35(. 0197)
P 19	0	25(. 0280)	5	30(. 0232)	80	35(. 0197)	12	40(. 0165)
P 16	0	30(. 0232)	5	35(. 0197)	80	40(. 0165)	12	45(. 0138)
P 13	0	35(. 0197)	5	40(. 0165)	75	45(. 0138)	17	50(. 0117)
P 11	0	40(. 0165)	5	45(. 0138)	75	50(. 0117)	17	60(. 0098)
P 9	0	45(. 0138)	5	50(. 0117)	70	60(. 0098)	22	70(. 0083)
P 8	0	50(. 0117)	5	60(. 0098)	70	70(. 0083)	22	80(. 0070)
P 7	0	60(. 0098)	5	70(. 0083)	70	80(. 0070)	22	100(. 0059)
P 6	0	70(. 0083)	5	80(. 0070)	70	100(. 0059)	22	120(. 0049)

Maximum "fines" allowed through smallest screen, 3%.

The shot number is roughly the size of the shot pellets in thousandths of an inch.

Percentages given are on the basis of weight.

deeply into the work instead of affecting a relatively thin layer, as is desired. The diameter of the shot should be less than the thickness of the work, since the depth of the compressively stressed layer increases as the shot diameter increases.

Appearance. The section thickness of the work also influences the shot size from the standpoint of appearance of the peened surface. Coarse peening is less offensive to the eye on thick sections than on thin sections.

Abrasion Desired. The amount of material that is abraded from the surface of the work, for any peening intensity, is greater when small shot is used than when large shot is used.

Loading of Part. For any shot velocity, the thickness of the compressively stressed layer is roughly proportional to the shot diameter. The desired thickness of the compressively stressed layer will depend on the manner in which the peened part is loaded in service, as well as on the section thickness. For members loaded in tension and for surfaces where peening has been superimposed on a deep prestress obtained by other means such as carburizing or overstressing, the compressively stressed layer should be thin. For member loaded in bending or in torsion, which are not otherwise prestressed, the compressively stressed layer should be relatively thick.

SHOT VELOCITY. The shot velocity that will be required for any specified peening intensity will vary with (1) the size of the shot, (2) the hardness of the shot, (3) the mass of the shot, and (4) the direction of the shot relative to the work.

Size of Shot. The size of the shot affects the shot velocity to be used for any specified peening intensity, because the depth of the compressively stressed layer is proportional to the shot size.

Hardness of Shot. If the shot is so soft as to deform on striking the work, some of its shot energy will be lost. The shot will also present greater areas of contact, and therefore the unit pressure and the peening intensity will be reduced unless velocity is increased.

Mass of Shot. The energy of the shot will vary with its mass and with its velocity. The mass of shot is changed, it is necessary to change the velocity to maintain constant peening intensity.

Direction of Shot. The energy of the shot that is absorbed by the work will vary approximately as the sine of the angle between the plane of the work and the line of motion.

the shot. To maintain constant peening intensity of the work, it is therefore necessary to change the velocity of the shot as the angle of impact is changed.

COVERAGE. By *coverage* is meant uniform distribution of peening stress over the surface of the work. Uniform stress means that the points of impact are so numerous that the stress induced by each impact overlaps the adjacent stressed area to produce essentially uniform stress.

The same instruments that are used to measure peening intensity are used to determine the time of exposure of the work to the shot stream to obtain adequate coverage. Since the total residual stress will continue to increase until the peened surface is uniformly stressed, the curvature of the test strip will continue to increase until saturation is attained.

Figure 5 is a chart of peening intensity plotted against time of exposure. The upper curve shows a condition in which the specified peening intensity reading is attained at A, but since the curve continues to rise with increased time of exposure, it is evident that the peening stress at point A was not uniform; that is, the coverage was inadequate.

The second curve shows correct combinations of shot size and velocity so that the required peening intensity is attained at B after a time of exposure sufficient to saturate the surface.

The lower curve indicates conditions under which the desired peening intensity cannot be attained because of insufficient depth of the induced stress.

To determine the time of exposure required to obtain adequate coverage, successive test strips are passed through the shot stream, varying only the time of exposure. The arc height reading of each strip is plotted against the time of exposure, as in Fig. 5. Alterations are then made in shot velocity or in shot size until the required peening intensity is obtained as the limit of arc height is approached.

SHOT CLEANLINESS. Good peening requires that only reasonably round shot of uniform size be used in the machine. Since a considerable percentage of normal commercial shot will eventually fracture or wear as a result of repeated impact against the work or against the wall of the cabinet, means have to be provided for discarding split or other fractured shot, undersized shot, and dust.

Undersized shot, split shot, and smaller fragments are objectionable because they (1) reduce peening intensity, (2) increase abrasion, (3) cut, rather thanpeen, (4) contaminate the surface of the work, and (5) increase the cost of peening.

1. Peening intensity is reduced because the small particles strike the work with less energy than the original-sized particles.
2. Abrasion is increased because the broken, sharp-edged particles wear away the surface much more readily than the round shot.
3. Many of the broken shot cut into the work like a knife, and may therefore reduce the fatigue strength of the work, since such cuts may extend deeply into the compressively stressed layer.
5. To maintain the specified peening intensity, it is necessary to increase the velocity as the shot breaks down. This increased velocity accelerates the breakdown of the remaining whole shot as well as the added new shot, thus requiring more replacement than if only clean, round material of the specified size were used. As the shot size is decreased, not only must the velocity be increased, but often the time of exposure must also be increased.

