INTRODUCTION TO THE PROCESS OF

SHOT PEENING

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INTRODUCTION

Shot peening is a particular case within the range of shot blasting processes, through which compressive stresses are induced in a metal surface by exposing it to a stream of spherical particles at high velocity, keeping the operating parameters under control.

During the process, besides producing the effect described above, the surface is cleaned as in a normal blast cleaning operation, but this is only a secondary effect: the main purpose is to increase the fatigue resistance of the material.

Hammering action with spherical particles

When spherical media is propelled in a high velocity stream and impacts a metal surface, it forms a surface profile of rounded peaks and valleys and produces plastic deformation of the metal. This deformation may extend between 50 and 250 microns in depth.

The effect obtained after peening is the flattening of the metallographic grains at the metal surface. Two effects follow from this:

- The grains spread out, compressing against each other and generating compressive stresses parallel to the surface. These compressive stresses cancel the residual stresses induced by previous operations such as machining, heat treatment or plastic forming, and they also oppose any tensile load the part may be subjected to in later service.
- As a secondary effect, as the grains spread they cover the intergranular spaces, reducing them considerably and therefore also reducing the rate of galvanic corrosion.
- In short, shot peening increases the fatigue resistance of parts subjected to bending and, as a secondary effect, increases corrosion resistance and removes residual stresses, inducing a uniform compressive stress over the whole surface, while also cleaning it.

Main applications

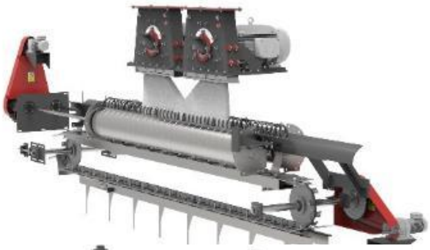
Shot peening is mainly used on components subjected to bending or torsional loads. These are the most common applications:

- Aircraft components
- Axial compressors
- Cams and crankshafts
- Shafts, pinions and gearbox crown gears
- Chain pins and side bars
- Diaphragms and clutch discs
- Mining components
- Rock drills
- Piston rods
- Torsion bars
- Coil springs, valve springs, leaf springs, etc.
- Components for the oil industry:
    - Sucker rods
    - Threaded pipe connections
    - Vertical drilling tool shafts

SHOT PEENING EQUIPMENT

The equipment used for shot peening is essentially similar to that used for other blast cleaning operations, with the addition of auxiliary systems that allow the strictest control of the process parameters.

There are two methods of propelling the shot:



- Centrifugal blast wheel: propels the shot at high velocity through a combination of radial and tangential forces. The advantages of this method include ease of speed control and high output.
- Compressed air: a high velocity air stream carries and propels the particles. This method is recommended for low output or localized treatments, because it allows high impact velocities and lets the stream be aimed precisely at holes, cavities, small radii, gear tooth roots and parts of intricate shape.

Recycling the shot is critically important. During operation the undamaged, reusable spheres must be separated from the dust generated and from the fractured media. An automatic system for continuous media replenishment is also recommended.

For a uniform treatment it is important to have handling systems that give the parts full exposure to the media stream.

Masking is another additional element, used when the treatment must be selective and only the areas to be treated are left exposed.

Glass bead media is used in either dry or wet equipment. Dry equipment is generally of the suction type, while wet equipment uses a pump for propulsion and mixing. Because of the high fracture rate of glass beads, high efficiency is required in the media separation and recovery equipment.

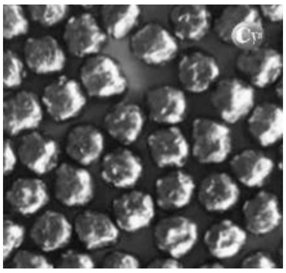
MEDIA USED IN SHOT PEENING

With the sole restriction of a spherical outer shape, the media most commonly used in shot peening are the following:

Cast steel shot, carbon or stainless

This is a widely used medium: through the appropriate heat treatment applied during manufacture it combines good hardness with an acceptable break resistance, and its cost is lower than cut wire shot. Sizes, screened by grading and classified, are standardized in SAE J444.

