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THE STORY OF SHOT PEENING

THE AUTHOR

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SHOT PEENING is a means of cold working the surface of metal parts by means of a hail or blast of round metal shot directed against the surface. It is equivalent to a myriad of small hammer blows impinged over the entire surface indenting the surface and causing plastic flow and work hardening of the surface metal. This work hardening of the surface metal increases its tensile strength and yield point and a small percentage of the beneficial results of shot peening are attributable to this effect. The greater benefit, by far, however, results from the fact that the surface metal is upset and put into compression; the surface compressive stress is extremely beneficial in obviating fatigue failures. What fatigue failures are and how shot peening helps to eliminate such failures will be dealt with later on.

Shot peening is a fairly recent renovation of a very ancient art and in order to have a clear conception of what occurs in the peening process, it might be well to go back in history and consider some of the early aspects of cold working or, as it would have been referred to in olden days, hammer hardening. In the Iliad, the Greek chronicler, Homer, refers to copper breast plates and spear heads and very poetically describes how some spear points penetrated the breast plates with ease while others merely bent on striking and fell to the ground without more than denting the armor of the wearer. The connotation of his writing is that some mystic force had permitted the spear of one warrior to penetrate the breast plate of his enemy while, in the other case, the armor of one would bend and turn aside the spear of his enemy.

Believe me, it wasn't the power of positive thinking that drove the spear head into the armor in one case and caused the armor to bend the spear head in another. It was the plain old fact that the reliable armorer knew from practical tests that cold hammered weapons and breast plates were harder and stronger than those which had been placed in a fire. The intuitive mystic, on the other hand, was so enthralled by the supposed merits of fire that his last operation was to heat the metal and thus anneal or soften it. Also, the unreliable armorer may have been smart--but lazy. He observed that the longer he hammered the copper, the harder it became to form it to the desired shape and he knew that by heating it, he could restore the softness and ductility and thus make his job easier. By annealing just previous to the final light taps of the hammer, he left the armor or spear head soft and probably cost the life of his customer.

If copper is hammered too much, it can become brittle and subject to cracking; however, it takes a lot of hammering to do this. It does show, none the less, that the armorer had to use experienced judgment in forming a spear head from a rough block of copper, First, he had to fire treat it (anneal) to make it soft and ductile and receptive to hammer forming. He next hammered it to rough form and then reannealed it to remove the hammer hardness prior to the final hammering of the spear point to its desired shape and strength. Knowing just how far he should carry his first hammer forming and annealing so that final shaping by hammer would give the weapon excellent hardness and strength without brittleness, called for a lot of experience and judgment on the part of the armorer.

A modern metallurgist would measure the increase in hardness and strength of the copper for measured amounts of cold working and then determine, by actual controlled tests, which percentage of cold work gave the optimum results for the use intended. If this happened to come out to say 205 reduction of metal thickness by cold rolling, the metallurgist would then specify a 20% cold roll reduction of the copper and the Quality Control Supervisor would set up an inspection procedure to assure that this was adhered to. As you can see, we haven't made any basic changes over the ancient armorers' methods, but we have developed standard methods (cold rolling in this instance), standard tests to determine just how much cold work to give the part, and standards of quality control to assure reproductibility. Modern man's achievement, in this and many other ancient arts, has been to take the guess work out of the operation.

Another historical use of cold working which is more directly analogous to modern shot peening was the old time blacksmith's art of hammer peening the tension side of carriage springs. He found out that if he bent the flat carriage spring in the same manner that it would be bent as part of a loaded carriage and then ball peened the convex (tension) side while bent, he could improve the life of the springs even for greater loads or when smaller springs were used. Today, we call this "strain peening" and some of the increases in service life of parts so treated are phenomenal. The old time blacksmith merely knew from past experience that it worked so he went ahead and did it. His shot was as big as the ball on the ball peen hammer he used. The striking intensity depended on the mass of the hammer and the strength of his muscles, modified of course, by whatever good judgment he had managed to accumulate from past experience. His peening rate was one indention at a time so one would suspect that a large ball was used to cover as much area as possible per blow and thus save some time. Any craftsman who was proud of his work would add the peening operation; however, he could hardly afford to use all of his day just to improve a few springs.

Here again, we have added but little to the art as used by the blacksmith. We have, however, greatly increased the scope of usage and our knowledge as to why of its effect. More than that, we have set up standard means for doing the same thing with a hail or blast of small, well rounded shot of specific hardness-we have developed means of specifying how to do a given job and we have set up controls to insure duplication of results.

MACHINES FOR SHOT PEENING

Machines for shot peening fall into two distinct categories. One is the wheel type machine wherein a bladed wheel rotating at high speed is gravity fed with peening shot and sprays this shot onto the work by the slinging action of the blades. The second is the air blast type machine wherein the shot is impelled onto the work by means of a blast of pressurized air.

The wheel has the advantage of emitting a terrific hail of high speed shot and thus greatly shortening the peening time necessary to gain the desired result (arc height). Due to the high speed and great volume of shot thrown, the work must necessarily be confined and fixtured in a cabinet. The resulting wear on the impeller blades, cabinet walls and fixtures can be excessive. Fixturing is also more difficult than with air blast machines and the cabinet limits the size of the part to be peened. Large wheel type machines are initially very expensive but a great many are used where there is sufficient production of the same types of items to constantly feed through the machine. The wheel type of machine is generally cheapest for large volume production.

The air blast machines vary as to method of feeding the shot into the air blast. In some, the shot is sucked up by the vacuum caused by the aspirating action of the blast; in others the shot is gravity fed into the air stream and some types have pressurized air to feed the shot into the air blast at the same pressure. Such machines are usually of the cabinet type, although a good many are utilized in a sealed room. The great advantage of the air blast machine is its versatility. The nozzle can be directed onto the work as required instead of having to fixture and position the work in a wheel blast which cannot be directed. For peening individual parts or short runs of the same part (say up to 50 parts), the air blast types are far superior and cheaper to operate than the wheel types.

I would like to mention here the superior advantages of the Vacu-Blast method for some types of work. This applies particularly to work which is round in nature and which must be peened on the' periphery. Examples would be large gears to be shot peened on the teeth only, or long torsion shafts or pipes which are to be peened over its entire surface. Due to the shot pickup principle incorporated in the Vacu-Blast design, it is not necessary to carry out the operation in a cabinet or sealed room. Although a small amount of shot will accumulate on the floor, it usually is less than will escape from a supposedly sealed cabinet of a wheel type machine. The most important feature of the Vacu-Blast pickup nozzle is the ease with which it can be applied to the type of work mentioned. A large gear, for instance, can be set up on a trunion and rotated while the blast nozzle is traversed across the gear face. Variations of traversing speed (a variable speed motor should be used) and blast nozzle air pressure will give a correct combination of arc height and coverage. (Note: These terms will be defined later.) In a like manner, a long torsion bar or oil well drill pipe can be surface peened merely by rotating the shaft or pipe on centers and traversing the blast nozzle along the length of the work. Here again, the speed of traverse and blast air pressures can be regulated to give the desired coverage and arc height.

TYPES OF SHOT USED FOR PEENING

Peening shot can be purchased as such from a good many companies. It is well rounded and screened to definite size ranges. It used to be assumed that the shot hardness had to be equal to or greater than the hardness of the metal being peened. Under these circumstances, the only shot available to peen carburized parts or tool steels having a hardness of 60 R_c was chilled iron which has a hardness of about 63 R_c. However, it has been found that heat treated steel shot having a hardness of 46 R_c is just as effective, as far as increasing fatigue strength is concerned, as is chilled iron. Steel shot is more expensive initially than chilled iron; however, the brittle nature of chilled iron causes it to break up very rapidly and, in fact, it has but one fourth to one sixth the life of steel shot. Chilled iron also presents a major separation problem since shot peenings specifications require that broken shot be separated and eliminated from the peening shot. Steel shot is therefore much cheaper in the long run; it is cleaner to handle and causes much less wear on cabinet walls, wheels, nozzles and fixtures.

Cut wire shot is another material used for peening; however since it is manufactured by clipping off short lengths of steel wire, it is, initially, not round and has sharp edges. Peening specifications require that this type of shot be blasted against scrap steel until it rounds out and this process, besides being time consuming, decreases the shot life. It is suggested that round steel shot be used for all peening operations on steel parts. By purchasing it, as such, much time and trouble will be saved.

It might be well to add here that a number of authorities in the shot peening field prefer cut wire to cast steel shot and John Almen states that cut wire can be used as cut on hard metals such as carburized parts and that he personally prefers clipped wire to so-called steel shot for peening steel hard enough to resist serious notching.

