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Importance of Controlling Parameters in Shot Peening Process

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Abstract: *The critical peening parameters for improving fatigue life include exposure time, shot flow rate, the distance between the shot-throwing station (blast wheel or nozzle) and the work surface, shot diameter, and shot hardness.*
The objective of the present work is to investigate the effects of these controlling parameters of shot peening on the material properties of the product to be treated. By analyzing how each parameter influences residual stress distribution, surface roughness, and microstructural changes, this study aims to optimize the shot peening process for enhanced fatigue performance.

Key Words: *Shot peening, Material properties, Process Parameters.*

I.INTRODUCTION

Shot peening is a mechanical surface treatment process in which small spherical media—called shots—are blasted at high velocity onto the surface of a material, typically metal. The impact of the shots creates tiny indentations (dimples) on the surface, which induce beneficial compressive residual stresses in the material's outer layer.

Shot peening is widely used in aerospace, automotive, and other industries for critical parts like gears, springs, and turbine blades.

The effectiveness and final outcome of the shot peening process are influenced by the interaction between the following two primary sets of parameters.

1) Material Parameters
2) Shot peening parameters

II.MATERIAL PARAMETERS

These include the microstructure, hardness, surface condition, and hardening characteristics of the work material. The interaction between these material parameters and the shot peening process parameters leads to:

1. Generation of residual stresses within the work material, which improve fatigue resistance.
2. Strain hardening of the surface and subsurface layers, enhancing strength and wear resistance.
3. Changes in microstructure and substructure, such as grain refinement or dislocation density increase, which contribute to improved mechanical properties.

Alterations in surface condition, including increased roughness or potential surface defects, depending on peening intensity and material response.

III.SHOT PEENING PARAMETERS

The shot peening treatment is defined by several critical parameters that must be precisely controlled to ensure consistently high-quality results:

1. **Shot material** – including the grade, shape, and hardness of the shot, as well as the proportion of broken or damaged shot particles in use.
2. **Peening parameters** – such as shot velocity, mass flow rate, peening time, and the impact angle at which the shot strikes the workpiece.
3. **Intensity and coverage** – representing the energy imparted to the surface (intensity) and the percentage of the surface area effectively impacted by the shot (coverage), both of which are determined by the peening parameters.

Careful control of these parameters is essential to consistently achieve top-quality shot-peened components, as deviations can significantly affect the resulting material properties and fatigue performance.

The influence of these parameters on the efficiency and outcome of the shot peening process is discussed in detail below.
Shot Material and Its Hardness: - The shots used for peening are typically made of cast steel, with a hardness of 40–50 on the Rockwell C (RC) scale. Cast iron can also be used as a shot material; however, due to its brittleness, it breaks down quickly, making it difficult to maintain consistent peening effectiveness.

Most shot peening applications utilize **ferrous shots**, which offer high impact energy and good durability. For **thin**

or delicate parts, **glass beads** are often preferred, as they allow lower peening intensities and avoid the need for decontaminating nonferrous parts after processing. However, glass beads have a higher breakdown rate and a greater risk of producing irregular particles in the blast stream.

Ceramic beads are very hard but have much lower density than ferrous shots. They are less prone to breakage compared to glass beads, but they come with a higher initial cost.

A key requirement is that the shot must be at least as hard as the surface being peened. Standard peening shot typically has a hardness range of 45–55 RC but is often supplied at the lower end of this range. When peening very hard parts—such as carburized and hardened gears with surface hardness near 60 RC—standard shot may not induce sufficient cold work. In these cases, **special hard shot**, with a hardness range of 55–65 RC, should be used to maximize the effectiveness of the peening process.

Residual stress studies on steel with a hardness around 60 RC have shown that using special hard shot can produce residual compressive stresses nearly double those achieved with regular hardness shot, significantly enhancing fatigue resistance

Shape and Size of Shots: - Shots or beads used in shot peening should be free of sharp edges and deformed shapes. For ideal peening performance, it is preferable that all shots are perfectly spherical and uniform in size and material properties. The **size of the shots** is selected based on the thickness and geometry of the workpiece:

- **Small shots** provide better coverage, ensuring more uniform treatment of complex or detailed surfaces.
- **Larger shots** deliver smoother finishes but may be less effective in reaching tight areas or achieving high coverage on intricate parts.