Conditioned cut wire shot (CCW)



This is the medium gaining the widest acceptance worldwide, because it has excellent hardness with a very low breakage rate. That means relatively low media consumption and, above all, it keeps a constant grading in a high percentage of the particles. Sizes, by grading and classified, are standardized in SAE J441.

Iron casting shot, spherical and nodular

This includes gray, white and malleable iron shot. It is used where a low initial cost shot peening operation is required, given the relatively low cost of this medium, despite a service life far shorter than steel shot because of its greater brittleness. In shot peening, media breakage is critical, since the impact on the surface must be made by a spherical particle — something difficult to control with a medium that fractures readily.

Nodular iron shot is used on a very limited scale, since its low hardness gives poor intensities and it leaves graphite residue on the peened parts.

Glass bead and ceramic media

These are used for forming thin sheet, giving low intensity values. They are used to peen stainless steel sheet or non-ferrous materials that must not be contaminated with carbon steel media.

The four media, compared

Abrasive	Characteristic	Standard	Note
Cast steel shot (spherical) acero fundido (esférica)	Good hardness and accepta-ble break resistance	SAE J444	More economical; as it wears it frac-tures, requiring more frequent classi-fication
Conditioned cut wire (CCW)	Very low breakage; keeps its spherical shape to the end of its life	SAE J441	Higher durability and a more stable operating mix
Iron casting shot	High brittleness: fractures easily	—	Poorly suited to shot peening. Nodu-lar type practically ruled out
Glass bead de vidrio (glass bead)	Low intensities, thin-sheet forming	—	For stainless and non-ferrous parts that must not be contaminated with steel

PROCESS VARIABLES

The most important variables in the shot peening process are the following:

- Media size and hardness
- Particle velocity
- Process intensity
- Impact density on the surface (coverage factor)
- Impact angle and distance
- Media breakage rate

The effectiveness and quality of shot peening depend on the efficient control of each of these variables.

Shot size

This factor affects the kinetic energy acquired, which converts into deformation energy — elastic and plastic — at the instant of impact. As long as velocity and exposure time remain constant, any increase in particle size means an increase in process intensity and a lower impact density. The smallest spherical particle that produces the required intensity is always selected, which gives the fastest process and the best coverage. Part geometry must also influence the choice of size, taking into account its smallest radii so that particle diameters are dimensionally compatible with them.

Particle hardness

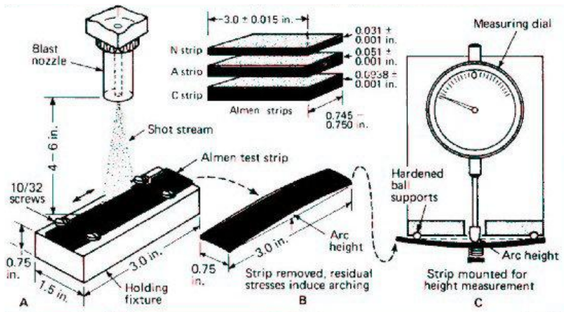
As long as the particle is harder than the surface, hardness does not affect process intensity. However, a particle should be selected that is only slightly harder, because an extremely hard particle is brittle and will have a high breakage rate. If the particle is softer than the surface, the softer it is the lower the intensity achieved.

Particle velocity

From an energy standpoint, increasing particle velocity increases its kinetic energy and therefore the shot peening intensity. In practice, that increase in velocity also produces a higher rate of particle fracture, which prevents the theoretical rise in intensity.

Process intensity

Shot peening intensity is measured by a standardized test, based on the curvature of a strip subjected to the impact of the spherical particle stream. It is called the Almen test and is described in the corresponding section. When one face of a relatively thin strip is exposed to the stream of spherical particles, the hammering effect described above produces the compressive spreading of the metallographic grains at that surface.