Clipped wire has the advantage of uniformity of mass (due to clipping off definite lengths from wires of uniform diameter) that cannot be achieved by screening cast steel shot. Conditioned, rounded by previous blasting against a hardened surface, clipped wire shot can be purchased and it is common practice to peen with this material and to make small additions of the unconditioned clipped wire shot as the original shot load diminishes due to wear or dragout. Actually, the size uniformity claim is somewhat obviated by the fact that the shot wears and becomes smaller in use and the lower limit of size is finally dependent, as with cast steel shot, on the efficiency of the dust removal system.

Some interesting experiments have been carried out concerning the effect on arc height which occurs by use of new conditioned clipped wire shot each particle of which has a definite mass. As a matter of idle speculation, one cannot help but wonder at the mass of research data that would be available on duplexing (the use of two or more shot sizes in different ratios as to quantity of each) if shot was available only in precisely definite increments of size. This variable may or may not be important and a great deal of research remains to be done on it.

Nonferrous metals can be peened with balls of nonferrous metals, or nonmetallic materials such as glass, plastics and the like. Generally speaking, aluminum would be peened with aluminum shot.

John Almen states that "some nonferrous metals can be damaged by peening with steel or iron shot because serious electrolytic corrosion may result from embedded iron particles and that this is particularly serious in magnesium." It might be well to note that soft metals such as magnesium and aluminum can be effectively peened with glass beads. In peening stainless steel with steel or iron shot, care should be exercised to make sure that any embedded shot dust is removed from the surface of the part by a post chemical treatment (passivating) since such particles can materially decrease the resistance of stainless steel to corrosion. It is, perhaps, a not too well known fact that stainless steel, the surface of which has embedded iron particles from such sources as an iron contaminated grinding wheel or iron oxide particles from buffing compounds, is prone to rusting. Many puzzling occurrences of rusting in stainless can be attributed to this effect and a good post passivation treatment can obviate the trouble.

SHOT PEENING VARIABLES

Peening rate and arc height attained can vary with shot size, shot hardness, shot speed, quantity of shot thrown per second and angle of impact.

Shot size is specified as having a diameter which is one half, or less, the radius of the smallest fillet or surface irregularity of the critical area being peened; therefore, if a part having a one sixteenth inch radius fillet is to be shot peened, the largest shot that should be used would have a diameter of one thirty second of an inch or less.

Shot hardness for practically all steel (ferrous) parts can be 45-50 R_c. In other words, a round, heat treated steel shot can be purchased and used effectively for all peening operations on steel regardless of hardness.

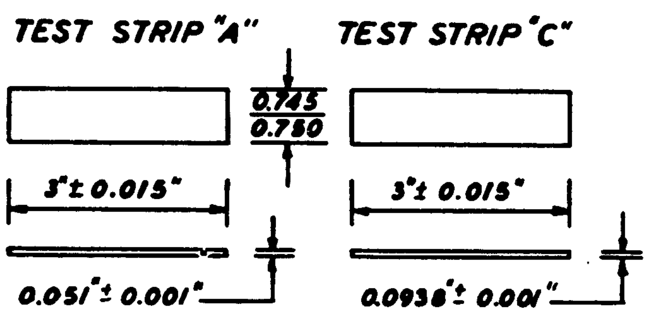
Speed of shot can be changed by regulating the air pressure or, in the case of a wheel, the wheel speed should be adjusted until the arc height and coverage required can be attained (to be discussed later).

Quantity of shot thrown is important only with respect to the amount of time it takes to do a peening job. If you can throw a lot of shot at a definite speed, the job can be finished in a shorter time. (More peened parts per hour).

The shot blast should strike the surface being peened as nearly vertically as possible; however, it is seldom that this can be accomplished in actual practice since the blast may be directed at a groove or fillet. It is common practice to peen such surfaces as though the bottom only was being treated and to accept the results due to peening some areas at an angle to the shot blast. In other words, it isn't worried about too much except in very critical areas. In very critical parts (those which are subject to rapid fatigue failures) every attempt should be made to direct the shot blast perpendicular to the surface subject to the highest loading (the point where the part has been failing). Some reduction in shot effectiveness can occur due to shot rebound when the blast is directed normal to a surface. This is particularly true in centrifugal machines.

STANDARDS OF MEASUREMENT FOR SHOT PEENING

For purposes of standardization, quality control and reproducability, some form of measurement must be set up for any specific process and, for the process of shot peening, the standard of measurement is arc height. This means of measurement was devised by John Almen while at the Research Laboratories Division of General Motors and the test strip used along with the dial gage for measurement are called the Almen Strip and Almen Gage. This test is based on the fact that a sheet of metal which is cold worked on one side only (as by shot peening) will deform, due to the compressive stresses set up on the cold worked side, and form a bow or arc (hence--arc height) with the peened side being convex. The more the peening the greater the arcing, up to a certain point. Almen standardized the sheet of metal used, both as to sire and physical characteristics as follows:



These strips of SAE1070 cold rolled spring steel are heat treated to 44-50 R_C. and must have a flatness of .0015 arc height as measured on the Almen Gage. It should be noted that practically all test strips purchasable today are about 46-48 R_C, and within 0.0005 arc height.

These strips are mounted on an Almen Block (Strip holder) which is usually carburized and hardened or made of heat treated tool steel to give solid backup for the strip and, primarily, to prevent damage to the block by continuous exposure to the shot stream. It should be noted that a soft steel block will give the strip the same arc height as a hardened block for the same shot peening exposure; however, after a dozen or more test exposures, the soft steel block will be badly indented and may need replacing. Almen blocks can be purchased but, in a pinch, a soft steel block can be made up for use. Dimensions and shapes of the Almen block and gage can be found in the SAE Manual on Shot Peening.

In use, this block, with secured Almen strip, is solidly placed at the same position with respect to the blasting nozzle or wheel as the work it simulates. In the case of a gear, the Almen block would be attached to a dummy or scrap gear of the same dimensions as the one to be peened. The attachment can be made by use of the same screws that hold down the strip. For short runs, a flat would merely be milled onto the gear surface and this flat would be drilled and tapped for the hold-down screws. The Almen strip would then be attached directly onto the milled surface for peening trials. The thing to remember is that you are peening the roots of the gear teeth so the Almen strip should be at the same distance from the nozzle as the root. The shot blast would be directed vertical to the root surface and peening would take place as the gear rotated on a spindle thus peening all of the gear teeth. In the case where the shot pattern (area of shot blast coverage on the peened surface) did not cover the full length of the gear teeth, the nozzle would have to be traversed down the length of the tooth while the gear is rotating under the blast thus assuring that all of the tooth surfaces are peened.

It is sometimes convenient, for field work, to tack weld a flange on to the Almen block so that the block can be "C" clamped onto any kind of a jury-rigged frame so as to hold it at the necessary distance from the blast nozzle. In other words, a dummy gear doesn't have to be a full gear but merely an extension from the rotating device (as an arm) on the end of which the block could be attached (by tack welding or screws) so that the Almen strip is at the same distance from the rotating center as would be the roots of the gear teeth.

I made mention, previously, of the necessary distance of the work being peened from the nozzle orifice. This distance can be any that is required to do the job. The thing to realize is that the closer the nozzle, the more intense and rapid is the peening action; however, the shot pattern is very limited in area and this necessitates moving the work or the nozzle or both around so as to cover all of the surface to be peened. If, by moving the nozzle 3 or 4 inches farther away from the work surface the blast pattern would cover all of the surface to be peened, then this would be the simplest procedure; here, however, it would be necessary to prolong the peening time to achieve the necessary arc height and coverage. (Coverage is the percentage of peened surface actually indented or struck by the shot. If 5 per cent of the surface of the Almen strip used in the test run, or the actual surface peened, was unindented by the shot then the coverage would be 95%).

Before going on to why we would peen to a certain arc height and how we would set up to accomplish this, I wish to clarify exactly what a specific arc height means and the "A" and "C" strips.

Suppose we have a Government or other specification that reads "The part will be shot peened on area as shown in accompanying print to .016A2." This merely means that the Almen #2 (2 for #2 gage) gage will be used (there used to be an Almen #1 gage but its use has been discontinued so there is actually only one measuring gage to worry about). The A stands for the Almen A test strip and the .016 is the actual thousandths of an inch that the dial gage point can advance due to the curvature of the A strip by peening. The dial of the gage reads in units, as 1, 2, 3, 4, 5 etc., but these are actually thousandths. Therefore, .016A2 means a 16 reading on an Almen A strip when a number 2 gage (the only gage in use) is used. A specification of .010C2 means a 10 reading on a C strip must be attained. Since the number 1 gage has been discontinued, you will often-times find designations of .018A or say .012C. The number 2 gage is inferred in such a case. You may even see specifications as I4A and this merely means .014A2.