SHOT QUALITY. Under shot quality may be listed such properties as (1) hardness, (2) impact fatigue strength, (3) shape, (4) soundness, (5) size range, and (6) mass.

Hardness. Residual compressive stress can be induced by shot softer than the material being peened, but, generally, shot should be as hard as, or harder than, the work. If the shot is too soft, it will lose its energy in deformation, and the induced stress in the work will be too small to produce the desired compressive stress unless the velocity is increased.

Impact Fatigue Strength. The rate of fracture of sound shot, used in peening, is measured by the impact fatigue strength. The impact fatigue strength of commercial chilled iron shot is low—hence the importance of good devices for separating fractured material from whole shot.

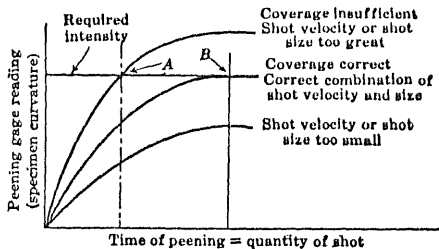


FIG. 5. Peening intensity versus time of exposure.

Table 2

Name of Part	Material	Hardness (R_c or Equivalent)	Thickness of Critical Section, in.	Surface Finish before Peening	Manner of Stressing	Kind of Shot Used	Size of Shot	Peening Intensity
Crankshaft	Steel	10-21	0.75	Polished	Reversed torsion	Chilled iron	P-28	0.014 0.015A
Connecting rod	Steel	37-44	0.16	Polished	Reversed torsion	Chilled iron	P-19	0.015A
Valve rocker arm	Steel	26-30	0.5	Polished and forged	One-way bending	Chilled iron	P-28	0.022A
Valve rocker arm	Malleable iron	3-16	0.2	As cast	One-way bending	Chilled iron	P-28	0.014A
Quill shaft	Steel	34-38	0.5	Polished	Reversed torsion	Chilled iron	P-19	0.14A
Tank track pin	Steel	24-47	0.9	Rough machined	One-way bending	Chilled iron	P-66	0.017C
Bolt head	Steel	33-35	0.25	Polished	Tension tension	Chilled iron	P-19	0.017-0.022A
Transmission gear	Steel *	60-62	0.3	As machined	One-way bending	Chilled iron	P-28	0.020A
Steering knuckle	Steel	26-34	1.5	Ground	Reversed bending	Chilled iron	P-28	0.018-0.026A
Truck axle shaft	Steel	24-32	1.75	As machined	Reversed torsion	Chilled iron	P-39	0.006C
Splined shaft	Steel	45-52	1.25	As machined	Reversed torsion	Chilled iron	P-23	0.028A
Universal joint	Steel *	60	0.8	Ground	Reversed bending	Chilled iron	P-23	0.008C
Coil spring	Steel	52-53	0.3	As rolled	One-way torsion	Chilled iron	P-28	0.017A
Torsion bar spring	Steel	48	2.2	Ground	One-way torsion	Chilled iron	P-60	0.015C
Coil spring	Steel	57-59	0.15	As drawn	One-way torsion	Chilled iron	P-28	0.012A
Flat spring	Steel	44-48	0.020	Zinc plated	One-way bending	Chilled iron	P-28	0.005A
Flat spring	Phosphor bronze		0.008-0.010	As rolled	Reversed bending	Malleable iron	P-17	Too low to measure
Specimen	Magnesium		0.063	As rolled	Reversed bending	Malleable iron	P-39	0.005A
Supercharger part	Magnesium		0.150	As machined	Service	Malleable iron	P-17	0.008-0.010A
Specimen	Malleable iron	131 BHN	0.9	As machined	One-way bending	Chilled iron	P-93	0.018-0.025C
Specimen	Alclad aluminum	105 BHN	0.04	As rolled	Tension tension	Malleable iron	P-66	0.002A
Specimen	Arma steel	20	0.9	As machined	One-way bending	Chilled iron	P-93	0.024C
Specimen	Cast iron	18-20	0.9	As machined	One-way bending	Chilled iron	P-93	0.019-0.024C
Specimen	Nickel	21-22	0.3	Polished	Reversed bending	Malleable iron	P-66	0.022A
Welded fan blades	Steel		0.4	As welded	Reversed bending	Chilled iron	P-19	0.015-0.018A

* Carburized.

Shape. The shape of the shot is important from the standpoint of uniformity of peening. However, it is not commercially possible to obtain only true spherical shot.

Soundness. A considerable percentage of normal chilled-iron shot is hollow. This usually fractures more readily than sound shot and is quickly eliminated when an adequate separator is used.

Size Range. The range of size of commercial screened shot has been specified by the Society of Automotive Engineers.

Mass. Shot for peening purposes may be made from material other than chilled iron or steel. For example, aluminum may be peened with glass shot, granules of plastic material, or walnut shell granules. These alternate materials avoid electrolytic corrosion, especially in magnesium, and the walnut shell and plastic granules also avoid abrasive contamination. The softer peening materials are not capable of inducing residual stress in steel; hence the standard peening intensity strip cannot be used to measure peening intensity. Aluminum or other soft metal strips, not yet standardized, will serve, however.

It is not possible to generalize with regard to peening intensity specifications because of the wide variety of machine parts made from many kinds of metals variously loaded and heat treated. As in specifying heat treatments, each case presents problems peculiar to itself. It will perhaps be helpful to indicate peening intensity specifications that have been reasonably successful when applied to typical machine parts. Such data are presented in Table 2.