That spreading increases the area of the peened surface while the opposite face keeps its original area, which is what curves the strip — a curvature that is a function of the peening intensity applied. Shot peening intensity is therefore measured from the arc height of the peened strip under standardized conditions. Assuming maximum impact density (saturation), intensity will depend on the velocity, size and hardness of the spherical particle projected, and on the impact angle and distance.

The lowest intensity capable of producing the required effects is the most efficient and the least expensive, because it uses the smallest particle and completes the process in the shortest exposure time. Another important factor is the depth of the layer that acquires the compressive stresses after peening: that depth depends on the process intensity and on the hardness of the material treated.

Impact angle and distance

This is the angle formed between the surface and the direction of the particle stream: 90° at the vertical, decreasing to either side. As the impact angle is reduced, shot peening intensity drops. Where the angle must be less than 90° for practical reasons, particle size or velocity must be increased to keep the required intensity. As for distance, intensity decreases as distance increases, so a value must be set and held throughout the process.

Breakage rate

Since only spherical particles should impact the surface being treated, broken particles must be removed from the circuit automatically and quickly. The percentage of spherical media must not fall below 85 %, and higher percentages are needed to hold certain intensities.

Impact density

This is a measure of the degree to which the treated area has been impacted by the spherical particles, and it is known as the coverage factor. Saturation of that impact density is reached when the coverage factor approaches 100 %. Below that, shot peening does not deliver the required fatigue resistance.

There is a direct relationship between the coverage factor and exposure time, given by:

$Cn = 1 - (1 - C_1)^n$, where:

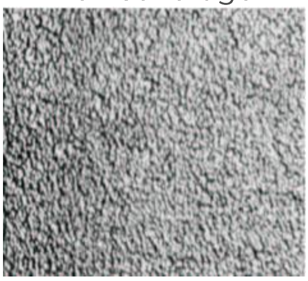
C_1 = coverage factor (%) for one impact cycle

Cn = coverage factor (%) after n impact cycles

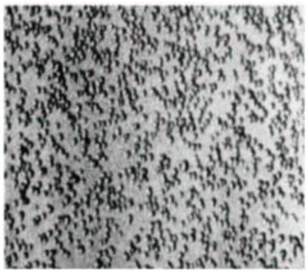
n = number of cycles

The relationship shows that the coverage factor tends to 100 % as the number of cycles increases.

Full coverage



Partial coverage



Accurate measurement of coverage factors above 98 % is difficult. A coupon with a lower coverage factor is therefore measured, related to its corresponding exposure time, and the time needed to reach the required coverage factor is calculated. Since measurement is only accurate up to 98 %, that value is taken arbitrarily as the saturation value. From there, the coverage factor is expressed as a function of exposure time, as a multiple of the time required to obtain 98 % coverage.

There are several methods to measure the coverage factor. The most widely used is the following:

- Give the coupon to be peened a mirror polish.
- Expose that surface to the media stream under predetermined conditions.

- Remove the coupon and project the exposed surface on a comparator at 50× magnification.
- On that projection, and on transparent paper, trace the marks left by the impacts, clearly distinguished from the polished areas. Measure the impacted surface enclosed by the circular marks: the ratio of that surface to the total surface, expressed as a percentage, is the coverage factor obtained.

Summary: what controls each variable

Variable	Effect on the process	Control criterion
Shot size	Larger size → more intensity, lower impact density	Smallest size that reaches the target intensity; compatible with the part's smallest radius
Particle hardness	If softer than the surface, intensity drops	Only slightly harder than the surface; if too hard, it becomes brittle and breaks
Particle velocity	Higher velocity → more intensity	Excess increases fracture and stalls the real gain
Process intensity	Results from the other variables; measured with the Almen test	The lowest intensity that produces the required effect: less exposure time and lower cost
Impact angle	90° gives maximum intensity; a lower angle reduces it	If it must be under 90°, compensate with size or velocity
Distance	Greater distance, lower intensity	Set a value and keep it throughout the process
Breakage rate	Broken particles lower the intensity	Spherical media must not fall below 85 %; remove broken particles from the circuit
Impact density	Below saturation the required fatigue resistance is not obtained	Controlled with exposure time; 98 % is taken as the saturation value

INTENSITY MEASUREMENT — ALMEN TEST

The Almen test is the method standardized by SAE J442 for measuring shot peening intensity. The effect used for the measurement is the curvature produced in a thin strip exposed to the stream of spherical particles under standardized conditions.