The A strip is used up to arc heights of .024A2 and the C strip above this reading. There is a direct 7 to 2 ratio between A and C strip readings, that is. an .024A2 reading would be equivalent to 2/7 (.024) or .007C2. The A strip is used between .004A2 and .024A2 and the C strip from .007C2 to .020C2. Shot peening intensities above .016C2 are seldom if ever required and most parts would be over peened at this arc height.

One thing to remember in measuring arc height is that the smooth or concave side of the peened strip should be placed against the gage so that the surface roughness will not effect the reading.

A published rough guide as to what arc height to peen parts to is based on the thickness of the part and is tabulated as follows:

Thickness of Part	**Arc Height**
1/16"	.004A2
1/8	.008A
1/4	.014A
3/8	.018A
1/2	.021A
5/8	.007C
¾	.008C
7/8 or greater	.010C

In actuality, 80% of all shot peening is held in the range of .010A2 to .020A2 and even fillets of ½" radius on a 4" diameter shaft are usually peened to .018A2.

John Almen gives considerable insight into the art of adjudging specifications for peening by his statement that "in peening clean, uniform parts, it is not necessary to use high intensities since all that is needed is to avoid surface weakness. Rough forged or other parts, which may be decarburized or scaled should be peened with sufficient intensity to reach deep uniform metal."

The tolerance on peening to a specified arc height is ±.002, therefore, a spec. of .016A2 means .014A2 to .018A2 and .010C2 would be satisfied by an arc height of .008 to .012C2.

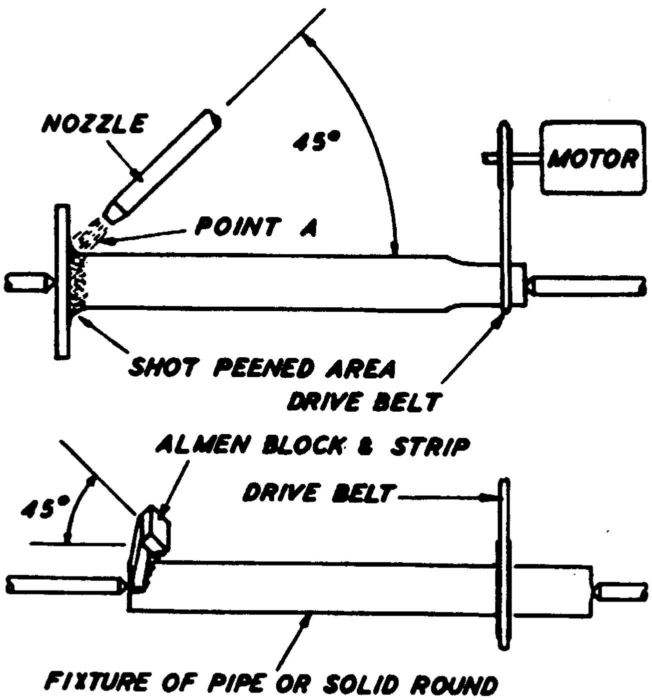
I wish to point out here why shot peening specifications are sometimes so haphazardly applied. There is a correct scientific way to arrive at an arc height specification for any particular part and the procedure is to shot peen a series of groups of the same part (usually 3 or 4 to a group) to definite intensities in steps. The parts of each group would be peened to the same arc height and the groups would be peened to say .006A2, .010A2, .014A2, etc. These parts would then be run to destruction in field or simulated field tests and the arc height conforming to the group which gave the longest service life would be specified.

The drawback here is the extreme expense of such tests and that it must be done on every component which is prone to service failure since the peening intensity which gives optimum life on one part will not generally give optimum life on another part. To counter-balance this we have the factor that shot peening a part by guess will generally give a very advantageous increase in fatigue life, and it is readily realized that it is much cheaper in the great majority of cases to peen between .012 and .018A2 and accept the increased service life resulting from this treatment than to try and get optimum results. . With respect to "guess peening" deep peening will reduce the "hazard," if any, of this process. Some parts, however, have been scientifically tested to establish the optimum shot peening conditions and any manufacturer who has expended such a large amount of money to establish this arc height has a bonafide right to demand that his parts be shot peened under controlled conditions and to precise arc heights. On this basis, and the basis that .all manufacturers want quality control to guarantee the uniformity of their product, we will discuss the method of controlled shot peening to meet a definite specification.

SHOT PEENING TO SPECIFICATIONS

The first step is to provide a fixture to support the Almen block with its test strip so that its position simulates the critical surfaces to be peened.

Second, a guess is made as to the peening conditions that will be necessary to meet the specification. As an example: say S330 tru-steel shot is used at an air pressure of 50 pounds and the nozzle is positioned 3 inches from the surface to be peened. As a specific example, let us assume that the work is a main drive shaft 3" in diameter with an integral coupling flange 8" in diameter on one end and that the area to be peened is the radius (fillet) where the shaft becomes the flange as shown in sketch. Assume .016A2 is the spec. (See following drawing):



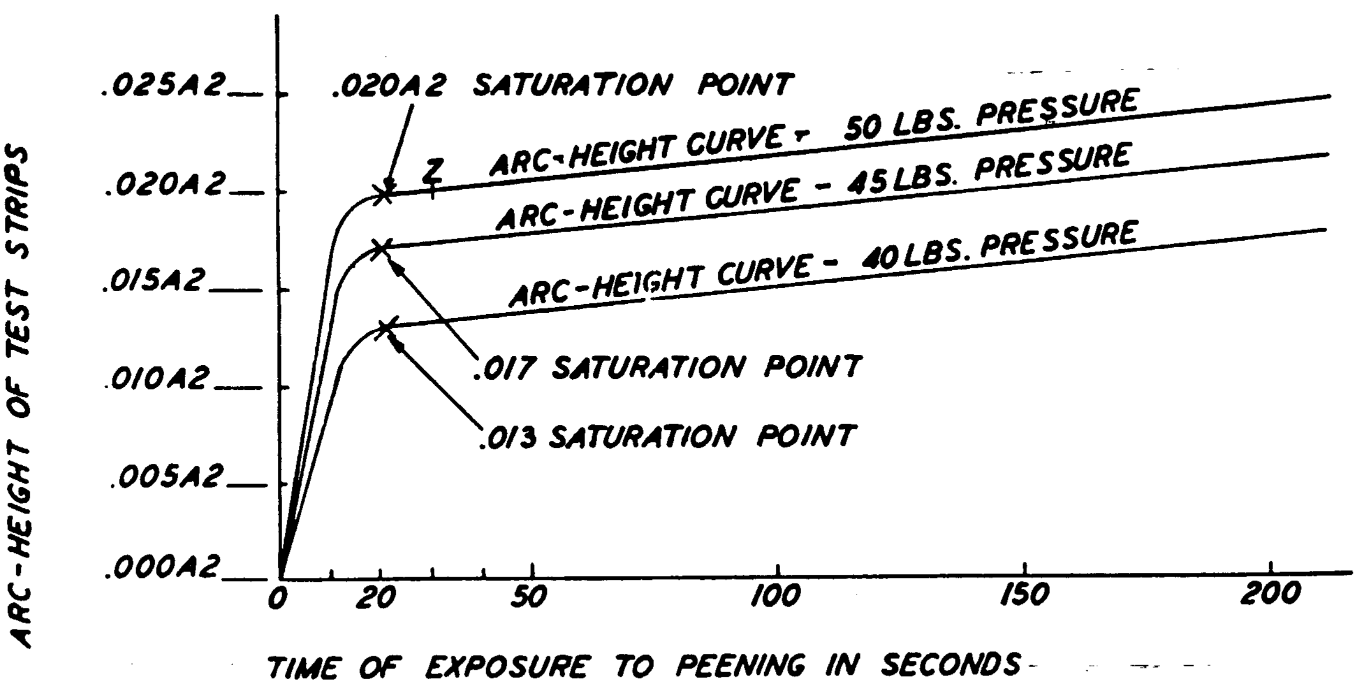
A dummy fixture (shown in lower part of drawing) would be made up which would rigidly hold an Almen block so that the distance from the center of rotation to the test strip would be the same as the distance from the axis of the shaft to point A which is halfway up the fillet. The block would be positioned so that its surface was at right angles to the blast stream when directly under it (45° angle to the axis of rotation). The fact that the ends of the Almen strip will come closer to the blast nozzle due to the block being flat instead of round is overlooked since tests are based on this arbitrary positioning in the first place. The position of the block should be the same as was originally used in deriving the specified arc height. If no derivation tests were originally run, the positioning described would be used.