It has been demonstrated in both laboratory and field studies that **uniform shot size** is critical: if shots striking the workpiece vary significantly in size, the improvement in fatigue strength can be substantially reduced—even if arc height and coverage specifications are otherwise met.

Using **steel balls** allows for higher deformation energy at the same impact velocity compared to lighter glass or ceramic spheres. However, the **maximum usable shot size** is limited by technical constraints: as ball diameter increases, the resulting surface roughness also increases, and equipment may face operating restrictions. A typical ball size used in shot peening ranges from **0.05 mm to 1 mm in diameter**.

Because shots degrade with repeated use, **regular maintenance** is essential. Metallic shots should be inspected every eight hours of operation, and glass beads every two hours, to ensure that no more than 10% of the shots or beads are deformed or broken.

For **fatigue life enhancement**, shot sizes are typically 1 mm or smaller, selected based on the smallest radius to be peened and the required depth and intensity of the treatment.

Cut wire shot, produced by chopping wrought steel wire into short cylindrical segments, offers superior performance. Once the edges are rounded (conditioned), cut wire shots provide uniform size, exceptional consistency, and a very low breakdown rate. However, cut wire shot has a significantly higher initial cost than cast steel shot, reflecting its superior durability and performance.

Shot Velocity and Impact Angle: - Shot velocity is one of the most critical parameters in the shot peening process. Because the kinetic energy of a shot is proportional to the square of its velocity, higher shot velocities result in greater work done on the material, producing higher compressive stresses in the surface layer. For a shot with mass m and velocity v, the kinetic energy (impact power) is given by:

$$E=1/2 \; mv2$$

In the **air blast method**, shots are introduced into a compressed air stream and directed onto the workpiece through a nozzle. The **compressed air pressure** directly determines the shot velocity, making it a critical control parameter. In this method:

- The direction of compressed air through the nozzle creates a low-pressure, high-velocity airflow in the suction line that conveys the shots.
- As the system does not need to lift the shots vertically, it is relatively cost-effective and suitable for low intensity peening applications.

For **high-intensity peening**, a gravity-feed system is required to provide sufficient shot flow and impact energy.
A key drawback of the air blast method is that compressed air must be reliably produced and maintained. Air pressure fluctuations—caused by other equipment drawing air—can lead to inconsistent peening intensities. Therefore, monitoring and controlling air pressure is essential. Additionally, the system requires **oil traps and air dryers** to ensure clean, dry air supply.

Only shots traveling at the **correct velocity** produce the desired peening intensity. If shot velocity is too low, it takes longer to reach the required surface saturation. Intensity monitoring can be performed by plotting a **saturation curve** during process development: saturation is defined as the exposure time at which doubling the time results in no more than a 10% increase in arc height.

Beyond velocity, the **angle of impact** also plays a significant role in shot peening effectiveness. The energy absorbed by the workpiece varies according to the sine of the angle between the workpiece surface and the direction of the shot. Optimal impact angles maximize energy transfer and compressive stress induction while minimizing surface damage or irregular coverage.

Shot Velocity and Impact Angle: - Shot velocity is a crucial parameter in the shot peening process. The kinetic energy of the shots, which determines their ability to induce compressive stresses, is directly proportional to the square of their velocity. Thus, higher shot velocities result in greater work done on the surface, leading to deeper and more intense compressive stresses. For a shot of mass m and velocity v, the kinetic energy (impact power) is given by:

$$E=1/2\ mv2$$

In the **air blast method**, shots are entrained in a stream of compressed air and directed onto the workpiece through a nozzle. The **compressed air pressure** controls the shot velocity, making it a critical process variable. Due to the design of the nozzle, a low-pressure, high-velocity airflow is created in the suction line that conveys the shots. Since this system does not require the shots to be lifted vertically, it is less expensive and well-suited for **low intensity peening applications**.

For **high-intensity applications**, a gravity-feed system is necessary to deliver higher shot mass flow and impact energy.

