SURFACE FINISHING AND SURFACE CONDITIONING
BY SHOT PEENING

Thomas N. Fritts  CMFGT
Repair Development Engineer
Cooper Airmotive

PROCESS DESCRIPTION AND EFFECTS

The primary benefit of shot peening is the generation of an even compressive stress pattern and the effective elimination of microscopic defects in the thin surface shell of the part.

Shot peening is more effective in reducing fatigue failures in parts subject to cyclic loading. Failures originate in surface areas under tension load and cracks will propagate from a surface defect or other stress riser. Shot peening prevents these failures by creating an even compressive stress layer in the surface of the part.

As each individual particle of shot strikes the metal surface, it produces a slightly rounded depression. Plastic flow and deformation of the surface occur at the instant of impact and the edges of the depression may rise slightly above the original surface.

As the part is loaded, its critical surface area will not develop tensile stresses until the peen induced compressive stresses are first overcome; this permits an increase in the allowable stress level and the service life of the part. The effect of shot peening toward the improvement of the surface integrity of the part is also important. No matter how carefully a part is manufactured, it will exhibit some surface imperfections. These may be localized areas of tensile stresses or phase transformations from machining or grinding as well as pits, scratches and other surface defects.
Thomas N. Fritts

In a completely peened part the compressive stress layer may have a depth of 0.001 to 0.020 inch, depending upon the peening impact and the hardness of the work surface (Fig. 1). The tensile stress in the under layers being within the yield point of the fibers, an equilibrium of stresses results and the surface fibers are said to be in residual compression when surface layer must return to zero stress before the fibers are subjected to a tensile stress. This tensile stress will be much lower than the surface compressive stress because it is distributed in a comparatively thicker core.

Most failures in machine parts have their beginning at stress risers on the surface. These are the result of a tensile stress or tearing apart of the metal fibers. Metal parts subjected to frequent cyclic stressing or frequent reversal of stress, tension and compression, or reverse twisting or torsional stressing, may ultimately fail through a fracture beginning at the surface. This type of failure is known as fatigue failure.

The magnitude of residual stress that can be induced by shot peening is limited to about half the yield strength in hard metals. This can be extended to near full yield strength by subjecting the surface to tensile stress while peening. Strain peening is commonly used on leaf springs and in the peen forming of aircraft wing contours. Heat treatment or machining operations which would remove the induced compressive stress layer are not feasible after shot peening. Light honing or lapping is permitted on steel, but is usually limited to one-tenth of the test strip arc height.

SHOT PEENING USES AND ITS APPLICATION

This process is used extensively on gear teeth, drive shafts, torsion bars, axles, ball studs, high strength fasteners and oil well drilling equipment. Often it is applied only at a critical area such as a fillet radius. Overspray of shot is often permitted. If not, simple masking techniques are usually sufficient. New uses of shot peening include the prevention of fatigue failures in automotive wheel rims and railroad car wheels. Peening will reduce the notch sensitivity of hard steels. When applied to highly stressed parts prior to chrome plating, peening acts to prevent any cracks or imperfections in the chrome deposit from spreading into the parent part.
High performance engines may be built from standard engine parts if the parts are shot peened prior to assembly. Peening is used on aluminum die cast transmission housings or gearboxes to prevent "leakers" or loss of lubricant through porous wall areas. Bearing surfaces and radius areas of engine crankshafts are peened to reduce fatigue cracking from repeated stress reversals, as well as to retain lubricants—the shot indentations acting as minute reservoirs. The aerospace industry has long used shot peening for the improvement of fatigue life of landing gear and other structural members. It is used extensively on jet engine parts such as compressor and turbine rotor components, including compressor blades, turbine blades, gears and hubs as well as many other parts. Some of this work is done with glass beads.

Stress corrosion is a problem which has become critical in recent years as a result of the use of higher strength materials. Failures are caused by the complex interaction of corrosive (environmental) attack and sustained tensile stress at the surface of a metal. Sustained static loadings are present in such structures as aircraft landing gear, which are stressed by internal hydraulic pressure while at rest on the ground.