Thirdly, using the setup described a shot peening (arc height) curve is determined. This is done by running (unpeened) new Almen strips for specific periods of time such as 5, 10, 15, 20, 25, 35, 45, 60, 90 and 120 seconds. The arc height on each strip is taken on the Almen gage and these arc heights are graphed against the corresponding time as shown.

Such arc height curves are very characteristic. They go up steeply at first then rapidly change to a much more gentle slope. The point X, just to the right of the slope change is called the saturation point and this is the degree to which such shot peening should be carried.

Say our first try gave us an arc height at the saturation point of .020A2. We would then decrease the air pressure to some lower value, say 40 pounds and rerun the curve. If the saturation point on the graph of this run came out as .013A2, we would increase the air pressure to, say 45 pounds and rerun the test. Say the saturation point came out at .017A2. Since the spec. is .016A2 (.014-xO18A2) we would be in tolerance and we would then examine the Almen strip at .017A2 to make sure that the coverage was as specified or better.

Coverage is usually specified at 90% minimum. If the time for the .017A2 strip was 25 seconds at 45 pounds pressure, we would polish the side to be peened on a new



Almen strip and then shot peen it at this setting. The strip would be removed and examined under a magnifying glass and an estimate of the coverage (indented surface) made. In nearly all cases this will be above 90% at the saturation point. If it is not, we would repeat the foregoing tests using a smaller size shot and would find that we could get above 90% coverage by using say 40 pounds pressure and a peening time of 45 seconds to give us a saturation point arc height of .016A2.

We would then be ready to start controlled production peening to specification. Using the smaller size shot, a shaft would be loaded into the rotation fixture and peened for 45 seconds at 40 pounds pressure.

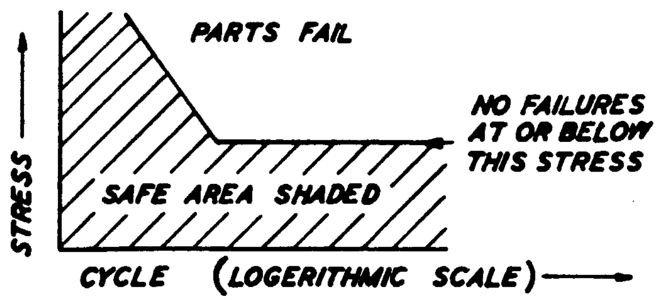
It would be well to point out at this point that, whereas our peening time here is 45 seconds, it would take at least four minutes of peening time to overpeen and, even then, it would not be damaging but would merely start to detract from the beneficial increase in fatigue life already gained. It is oftentimes the practice, therefore, to peen beyond saturation to some point (Z) on the curve thus giving assurance that the saturation point has been reached and complete coverage effected. In doing this, we have increased the peening time so, to prevent the arc height from going over spec (.018A2) we decrease the air pressure slightly to compensate. I might add that this is fairly common practice; however, with a little experience, you will find that peening to saturation is not difficult and this should be the technique used.

FATIGUE FAILURES

We have repeatedly stated that shot peening greatly extends the fatigue lift, of metals. The definition of fatigue taken from the ASM "Metals Handbook" is as follows: "the tendency of a metal to break under conditions of cyclic stressing considerably below the ultimate tensile strength."

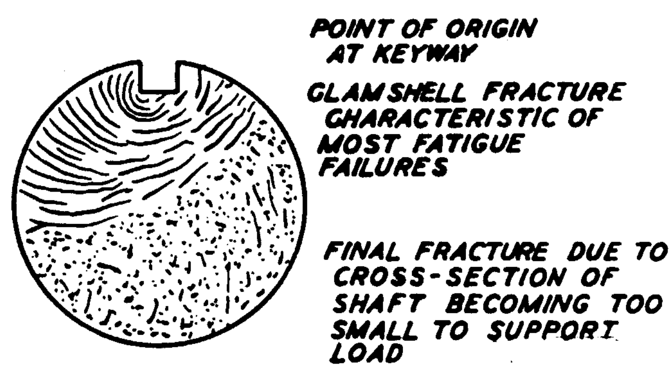
To quote Robert Burns, "The Best laid plans of mice and men gang aft aglae." Here we have a case of mankind using his scientific knowledge to find out the strength of steel in p. s. i., calculate the loading produced on a steel member in a machine and then very wisely designing the member out of steel so that it would take all of the loading it would get. Being of a cautious nature, he made the member at least 50% stronger than his tests and calculations said it had to be. This is known as a "factor of safety" and is a clear acknowledgement that mankind isn't too sure of himself. It's rough on a design engineer to find out that his liberal pad of protection wasn't liberal enough in the long run. The machine performed beautifully for awhile. Then the member busted; though this "failure by fracture" usually had the aggravating habit of occurring after the guarantee period had passed.

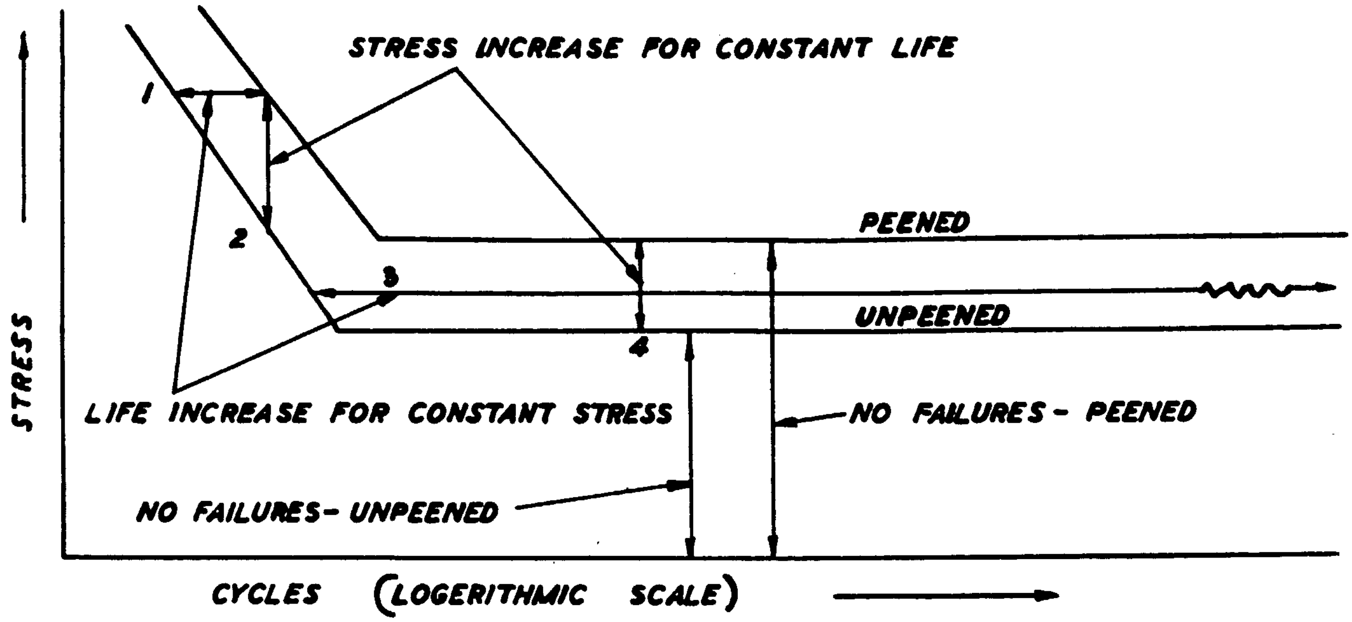
It is easy to visualize the amount of soul-searching and recrimination that took place in the engineering world. It wasn't just one machine that broke but a lot of them. The engineers knew something was wrong and began to wonder if maybe the static loading tests they had performed so meticulously on bars of steel might be inapplicable with respect to machine in motion. To cut it short, this proved to be the right answer and a lot of research resulted in the fatigue diagram as follows:



10,000,000 cycles on this diagram is considered as an indefinite life span. Up to a certain stress (horizontal--no failure line) you could cycle stress a part over 10,000,000 times and it would not fail. Above this line you could cycle it for say 200,000 cycles and then it would break. At a still higher stress (less than the ultimate tensile strength as determined by static loading) the part could fail in 1000 cycles or less. The result is, that for reciprocating. rotating or vibrating parts, we no longer design on the basis of static tests but on the basis of fatigue tests.