The test is expressed in three intensity ranges — N, A and C — and the thickness of the test strip differs for each range.

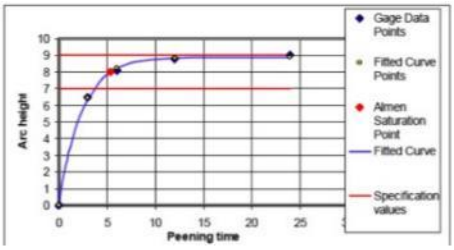
The measuring instrument consists of a dial gauge graduated in thousandths of an inch (0.025 mm), with a base perpendicular to the measuring bar and four support balls forming the plane on which the strip rests. The strip curves during the shot peening process, and the height of the combined longitudinal and transverse curvature is measured on the unpeened face.

The measurement is given by the Almen number shown on the gauge together with the letter of the corresponding strip. Thus 13 A means that, in the Almen test with an A strip, the intensity obtained is 13.

In practice, the choice of range depends on the thickness of the part and on the intensity required by its specification.

The measurement is carried out as follows:

1. Expose the surface of the strip to the particle stream under normal working conditions and measure the exposure time.
2. Remove the strip from its holder and measure the arc height with the Almen gauge, with the instrument previously zeroed.



3. Repeat the two steps above with different exposure times, to plot a curve like the one shown in the figure.
4. The saturation point accepted in the industry is identified when doubling the exposure time increases the arc height by no more than 10 %.

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EFFECTS OF SHOT PEENING

The fundamental application of shot peening is to increase the fatigue resistance of a wide range of components. Other secondary uses are the following:

Fatigue resistance

Parts subjected to shot peening show a considerable increase in fatigue resistance, particularly components such as springs, strips, gears and bars, and tools such as milling cutters, drills, punches and dies.

Metal forming

Shot peening is suitable for certain thin sheet forming operations. It is used particularly on structural components for the aerospace industry, such as fuselage skins. If those curvatures were produced by cold or hot mechanical forming, the sheets would acquire very high residual stresses, unsuitable for the service required.

Removal of localized residual stresses

This is the case of parts left under stress after heat treatment, forming or machining. Shot peening removes the residual tensile stresses, giving a uniform compressive stress over the whole surface.

Increased corrosion resistance

The corrosion resistance of a peened metal increases because the intergranular spaces at the surface are reduced, and also because the residual tensile stresses are removed — stresses that raise the energy of the system and with it the likelihood of corrosion.

Silver plating adhesion test

The adhesion of silver sheet on steel, of great use in certain processes, is effective when excellent anchoring is achieved between the two. One way to measure it is to subject the assembly to shot peening: in the areas where that anchoring is poor, the silver sheet will deform and leave the surface rippled.

Processes after shot peening

Parts treated by shot peening cannot subsequently be subjected to mechanical deformation, heating — other than very mild heating —, machining or polishing, because the surface layer that acquired the compressive stresses is very thin. The only treatment accepted afterwards is surface passivation as corrosion prevention.