Shot peen forming of aircraft skins has been successfully carried out for a number of years. Only recently, however, has the full potential of this forming system been realized, eliminating the need for costly stretch and forming dies.

Peening is sometimes used to straighten parts which may have bent in heat treatment, etc. Rings which are out of round can sometimes be corrected by peening. Machined bulkheads and other large structural shapes, which twist or deform as a result of machining operations, can sometimes be straightened by selective peening. The technique used in such a case is to select and peen a critical area which, if expanded or elongated, will straighten the part.

Recently, as a solution to the problem in the overhaul of fan jet engines where the mid-shaft was bowed or bent beyond serviceable limits, selective shot peening was used to restore eight shafts to the required .003 to .005 F.I.R. Originally, these shafts were out of tolerance in the range of .031 to .085. The price per part savings is approximately $43,000.00.
Shot peening has been poorly understood by many design engineers and its application has often been left to those who do commercial shot peening. On the other hand, the results of extensive testing to determine the best peening application for a specific type of part often are not widely disseminated or are withheld as proprietary information.

RECAP OF SHOT PEENING USES

1. Increase in fatigue life
2. Reduction of stress corrosion cracking
3. Reduction of fret corrosion failures
4. Straightening
5. Forming
6. Reduction of tensile stresses after grinding
7. Prior to chrome plating to increase fatigue strength
8. A testing mechanism for electro-plated surfaces
9. Reduction of porosity in castings
10. A slight expansion of undersized parts
11. Treatment to improve oil retentive properties of the surfaces
12. Improvement of decarborized steel surfaces
13. Deburring
14. Decorative texturing of surfaces

TYPES AND SIZES OF SHOT

Shot used for shot peening can be made from several different materials. These include cast steel shot, cast iron shot, malleable iron shot, chilled iron shot, stainless steel shot and glass beads.

Shot can be identified by a standardized numbering system. Sizes range from S-70 to S-1320. The shot number is coded to indicate the approximate diameter of the individual pellets in thousandths of an inch. For example, S-70 shot is 0.007" in diameter. S-280 shot is 0.028" in diameter. Standard size specifications for cast shot has been established by the SAE and is shown in Figure 2.

The life of steel shot varies inversely with the shot diameter as shown in Figure 3. It must also be remembered that not only is the average life of small diameter shot longer in number of impacts, but the number of pellets per pound is greatly increased as the shot diameter is reduced. The number of shot pellets per pound is shown in Figure 4.
The ideal peening application would use perfectly round shot of uniform size with each particle having the same hardness and density and applied at the same velocity and impact angle. In practice, of course, this is impossible.

Selection of the shot size depends upon thickness of the work, the appearance desired, the size of fillets and the intensity desired. At a given velocity, smaller shot will give a lower intensity and larger shot will give a higher intensity. More particles per pound provides wider coverage and is therefore more economical. Peen forming of heavy sections may employ steel balls up to 1/4" in diameter or larger. The use of the larger balls provides a smoother finish.

Most peening as in manufacturing aerospace and other applications is done with cast steel shot sized to SAE recommended practice J444 with a hardness range of 40 to 50 Rockwell C. Some aerospace companies and the U.S. Air Force have developed shot specifications which require closer control of size, hardness, allowable non-rounds and unacceptable shapes.

The use of glass beads as a peening medium has increased in recent years. This material is applicable to thin sections requiring low peening intensities. Steel shot will leave ferric contamination of aluminum. This can be removed by acid dipping and in some cases by over-peening with glass beads. Because glass beads are inert, they will not contaminate the aluminum or titanium and other exotic space materials.

**SHOT VELOCITY AND IMPACT ANGLE**

Air pressure or wheel rpm are varied to change shot velocity. Since only the shot traveling at the highest velocity in a given application will produce the maximum peening intensity, any shot at lower velocities has the effect of extending the time required to reach desired intensity. Figure 4 showing the number of pellets per pound versus shot size illustrates the economical advantage of using the smallest size shot which will accomplish the task.