Parts which fail by fatigue are fairly easily recognized both by the origin of the failure and the clam shell markings over a part of the fractured surface. Such failures generally originate at a stress riser which can be a fillet, hole, keyway. forging lap, punch mark, seam, corroded area or steel having variations in structure (as hard spots). Failure originates at one of these points and a crack gradually works into the part. It should be realized that the part still has ample cross-section to sustain the loading under static stresses and, therefore, does not fail until the cross-sectional area has been reduced to a point where it can no longer sustain the applied load. It then fails suddenly. The part (area) which lets go all at once has a crystalline appearance, whereas, the area which failed over a period of time has a clam shell appearance resulting from the rubbing action of the surfaces on each other a, illustrated in this diagram:





HOW SHOT PEENING INCREASES FATIGUE STRENGTH AND LIFE

Shot peening, in effect, raises the demarcation line on the fatigue diagram as shown above.

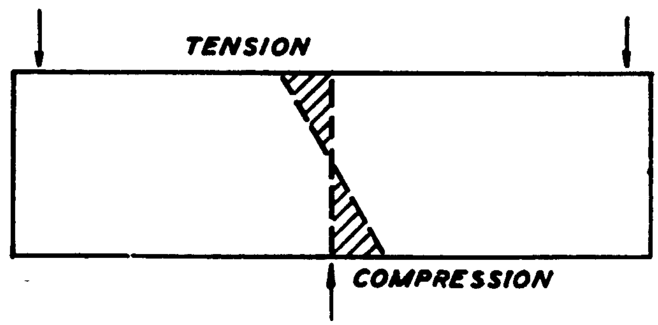
This diagram is from the SAE Manual on shot peening and is, of course, idealized for demonstrative purposes. It can be seen, that for the stress (load) at point 1, the service life of the part would be almost doubled and at point 2, for the same service life, the load on the part could be increased by about 40%. Point 4 would allow an increase of loading of about 50!%f" without failure and a part that would fail within say 200,000 cycles at point 3 would last 10,000,000 cycles or more if peened. It can readily be seen from this diagram why some parts when shot peened can have a hundred fold increase in service life over critically loaded unpeened parts:

WHY SHOT PEENED PARTS RESIST FATIGUE FAILURE

In about 90% of the cases, fatigue failures originate at the surface of the part at some point which acts as a stress raiser. A few failures originate at subsurface defects such as slag inclusions, porosities, flakes, or the like, in the steel. This is particularly the case where the surface is in compression due to shot peening, nitriding, carburizing, or the like, and where the part is very highly loaded. Subsurface fatigue failures are rare and need not be dealt with further.

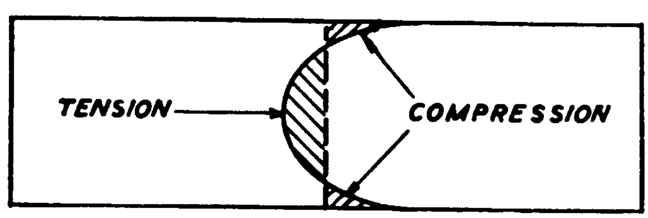
The surface is the weakest part of a structure since it is here that imperfections that act as stress raisers occur and, also due to the fact that, under beam loading, the tensile stresses in the part are at a maximum. Even so, these explanations do not wholly account for the surface weakness of a part under fatigue conditions. It may be due to the fact that surface grains are supported (buttressed) from the inner side only, although this is merely conjecture. The fact remains that the surface of a working part is extremely critical fatiguewise.

Under beam loading, as shown in following diagram, the convex side of the part is under tension (undesirable) and the concave side is under compression (desirable):

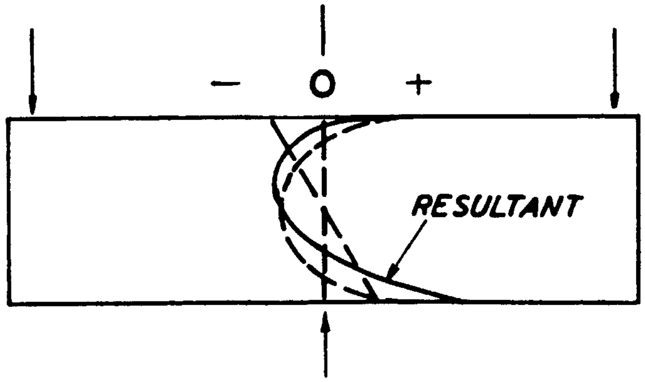


The same part, when shot peened overall in the unloaded condition, has its surface in compression due to the cold working and plastic upsetting of the surface metal by the hail of shot. Since the surface is in compression, the core is in tension to balance out the forces as shown in following diagram:

STRESS IN A SHOT PEENED PART



If the shot peened part is beam loaded, the stress which results is an additive combination of the stresses due to beam loading and the initial stresses due to shot peening as shown in following diagram.



The resultant stress shown as a heavy black line shows that the surface of the part is still in compression even on the convex side of the beam loaded part and fatigue failures do not occur! in a compressed area. The center is under a high tensile stress; however, it is no where near as detrimental here as it would be at the critical surface. We can load the bar beamwise until the convex surface of the peened part is in tension but this tensile stress would be far less than it would be. if the part were not peened and would probably be well within the fatigue strength of the material. The surface compressive stress set up by shot peening counteracts the tensile stresses set up by beam loading and thus brings the surface metal into the safety area of cyclic stress loading.

OTHER USES OF SHOT PEENING

As mentioned before, shot peening is primarily used to increase the fatigue life of cycle stressed parts; however, there are a good many other fields which can derive unique benefits from shot peening. These will be listed and discussed numerically.

1. As an aid in prevention of stress-corrosion cracking.

This form of failure was originally called Season Cracking and, whereas it has existed as long as mankind has worked with metals, it was attacked as a metallurgical problem after British troops in India began to experience a rash of failures of brass cartridge cases. These cases were inspected on arrival and were supposedly sound; however, during the seasonal wet weather characteristic of the Indian monsoons, the cartridge cases would split open without even being fired. Metallurgical sleuthing revealed that these cases were cold drawn and that surface tensile stresses were set up during the process. It was also found that most metals and brass, in particular, would readily crack when such parts were exposed to corrosive media or conditions such as the hot, humid monsoon climate of India. The solution to the problem was to anneal the cases to relieve the damaging surface tensile stresses which were locked in by mechanical working of the metal.

John Almen gives another version of the name. Season Cracking, to the effect that brass carriage lamps had a tendency to split open during the early summer season and subsequent investigation revealed that it was due to the corrosive attack of ammonia generated by barnyard manure piles.

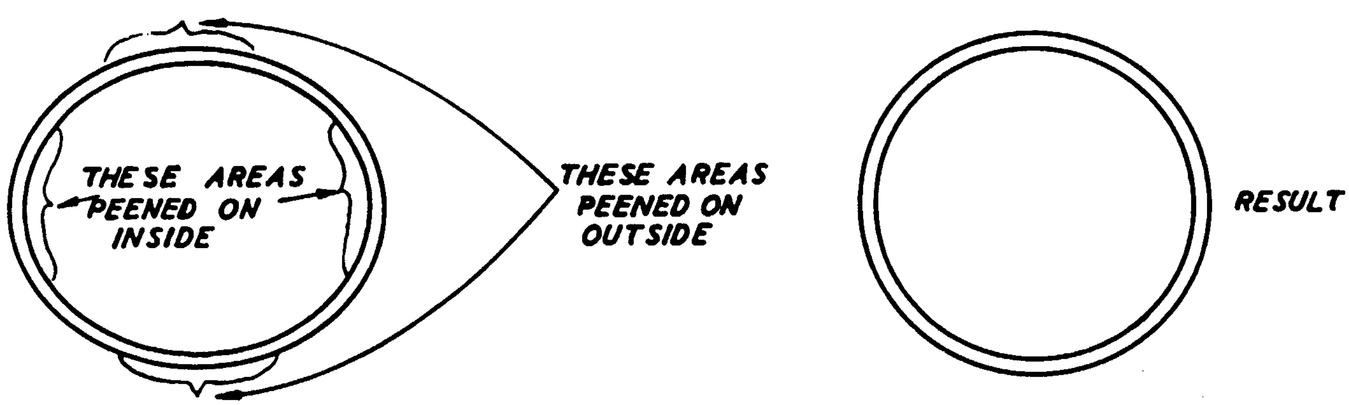
As mentioned, annealing will obviate this form of failure; however, shot peening has also been used to correct the defect. Shot peening counteracts the surface tensile stresses by superimposing surface compressive stresses which are not subject to cracking under corrosive condition.