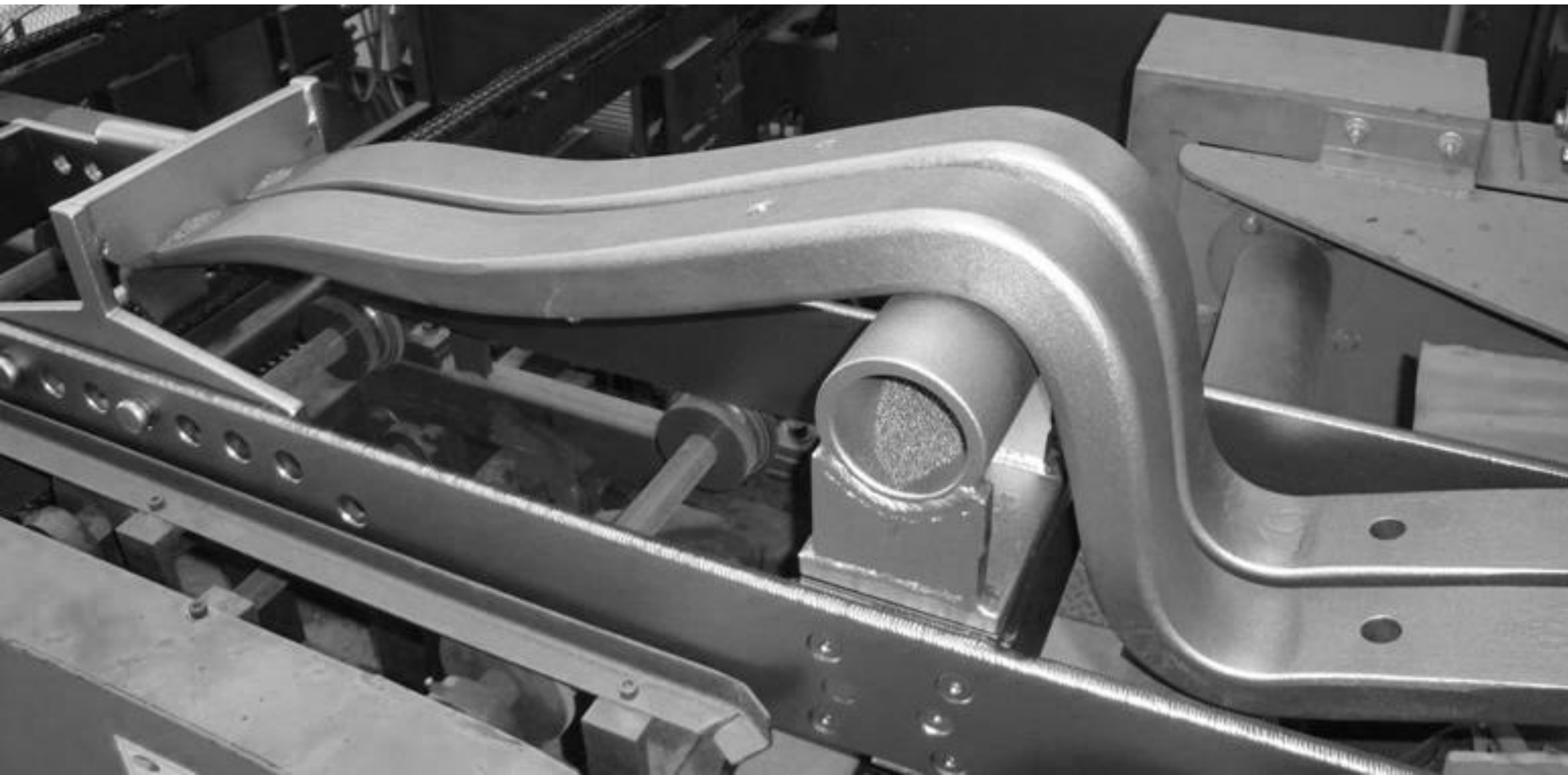
SAE STANDARDS AND BIBLIOGRAPHY

For further information, refer to standards SAE J441, SAE J442, SAE J443, SAE J444, SAE J445 and SAE J827, or to the SAE HS-84 Manual on Shot Peening.

EQUIPMENT

CYM Materiales designs and manufactures in Argentina shot peening equipment, both centrifugal wheel and compressed air: rotary tables, indexed satellite machines, equipment for gears, pinions and crown gears, coil springs and leaf springs, drill pipe threads, and localized shot peening with manipulators and robots.

The Engineering department also develops custom equipment based on a technical survey of the customer's process.



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