A primary drawback of the air blast system is the need for a reliable supply of compressed air. Air pressure must be monitored closely, as fluctuations—such as those caused by other equipment using the same air supply—can lead to inconsistent shot velocities and peening intensities. Additionally, the system requires **oil traps and air dryers** to ensure clean and dry compressed air, preventing contamination of the peening process.

Proper peening intensity is achieved only when shots travel at the correct velocity. If the shot velocity is too low, it takes significantly longer to reach **saturation**. Saturation can be evaluated by developing a **saturation curve** during process setup: saturation is defined as the exposure time at which doubling the duration causes the arc height to increase by no more than 10%.

In addition to velocity, the **angle of impact** is equally important. The energy absorbed by the workpiece varies with the sine of the angle between the plane of the work surface and the trajectory of the shots. Optimizing the impact angle is essential for maximizing compressive stress induction and achieving uniform surface treatment while avoiding excessive surface roughness or damage

Surface Coverage in Shot Peening: - Coverage in shot peening refers to the percentage of a surface that has been impacted by the shot, producing uniform indentations. It is a critical parameter, as incomplete or inconsistent coverage can lead to inadequate residual compressive stress and reduce the effectiveness of the treatment.

Measurement Method (AGMA 101.05):- Coverage can be measured using a polished Almen strip, as outlined in AGMA 101.05. This method is primarily used during machine setup to establish the conditions required to achieve the desired coverage.

Once the appropriate machine settings are determined, consistent coverage can be achieved by maintaining the following shot peening parameters:

- Shot size
- Shot velocity
- Shot flow rate
- Exposure time (or conveyor speed)
- Position of the workpiece in the blast stream

If these parameters are consistently replicated, both **arc height** and **coverage** should fall within specified limits.

Visual Coverage Specification: - Coverage is often specified as **"visual coverage"**, particularly when **98% coverage** is required. This means that, upon inspection with a **10x magnifying glass**, there should be **no visible un-peened surface**—i.e., all areas should show signs of impact.

Tracer Method (Visual + UV Examination):- To enhance accuracy in visual inspection, a **liquid tracer system** may be used:

1. A **test specimen** (often a strip or part surface) is coated with a tracer liquid.
2. The tracer is allowed to **dry** completely.
3. The specimen is **shot peened** under the required conditions.
4. The peened part is examined under **ultraviolet (UV) light**.
5. **Complete removal of the tracer** indicates full coverage.

This combination of methods ensures that both machine performance and process repeatability meet the quality standards required for critical applications.

Quantitative Analysis:- Surface coverage is a quantitative measure of the percentage of the component's surface that has been impacted (indented) by shot particles during the peening process. Full or near-full coverage ensures uniform compressive residual stress distribution, which is essential for fatigue strength and stress corrosion resistance.

Coverage is defined as:

$$\text{Coverage (\%)} = \left(\frac{\text{Peened Area}}{\text{Total Area}}\right) \times 100$$

- **98% Coverage**: Implies that 98% of the surface has been impacted at least once.
- **100% Coverage**: Implies that no original surface remains untouched.

Shot Peening Intensity: - Shot peening intensity is a quantitative measure of the energy imparted by shot particles onto the surface of a material. It reflects the kinetic energy and deformation capability of the shot stream, and it directly influences the depth and magnitude of the residual compressive stresses induced in the surface layer. **Shot peening intensity** is the most critical parameter in the shot peening process, characterizing the energy imparted to the component's surface. The standard measure is the **Almen intensity**, defined by the arc height of a standardized steel strip after peening.

1) **Definition: -** Shot peening intensity is defined as the **arc height** produced on a **standard Almen strip** after it has been subjected to a **specific peening process**.

- It is expressed in **thousandths of an inch (0.001")** or **millimeters (mm)**.
- The intensity is measured using **Almen strips** (Type A, N, or C), which deform due to peening.

2) **Measurement of Almen Intensity:**

- A thin **Almen strip** (made of standardized spring steel) is fastened to a rigid metal block using four screws.
- The strip is shot peened under the same conditions intended for the actual component (shot size, velocity, flow rate, time, and angle).
- Only one side of the strip is peened; upon removal, the strip **deflects into a convex shape** away from the peened surface.