2. As an aid in eliminating fret-corrosion failures.

Metal parts which fret (periodically rub or impact) against each other under corrosive environment are subject to pitting and disintegration. Since surface compressive stresses in parts subject to such failures will greatly ameliorate the condition, shot peening is resorted to as a corrective measure. This is particularly true on aircraft parts.

3. Straightening of parts by shot peening.

An Almen strip bends (arcs) due to the compressive forces and metal upsetting caused by peening. This same effect can be used to straighten parts which are fairly thin or quite large compared to their cross-section. For instance, large fairly thin (¾" thick) ring gears which were considerably out of round have been selectively shot peened to bring them within a .003" out of round tolerance. As an exaggerated example, we will use peening to round out a steel hoop which is elliptical in shape. Automobile axle shafts can be straightened out by peening after heat treating with life increases of more than a hundred fold.



4. Peen-forming.

Peen straightening is actually peen forming; however, in the aircraft industry, whole wing sections are given camber (wing curvature) by selective shot peening. You could visualize the original plate as being a large Almen strip which is shot peened at a variable intensity over its surface to give a variation in curvature. This forming could be done by dies; however, the convex surface of the part would have a detrimental surface tensile stress which would be prone to failure by fatigue or stress-corrosion attack. By shot peening, the peened (convex) surface is put into compression by the plastic upsetting of the surface metal while the opposite (concave) surface also is surface compressive (concave side of a bent part is in compression).

Saw manufacturers and saw filers form circular saws by peening. A very old art. They do not use small areas of impact but hammers having large radii of curvature. Another such use is the hammering of piston rings to make them open up. By doing this, they have to be closed in, compressed, to fit into the cylinder barrel and assume their original true circle shape when so compressed. Were these rings merely flex bent outward, they would yield at the weakest point and would not resume a true circle form on being pressed into the cylinder.

5. Shot peening as a corrective measure for grinding defects.

Ground metal surfaces are generally in a surface tensile state due to upsetting of the surface metal by the heat generated in this process. Severe grinding with a loaded or dense wheel will generate so much surface heat and upsetting that the surface will actually split, on cooling, due to the exceedingly high tensile stresses set up. These grinding cracks look much like the craze pattern on a sun-baked sheet of mud and are caused by the same forces. As a sheet of mud, left from a dried pond or puddle, dries, it shrinks due to evaporation of its contained water. This shrinkage sets up tensile stresses and the mud sheet develops a crack pattern when these stresses exceed the cohesive forces between the mud particles.

Shot peening counteracts these deleterious surface tensile stresses by superimposing a higher surface compressive stress. Below is a rough graph of some experimental results conducted on ground and shot peened specimens.

6. Shot peening of parts prior to chrome plating to correct loss of fatigue strength inherent to chrome plated parts.

Chromium plating greatly decreases the fatigue life of the plated part; however, by shot peening the surfaces to be chrome plated prior to the plating operation, this defect can be obviated. On the next page is a graph, based on experimental work, which illustrates this.

7. Peening as a means of testing the adhesion of electroplates.

Such articles as silver plated aircraft bearings require excellent adhesion of the electroplated metal to the base metal and this adhesion can be checked on a control basis by shot peening a selected percentage of the silver plated bearings. If adequate adhesion is not present, the shot peening will cause the silver plate to blister and peel at the defective areas.

8. Shot peening as a means of porosity correction in castings.

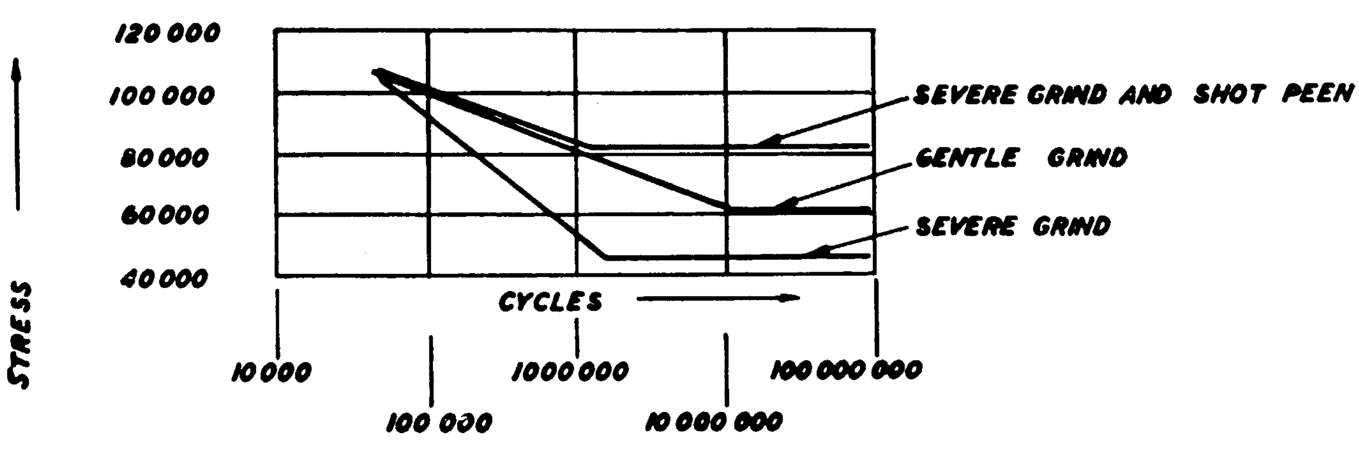
Small pores in castings can sometimes be sealed by the plastic flow of the surface metal due to shot peening. It is not effective for large pores.

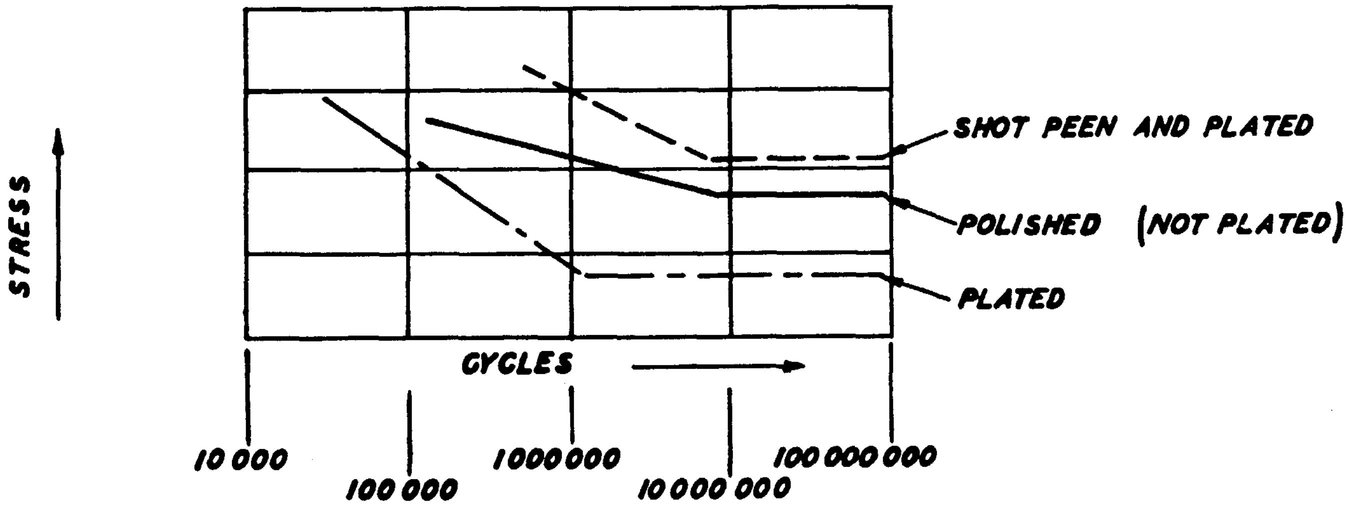
9. Shot peening to give an oil retentive lubricating surface.

This is a very valuable technique and has been largely overlooked by the engineering profession. One German automobile has cylinder barrels which have been shot peened and then chrome plated. The indentations caused by the shot peening are oil retentive. Due to the increase in fatigue properties, this process is probably superior to the porous chrome plating of cylinder barrels.