**MEASUREMENT OF SHOT PEENING INTENSITY - PROCESS CONTROL**

Shot peening intensity, or the effect of shot peening on a work piece, is measured by determining the resultant effect on standard Almen test strips as shown in Figure 5.
Specifications for standard Almen test strips are as follows:

1. SAE 1070 steel CRS spring steel
2. Bright or blue temper finish
3. Heat treated and tempered to 44-50 Rockwell C
4. Arc height, flat $\pm 0.0015$" as measured on standard Almen gauge

The test strip must be shot peened while firmly located in a holding fixture. Design of the Almen test strip holding fixture is shown in Figure 6.

Since the cold working of the outer layer of metal by shot peening causes a compressive stress, the test strip is contoured in a manner with the shot peened surface on the convex side as shown in Figure 7.

The amount of contour in a test strip after shot peening is most conveniently measured by a gauge developed by J. O. Almen of the Research Laboratories Division of General Motors Corporation. His gauge is known as the "Almen Specimen Gauge" and is shown in Figure 8.

Shot peening intensity results from the momentum of the shot hitting the surface and the number of hits per square inch. This intensity is usually measured prior to shot peening production parts by exposing one or more test strips in the same manner and for the same length of time as the production parts will be processed.

The shot peened test strip, after exposure, is contoured both longitudinally and transversely. The Almen gauge is a precision instrument having four bearing points in fixed positions, accurately spaced. The dial indicator plunger is located on the unpeened surface, mid-way between the four points and gives the arc height reading in thousandths of an inch. For example, 0.15 inch is equivalent to .015 Almen A intensity.

Recommended shot peening intensities for steel, aluminum and titanium alloys are given in Figure 9. These values should be used only as a guide. To obtain the maximum value from shot peening, the actual part under simulated or actual conditions should be tested for optimum processing.

Shot peening to a high Almen intensity can cause unwanted warpage in a production part. Figure 9 can be used as a guide to avoid part warpage.
The effect that shot peening has on metallic surfaces is affected by many process variables. Because of this, it is important to be aware of the effects of each variable and control the process to insure uniform and consistent shot peening quality. Following is a list of process variables:

1. Shot material
2. Shot hardness
3. Shot uniformity
4. Shot shape
5. Shot velocity
6. Angle of impingement
7. Work piece material
8. Work piece hardness
9. Work piece heat treatment
10. Shot peening coverage
11. Almen arc height
12. Post shot peening thermal treatments
13. Post shot peening mechanical treatments
14. Air pressure
15. Distance from nozzle to work piece
16. Speed and rotation of work piece
17. Nozzle movement, vertical and horizontal, as indicated by saturation curve on Almen test strips
18. Centrifugal wheel RPM

Since there are so many processing variables affecting the quality of shot peening, processing standards are necessary to insure consistent quality. Many manufacturers have developed their own process standards either to cover the shot peening process in their plant or to cover specific production parts. Many of these standards are patterned after the following military and engineering specifications:

MIL-S-13165B  Shot Peening of Metal Parts
MIL-S-851  Steel Grit, Cut Wire Shot, Iron Grit, Shot Blast Cleaning and Peening
MIL-A-9954  Abrasive, Glass Beads

ARC HEIGHT EXPOSURE CURVE

Shot peening engineering requirements usually specify the shot size and type, Almen arc height, percent of coverage and area of part to be shot peened.
At this point, it would be well to define some terms which frequently become confusing when specifying shot peening operations.

Almen Arc Height

The amount of total indicated curvature on a standard test specimen in thousandths of an inch when placed in a standard Almen arc height gauge.

Visual Coverage

One hundred percent (100%) visual coverage occurs when a shot peened surface no longer retains any of the original surface which has not been struck by peening shot. Fifty percent (50%) coverage refers to that surface which retains 50% of its original surface. A practical value of 98% coverage is commonly used instead of 100% to avoid close inspection with a microscope and to avoid insuring that the absolute last portion of a surface has been covered. Figure 11 shows the practical reasoning behind the use of the 98% coverage figure.