The **arc height of the strip's curvature** is measured, typically in thousandths of an inch (mils) or millimeters, and recorded as the **Almen intensity**

3) **Saturation Curve Method: -** To determine correct intensity:

- Peen several Almen strips at varying exposure times.
- Plot **arc height** vs. **peening time** on a log-linear graph.
- The **saturation point** is the time where doubling the exposure results in **less than 10% increase in arc height**.

Peening Time (sec)	Arc Height (mm)
30	0.20
60	0.27
120	0.30
240	0.32

Here, the intensity is 0.30 mm at 120 sec — the **saturation point**.

4) **Control of Peening Parameters:** :- Almen intensity is used to **set and verify** machine parameters to achieve desired peening results. Engineers specify required Almen intensities for components to ensure adequate compressive stresses are introduced, improving fatigue strength and resistance to stress corrosion.

5) **Almen Strip Types:**

- Standard Almen strips are produced in three thicknesses:
  - **A Strip:** medium thickness; most used for general-purpose peening.
  - **N Strip:** thin strip; for lower intensity peening, such as for thin or delicate parts.
  - **C Strip:** thickest strip; used for high intensity peening applications.
- All strips share identical length and width dimensions but differ in thickness. Precise specifications for thickness and flatness are provided in standards (referenced in **Table 1**, which you should include separately if you have it).

In the **shot peening process**, spherical particles—commonly referred to as *shot*—are propelled at high velocity either through a **blast nozzle** (air blast) or a **centrifugal wheel** (mechanical blast) to impact a metal surface. These controlled impacts induce beneficial **compressive residual stresses** in the surface layer of the material, improving fatigue resistance and durability.

The **work done to the surface** during shot peening depends on several key factors:

- Size and material of the shot
- Velocity of the shot particles
- Flow rate or shot mass flow per unit time
- Impact angle relative to the surface
- Dwell time or exposure time on the target area
- Coverage uniformity (percentage of area impacted)

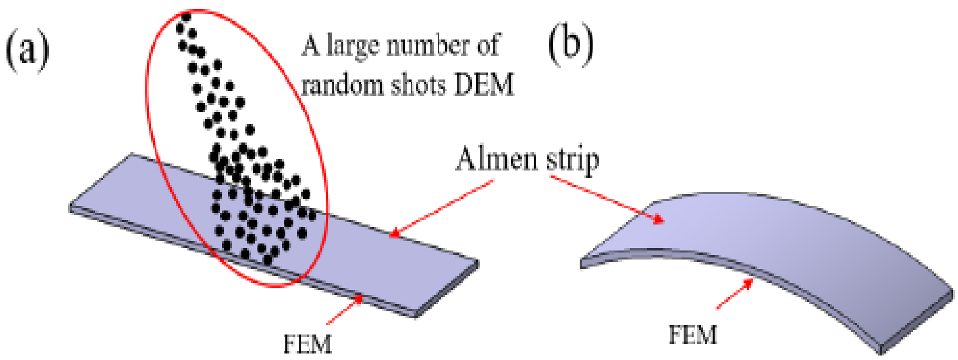
The **combined effect** of these parameters determines the **relative work done per unit area** on the surface and is quantitatively described as **Peening Intensity**.

Key Principle:- The **greater the curvature (arc height) of the Almen strip**, the **higher the peening intensity**, directly indicating a more aggressive peening treatment.

Table 1: Standard Almen Strip Dimensions and Tolerances

Parameter	Almen A Strip	Almen N Strip	Almen C Strip
Length	76.2 ± 0.8 mm	76.2 ± 0.8 mm	76.2 ± 0.8 mm
Width	19.1 ± 0.4 mm	19.1 ± 0.4 mm	19.1 ± 0.4 mm
Thickness	1.29 ± 0.03 mm	0.79 ± 0.03 mm	2.39 ± 0.03 mm
Flatness before peening	≤0.025 mm (0.001 in)	≤0.025 mm (0.001 in)	≤0.025 mm (0.001 in)
Material	SAE 1070 spring steel, Rc 45–48, free of scale, decarburization, and surface defects		

A Strip (1.29 mm thick): standard for most general-purpose peening
N Strip (0.79 mm thick): for low-intensity peening or thin parts
C Strip (2.39 mm thick): for high-intensity peening applications
Strips must meet strict requirements for **material hardness, flatness, and surface finish** to ensure accurate, repeatable measurements.