10. Shot peening can be used to roughen and expand slightly undersized parts to create tight fits. Knurling is used to accomplish the same thing.

11. Decarburized steels and, particularly, parts which are only partially decarburized, can be improved by shot





peening; however, shot peening will not improve a decarburized part to the point where it is as good as a properly heat treated part.

12. Ultrasonic activated parts, such as cutting tools, which are subject to extreme cycling (such a tool expands and contracts 27,000 times per second), can be greatly enhanced lifewise by shot peening. This is a case of fatigue property improvement.

13. Another case which nicely illustrates the improvement in fatigue life due to shot peening is its use on overload protection devices. A machine which was subject to jamming and breakage of integral parts due to overload, was given overload protection by machining a fillet in the drive shaft so as to cause the shaft to shear at the fillet when a jam occurred. This fillet served the purpose intended but failed rapidly by fatigue. By shot peening the fillet, the fatigue failures were eliminated and the overload device functioned effectively.

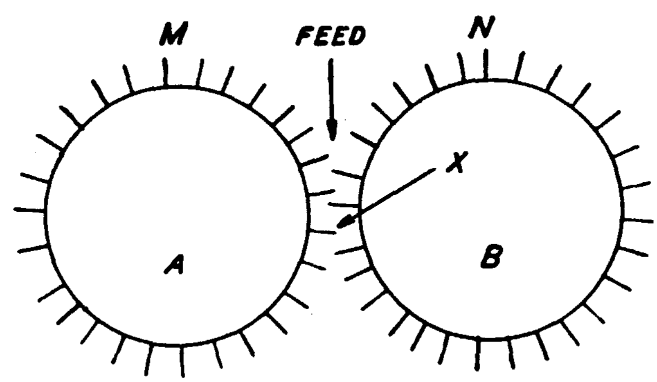
14. Deburring by shot peening.

Deburring can sometimes be effectively and economically accomplished by shot peening. A part which is to be carburized or hardened can, in some cases, be left undeburred and be hardened by shot peening. The peening blasts away the hardened burrs and the increase in fatigue strength resulting from the peening more than offsets any detrimental surface effects caused by the burrs being broken away.

15. Some parts are shot peened as a means of texturing the surface for esthetic purposes.

I would like to mention strain peening at this point. This has previously been referred to with respect to the hammer peening of carriage leaf springs on the convex side while subject to a bending load and tests show that it is particularly advantageous in the spring field for both coil and leaf types. If a coil spring, subject to compressive loading in service, is compressed to about 80% of the tensile strength in a jig and then shot peened, its resultant fatigue life can be increased some twenty fold over the life expectancy that would be achieved if it were shot peened to the same extent in the uncompressed state. The fatigue lives of an identical set of Springs, one of which was unpeened, one normally peened and one strain peened would be of the order of magnitude of 1 to 10 to 200. It should be borne in mind that any flexed part is essentially a spring whether used for that purpose or not and that by flexing the part under a jig imposed load in the same direction that it would be flexed in service and then shot peening the convex (tension stressed) side, we are strain peening the part and its fatigue life will be greatly enhanced.

A specific example in mind would be the use of strain peening to prolong the life of shredder tynes. These tynes are merely round heat-treated steel spines, a multitude of which protrude from the peripheries of two rolls as shown in sketch.



In this device, one roll (B) rotates at a greater speed than the other (A) and such materials as linoleum scrap are fed through the tynes for shredding so that the material can be reprocessed. Due to the difference in speed of the rolls and the resistance of the scrap linoleum against the tynes, the shredder tynes of roll B are flexed (bean loaded) in a clockwise direction (Up-at the point of contact X) while those of roll A are flexed down (also in a clockwise direction). If then, with reference to the point X, the tynes of roll B are flexed up and peened on the underside and those of roll A are flexed down and peened on the top side, we will have appropriately strain peened the tynes and greatly improved the life of a part which would otherwise be very prone to failure. In actual practice, these tynes would be flex loaded and peened in a holding jig and then inserted into the holding holes of the shredder rolls. Care would have to be exercised to see that the tynes were properly positioned. At the point M on roll A, the peened side of the tyne would be to the left since this tyne would be flexed downward at the shredding point X. The tynes at point N of roll B should also have the peened side to the left since (at point X) the tyne will be flexed upward.

An alternative and far simpler method would be to shot peen the tynes overall or cold work their surfaces in a tumbling barrel. This would not give the life advantage of strain peening but would give a valid life increase and, at the same time, permit the tynes to be assembled at random. There Are many instances where one factor (the greater life increase due to strain peening) will outweigh the other (simplicity of accomplishment and ease of assembly) and vice versa.

For informative purposes, we will mention some specific article applications of shot peening.

1. Hamilton Standard uses shot peening on propeller hubs to increase the fatigue life.

2. In the aircraft industry, bolt heads which are subject to high loading and vibration are peened in the fillet between the head and the shank.

3. Starter rotors the teeth of which broke out at 45,000 rpm due to fatigue, were shot peened and gave excellent service at speeds in excess of 45,000 rpm.

4. Other items on engines such as piston rods, tappets, shafts, rocker arms, etc. were shot peened in their critical areas (fillets, angles or points where the parts change from heavy to thin cross section) to improve their fatigue life.

5. The following graph shows the life results on some latch springs given various treatments.

6. In the oil well industry, such items as drill pipe, sucker rods, mandrels, swivel pins, cutter bodies, etc. are peened to give extended life.

7. Torsion bars--by shot peening and presetting, the life of torsion bars can be increased from about 30,000 to 250,000 cycles or an eightfold increase.

8. Gears, whether carburized, quenched and tempered or annealed, are shot peened to increase fatigue life.

One example is that of a case hardened gear, stressed to 80,000 psi in service, which had its cycle life increased from 200,000 to 30,000,000 cycles as a result of shot peening.

9. Marine propellers-shot peened to prevent cavitation and fatigue.

10. Airplane propellers--peeved near hub end to increase life.

11. Propeller hubs--peeved on cone seat bearing area to prevent fret corrosion cracking.

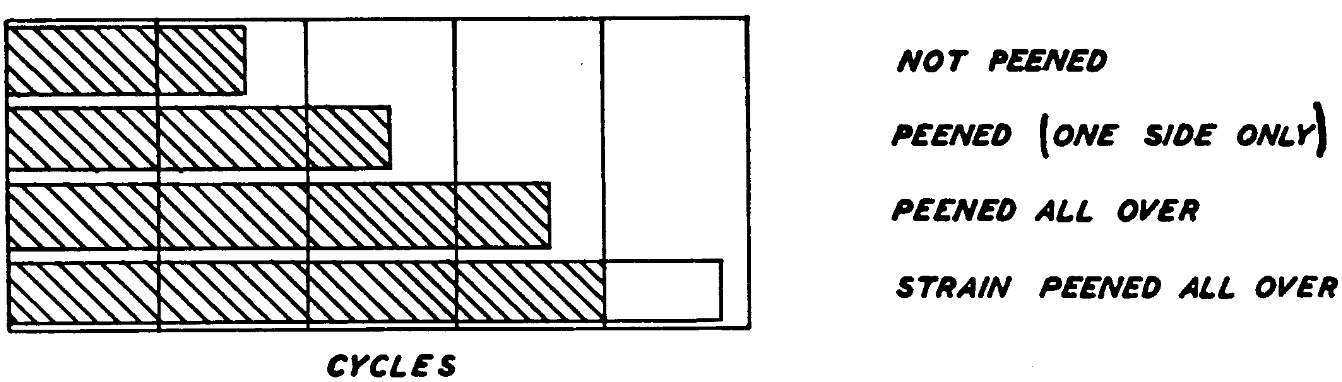
12. Exhaust pipes are peened to improve fatigue life and this gives effective improvement even though the part reaches a temperature of 850° F.

With respect to high temperatures, it has been demonstrated that by shot peening notched (notch serves as a stress riser) specimens of Nimonic 80 at .008A2 intensity a 30% improvement in fatigue life resulted even after tempering (heating) the shot peened parts for 50 hours at 1000° F. A high strength alloy steel shows a strength loss of only 1000 psi after shot peening and tempering for 100 hours at 700° F.

13. Link belt chain rollers gain an effective life increase by shot peening.

14. Pole line hardware such as eye bolts and turnbuckles can be improved by peening.

15. Brittle failure from low temperature can be avoided by shot peening.



These springs are shaped as shown by loading in a jig which forced the ends and were strain peened together.