SHOT PEENING INTENSITY

The Almen arc height is measured on an arc height exposure curve where, under ideal conditions*, the curve becomes horizontal or flat. A more practical definition, under less than ideal conditions, is the Almen arc height value of the test coupon when exposed for a time sufficient to be past the "knee" of the arc height exposure curve; or, the Almen arc height obtained at an exposure time, which when doubled does not exceed 10% in arc height value.

If Almen test strips are exposed to a uniform blast stream of shot for progressively longer exposure times, the curve levels. Saturation is that point at which the rate of increase of intensity with exposure time beings to decline. The saturation point is just to the right of the knee of the curve and it indicates that the test strip, but not necessarily the part, has approximately 100 percent coverage. Beyond the knee of the curve, a 100 percent increase of exposure time will produce an increase of approximately 10 to 15 percent in test strip arc height. The use of this curve is valuable in

*Ideal conditions would include shot of constant velocity striking the specimen at a constant angle and identical in size, weight, shape and hardness.
evaluating and controlling a peening application. This is typical of arc height exposure used in the shot peening applications in all types of metal and a multitude of parts processed today. In making a set-up, the test strips are carefully placed to cover all areas to be shot peened and to present the same angles to the stream to duplicate actual production conditions.

SHOT PEENING EQUIPMENT - AIR BLAST AND CENTRIFUGAL WHEELS

The air blast methods are divided into three different basic systems: Direct Pressure, Gravity and Induction Suction.

Direct Pressure

In the direct pressure system, the shot in a pressurized pot is fed directly into the blast cleaning equipment hose and discharged through a nozzle. The shot is ejected at higher speeds and with greater concentration than in the gravity method. Nozzles and lines are subjected to greater wear and more shot is consumed.

Gravity

In the gravity fed system, a shot feed hopper is located above the nozzle and shot flows by gravity to the nozzle where air entering from a separate line mixes with the shot to propel it. A wider spray pattern results from this method and the shot has less force than that from the direct pressure type.

Induction Suction

In induction suction blast cleaning equipment, a variation of the gravity blast method, the medium is drawn from the shot collecting hopper into the nozzle by a partial vacuum created in the suction line leading to the nozzle by high velocity air flow. A larger proportion of air to medium makes this method ideal for light applications.
Air Blast System

The most efficient air blast system for peening, in terms of cubic feet per minute of air required per pound of shot moved, is the direct pressure method.

In the direct pressure system the peening shot must be contained in a pressure vessel so that it will drop by gravity through a metering orifice into the high pressure air line. When the system is continuous the pressure vessel has an upper chamber which can be vented to the atmosphere while it is filled and can be pressurized while the charge is dropped into the constantly pressurized lower chamber, which in turn feeds continually into the high pressure air line. A cycling mechanism controls this operation and insures a continuous flow of shot into the lower pressure vessel.

Because of their size, air nozzles are readily aimed to reach difficult areas. Also, various nozzles can be adjusted to different angles and air pressures in one set-up for a difficult part.

Airless Blast System

Centrifugal wheels are efficient peening shot throwing devices. They have been used for many years for peening automotive springs and other parts for which high production was required and for which the wheels could be fixed in location.

Shot from centrifugal wheels does not vary in velocity and its control is simply a matter of dial settings.

In addition to a method for propelling the shot, a peening machine must provide means of collecting the spent shot and recycling this shot for reuse. The shot should be passed through an air wash separator for the removal of extreme fines and a coarse screen for the removal of debris and foreign objects. A screening system should also be provided to maintain correct shot size. A shot replenisher may be required on larger machines. Work handling systems may range from simple turntables to complex, variable speed work cars. Indexing table systems with one or more peening stations are adaptable to small and medium sized parts and extensive production.
Equipment must be automated for repeatability, tooling, masking and fixturing as required for proper positioning and rotation for coverage.