- The strip is fastened flat during peening; once released, it curls convexly away from the peened side.
- The maximum **arc height (deflection)** is measured using an Almen gauge (arc height gage).

Table 2: Standard Almen Strip Dimensions and Tolerances

Almen Strip Type	Thickness (mm)	Thickness Tolerance (mm)	Maximum Flatness Deviation (mm)
A Strip	1.29	±0.03	≤0.025
N Strip	0.79	±0.03	≤0.025
C Strip	2.39	±0.03	≤0.025

- All three strip types have identical length (76.2 mm) and width (19.1 mm), but differ in thickness.
- **Maximum flatness deviation** (before peening) must not exceed 0.025 mm (0.001 in) for accurate intensity measurements.
- Strips must be made from SAE 1070 hardened spring steel, Rc 45–48

6) Measuring Almen Arc Height: -

- The **curvature (arc height)** of the Almen strip is measured using a dial gauge.
- The strip is placed against two pairs of ball contacts set a fixed distance apart; the gauge is zeroed with an unpeened strip.
- After peening, the strip is flipped (unpeened side towards the gauge) to read the arc height directly (in thousandths of an inch or mm).

7) Almen Strip Types & Applications: -

- **A Strip (0.051" thick)**: Standard for most shot peening; typical arc heights like 0.015" A
- **N Strip (0.031" thick)**: Used for lighter peening (arc height <0.006" A).
- **C Strip (0.093" thick)**: Used for heavy peening (arc height >0.023" A).

8) Almen Strips: - Almen strips are manufactured from steel of carefully controlled structure and heat treated to ensure repeatability. They have the standard dimensions and act purely as a means of duplicating a peening intensity that has already been established on the specified part.

a. Almen N scale for low intensity of shot peening usually below 6 A.
b. Almen A scale for medium intensity of shot peening usually 6 A to 24 A.
c. Almen C scale for high intensity of shot peening above 24 A.

IV. PEENING SATURATION

Saturation refers to the condition where shot peening has essentially reached its maximum beneficial effect on the Almen strip. More precisely, for a specified arc height, saturation is defined as the time **T** required to achieve that arc height such that continuing penning to **2T** does not increase the arc height by more than **10%**.
Only when saturation has been achieved can the measured arc height be validly referred to as the **Almen intensity**.

Exposure Time and Peening Intensity: - Although peening intensity depends on factors related to the equipment — such as air pressure, shot size, shot hardness, and shot velocity — the **time of exposure** is also critically important. Generally, the peening intensity, indicated by the **arc height** of the Almen strip, increases with exposure time until a **saturation point** is reached. At this point, any further increase in exposure time results in only a marginal rise in arc height.

If continued blasting for a prolonged period does not produce the required arc height, it indicates that the process has reached saturation, and to achieve the desired intensity, either a **larger shot size** or a **higher shot velocity** must be used.

In practice, **specifications for peening intensity should always be defined based on arc height values measured at saturation**, as this ensures consistent and repeatable surface properties and fatigue performance.

Characteristic Saturation Curve: - When Almen strips are peened at constant peening parameters (e.g., shot size, pressure, velocity) for various exposure times, and the resulting **Almen arc heights** are plotted against peening time, the result is a **characteristic saturation curve**.