ADDITIONAL NOTES ON SHOT PEENING WHICH ARE WORTH REMEMBERING

1. Except for the very smallest sizes of shot, air pressures over 50 psi should not be used.

2. In most cases, the increase in fatigue life it not particularly influenced by shot size; however, some recent tests have shown that bigger shot may cut fatigue strength. It is therefore advisable to use the smallest shot that will give the correct arc height and coverage at the saturation point.

3. Care should be taken not to overpeen metals (such as copper, self hardening manganese steels and some types of stainless steels) which work harden rapidly.

4. Surface finish prior to shot peening has a good deal of influence on fatigue life. Shot peening actually tends to roughen fine finishes; however, this roughening effect is not detrimental due to the increased fatigue strength which results.

5. The new SAE numbering system for shot sizes is based on high and low limit screening; however, the number following the S is actually the nominal size of the shot in ten thousandths. For example, the largest size shot (S-1320) has an approximate nominal size of .1320" diameter. S-330 bas .033" diameter and the smallest size shot (S-70) has a nominal size of .007" diameter.

6. Improved fatigue life of steel parts increases as the hardness of the parts increase and shot peening becomes less effective as the mass of the part increases.

7. Shot peening is less effective on straight push-pull types of cycling than for other cycle induced stresses; however, it oftentimes renders life improvement even in this case.

Don't be afraid of shot peening. Considerable material has been covered in this treatise to demonstrate the how and why of shot peening to controlled specifications; however, there is another side of the story and it concerns the shot peening of parts by operator judgment only. In spite of the fact that there is a correct (scientific) way to establish the proper arc height and peening conditions to give optimum fatigue life improvement to a specific part, the fact still remains that this method is exceedingly time consuming and expensive. It is seldom justified except in the case where the cost can be prorated over a very large production volume or where the part is so prone to failure that it is absolutely necessary to establish the optimum conditions for fatigue life improvement.

It can honestly be said that most shot peening specifications are based, not on experimental results, but on the basis of a conservative guess by a person with some background knowledge in this field. The percentage of improvement in the fatigue life of cycled parts is so considerable, and the number of such cases where it works effectively is so favorable, that one is justified in assuming that a cycled part will be benefited if it is peened under the following conditions: 1. air pressures used are below 50 psi except for the very smallest shot, 2. coverage is fairly complete as judged by eye, 3. a small (S70 to S170) to medium (S-230 to S-460) size shot is used and 4. care is taken that the critical areas being peened are fairly uniformly and completely covered. Though these conditions will seldom give maximum improvement to the part, they will almost invariably improve the part.

Suppose for example that a trip hammer on E machine was constantly failing. This would probably be due to fatigue and shot peening the area where failures occurred could very probably remedy the failures or, at least, greatly decrease them. The peening procedure would be to establish the critical areas on the part and, with a nozzle pressure of 40-50 psi, direct a blast of S-110 to S-230 steel shot against the critical areas until the coverage seemed complete by visual examination. If the critical areas were not readily apparent, the part would be shot peened overall except for areas which are machined to a fit tolerance. Such machined areas would be stopped off by plugging holes (as threads) or bores with rubber (or even wood) plugs and outer surfaces would be covered with rubber adhesive tape (scotch or friction tape can be used). There is little doubt but that the part would be improved and that this is a valid operating procedure. If there were a considerable production of these parts, they would be fixtured and peened under controlled conditions to give the customer the assurance of uniformity of quality in his product to which he is entitled.

By way of substantiating this method of approach, let us examine some of the basic ideas behind it.

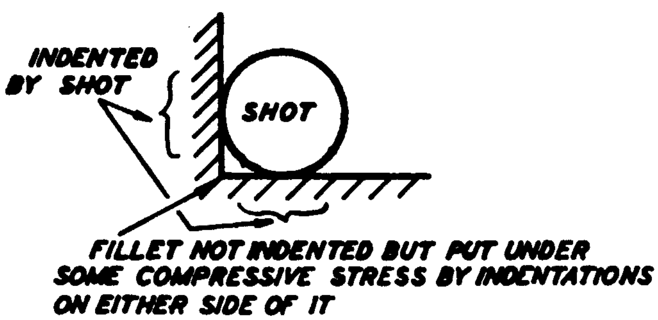
1. There is nothing mysterious as to why shot peening is so beneficial in obviating fatigue failures. It creates surface compressive stresses in the part and there is a wealth of evidence to show that fatigue failures do not occur where such stresses exist. Even plate glass is made immeasurably stronger when processed so as to create surface compressive stresses although (due to the brittle nature of glass) this is done by thermal upsetting. Other nonmetallic materials (as rubber and plastics) can accrue lengthened service life by inducing such beneficial surface stresses in them.

2. We have already mentioned the ancient use of hammer peening and it is well to note that the shot size in this instance was the size of the ball on the hammer. Another interesting anecdote along this line was told by a professor of metallurgy at the University of California to the effect that an early Wright diesel airplane engine owned by an Alaskan bush pilot developed a crack in a critical area and this crack gradually propagated until it became a matter of extreme concern to the pilot. Rather than be put out of operation while waiting for a new part, the pilot took a chance and heavily ball peened the metal at the end of the crack. This engine was used for over five years in the cracked and peened state and was taken out of service for general debility and not because of the crack. This is a case where a crack (stress raiser) propagating by fatigue could not penetrate through a compressively stressed metal area.

3. Even sandblasted metal parts show improvement in fatigue life over uncleaned parts. Sand is a pretty sharp edged type of shot.

4. In the automotive industry, shot blasting is used for cleaning a good many parts and this blasting improves them fatiguewise. Shot blasting can be considered as shot peening in its most uncontrolled form.

5. With respect to coverage, it has been shown that a coverage of as little as 30% will give 80% of the effectiveness in increased fatigue life that can be achieved by full coverage and it has been demonstrated that the unimpinged areas between the shot indentations are in a state of compressive stress though not to the same degree as they would be with full coverage. It can be seen from this that a very sharp groove or fillet into which a shot particle will not quite penetrate will, nonetheless, be improved fatiguewise by the indentations set up at either side of it as shown:



In spite of the fact that improvement will result in this case, the fillet at least should be gone over with a blast of finer shot to give added improvement.

6. If one were to examine strain peening theoretically and without knowing the excellent end results it achieves, we would be very apt to condemn such a method on the basis that it would probably result in over-peening.

It can be seen from the foregoing that shot peening by operator judgment is a valid, though not an optimum, method of approach providing, of course, that the operator has reasonable skill and experience.

UNINVESTIGATED VARIABLES IN SHOT PEENING

An example of a variable which, to my knowledge, has not been investigated would be the shot peening of a part at different temperatures. There is no good reason to assume that a part receives optimum benefits by being shot peened at room temperature as is now universally done. It is entirely probable that a different improvement, or lack of it, would result if a part were peened while hot (as immediately on removal from a tempering furnace) or cold (as immediately on removal from a deep freeze box). This might well be an insignificant variable and any improvement resulting from such an operation might be too inconsequential to be worth the added effort; however, until valid experiments have been carried out in this direction no one can assume that the results would not be significant and worthwhile. I have made some very cursory experiments along this line by the simple expedient of taking an Almen "A" strip, block and holding fixture (the strip being already attached to the block and fixture) to a desired temperature and then shot peening it immediately to a definite room temperature arc height. That is, the entire assembly was taken to the desired experimental temperature, shot peened for a definite time and intensity (.015A2 at room temperature) and immediately removed and measured for arc height while still hot. 25°F increments between -80°F and +400°F were checked with plotted results of arc height against temperature showing an increase of .001A2 arc height for about every 100°F increase in temperature. Arc heights varied from .013A2 at the lowest temperature to .019A2 at the highest temperature. After the strips had returned to room temperature the arc heights remained within .0005A2 of the original (hot or cold) measurement with the distinction that those measured hot increased slightly but very definitely when re-measured at room temperature while those measured cold decreased slightly but very definitely in arc height when remeasured at room temperature.

This demonstrates that the temperature of the part being peened is a bona fide variable; however, a great deal of research will be necessary to determine whether or not such variations will greatly improve a part so treated.

Another interesting experiment is that done by Richard Harvey wherein he marquenched parts and then shot peened them while they were still at the marquench temperature and, hence, still in the austenitic state. The resulting benefits were substantial though the specific applications of the process have to be much more thoroughly investigated.

This is a fairly lengthly treatise; however, I feel that it will give the reader an insight into the process of shot peening which cannot be attained except by experience and considerable reading of other literature. In concluding, I would like to mention that there are a great many aspects and uses of this process which have not yet been developed. If a part is failing, it won't hurt to try it.