Remember, there is no way to inspect shot peened work. You must be sure of the peening operation—the parameters, the equipment and the process control—to be sure of the results.
REFERENCES

(1) Almen, John, Black, Paul, "Residual Stresses and Fatigue in Metals"

(2) "Society of Automotive Engineers Aerospace Materials Specifications", AMS 2430

(3) "American Society of Metals", publication

(4) "SAE Standard and Recommendations, SAE Manual on Shot Peening", SAE J8082

(5) Military Specifications:
   MIL-S-13165
   MIL-S-851
   MIL-A-9954

(6) Society of Manufacturing Engineers, "Tool Engineers Handbook"

(7) Vacu-Blast Corporation
<table>
<thead>
<tr>
<th>CMA Size</th>
<th>All Pass U.S. Screen Size</th>
<th>Max 2% on U.S. Screen</th>
<th>Cumulative Max. 50% on U.S. Screen</th>
<th>Max. 6% on U.S. Screen</th>
<th>Max. No. of Deformed Sheet Acceptable</th>
<th>Hardness &amp; Economy Notes SAE Designations</th>
</tr>
</thead>
<tbody>
<tr>
<td>...</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1. Standard Peening Sheet Hardness 50 Rockwell C Average
2. SAE peening designations preceded by P were omitted from SAE specification in 1947
3. Premium peening sheet is conditioned to eliminate scale
SHOT SIZE
S-780
S-660
S-550
S-460
S-390
S-330
S-280
S-230
S-170
S-110
S-70

PELLETS PER POUND
9,350
16,200
23,625
38,100
74,250
114,850
206,400
376,600
852,650
2,520,000
9,651,000

FIGURE 4

FIGURE 5

Shot-peening test-strip specifications.

Analysis of stock: SAE 1070, cold-rolled spring steel edge No. 1 (on 3-in edges).

Finish: Blue temper (or bright), uniformly hardened. Heat set between flat plates under pressure for a minimum of 2 hr at 300°F ±25°F. Hardness 44 to 50 Rockwell C.

Flatness: =0.001 in arc height (strip A); =0.0013 in (strip C); =0.001 (strip N) as measured on a standard Almen gage No. 2.

Diagram of shot peening test strip assembly to test holder.

PEENED SIDE

TYPICAL REACTION ON PEENED ALMEN TEST STRIP

FIG. 7

FIG. 8

Almen gage No. 2 for measuring test-strip arc height.
### RECOMMENDED SHOT PEENING INTENSITY

<table>
<thead>
<tr>
<th>Material</th>
<th>Steel under 200 psi and titanium</th>
<th>Steel over 200,000 psi Steel</th>
<th>Aluminum alloys (Steel Shot)</th>
<th>Aluminum alloys (Glass beads)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Under .090 inch thickness</td>
<td>.006 to .010 A</td>
<td>.010 to .014 A</td>
<td>.012 to .016 N</td>
<td></td>
</tr>
<tr>
<td>.090 to .375 inch thickness</td>
<td>.008 to .012 A</td>
<td>.006 to .010 A</td>
<td>.008 to .012 N</td>
<td></td>
</tr>
<tr>
<td>Over .375 inch thickness</td>
<td>.012 to .016 A</td>
<td>.006 to .010 A</td>
<td>.010 to .014 A</td>
<td></td>
</tr>
</tbody>
</table>

#### FIGURE 9

**FIGURE 10 - PART THICKNESS VERSUS SHOT PEENING INTENSITY**

<table>
<thead>
<tr>
<th>THICKNESS OF PART</th>
<th>MAXIMUM RECOMMENDED ARC HEIGHT</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/16&quot;</td>
<td>.0042A</td>
</tr>
<tr>
<td>1/8&quot;</td>
<td>.008A</td>
</tr>
<tr>
<td>1/4&quot;</td>
<td>.014A</td>
</tr>
<tr>
<td>3/8&quot;</td>
<td>.018A</td>
</tr>
<tr>
<td>1/2&quot;</td>
<td>.021A</td>
</tr>
<tr>
<td>5/8&quot;</td>
<td>.007C</td>
</tr>
<tr>
<td>3/4&quot;</td>
<td>.009C</td>
</tr>
<tr>
<td>7/8&quot; or greater</td>
<td>.010C</td>
</tr>
</tbody>
</table>

#### FIGURE 10

Fig. 11 Relationship of peening coverage to exposure time. Coverages above 100 percent are direct multiples of time required for 100 percent coverage.