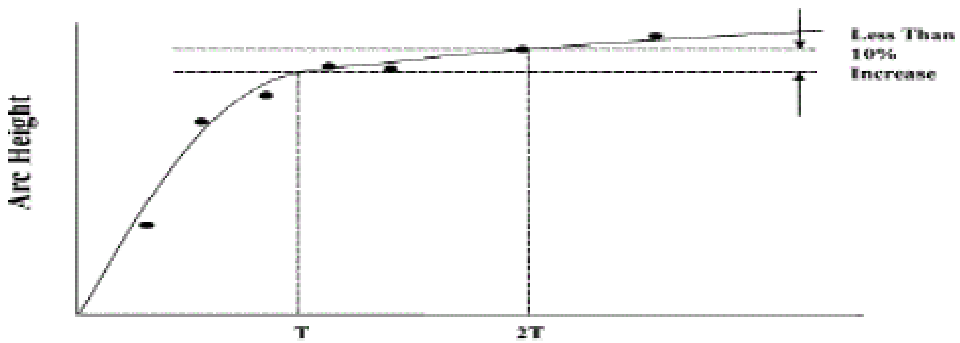


Fig: - Saturation Curve Indicating Intensity and Exposure Time

Because steel parts are harder than aluminum, the dimples formed during shot peening at a given intensity will be smaller on steel surfaces compared to aluminum. Consequently, to achieve full surface coverage (complete dimpling) at the same peening intensity, steel parts require a greater number of impacts (dimples), which in turn necessitates a longer peening time. Therefore, the peening time should be determined based on the time required to achieve uniform and complete surface dimpling of the part.

V. SELECTIVE TREATMENT

It is not always necessary to peen an entire component uniformly. Selective shot peening can be employed, focusing only on areas subjected to the highest stresses. For example, as illustrated in **Fig. 2**, certain regions of a part may experience localized stress concentrations that require peening to improve fatigue resistance.

A classic case is a motor vehicle leaf spring: during operation, one side of the spring consistently undergoes fluctuating tensile stress, which makes it susceptible to fatigue failure initiating from the tension side. By peening only the tension side, a layer of compressive residual stress is introduced, significantly enhancing fatigue life. Conversely, the opposite side of the spring remains under compressive stress during service and is less prone to tensile fatigue cracks; therefore, peening that side is unnecessary.

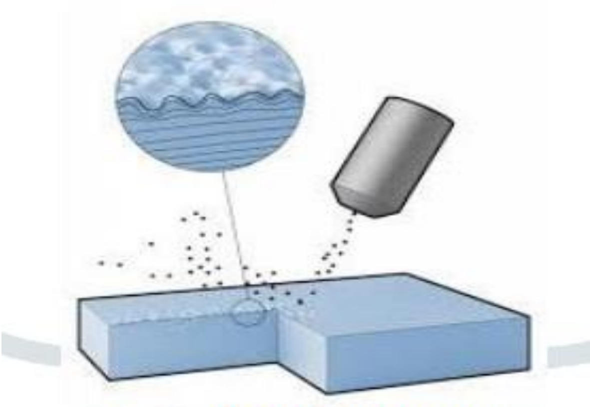


Fig. 2: Selective Shot Peening

Shot peening increases the surface roughness of gear teeth, which can be problematic in applications that demand extremely smooth operation and low friction on the tooth flanks. Elevated roughness can lead to increased noise, wear, and reduced efficiency. To prevent these issues, the tooth flanks can be masked during the shot peening process, allowing peening to be applied selectively to the tooth root area. This approach preserves the smoothness of the gear's working surfaces while still imparting beneficial compressive stresses at the root, where fatigue cracks are most likely to initiate.

VI.RELEANCE OF SHOT PEENING TRIALS

To fulfill customer requirements and ensure optimal performance, extensive shot peening trials are conducted on representative workpieces. These trials are designed to determine critical process parameters, including the optimal position of the blast wheel or nozzle, blasting intensity, abrasive flow rate, and blasting time. Based on these findings, shot peening programs are tailored precisely to the specific production process, ensuring consistent and reliable results. The information gained from these tests also helps identify the most suitable machine configuration for the application. Machine design and setup can then be customized to meet the customer's specific needs and application requirements.

Process reliability is paramount in shot peening. It is primarily controlled by monitoring the Almen intensity and surface coverage. Because all process parameters—such as part feed speed, blasting duration, media discharge velocity, shot size, and distribution—are precisely defined in a controlled shot peening system, it becomes possible to accurately adjust and verify both Almen intensity and coverage. To maintain process reliability, these parameters are routinely checked at specified intervals, and compliance with the required standards must be ensured at all times

VII.CONCLUSION

Controlling the parameters in the shot peening process is critical to achieving consistent and reliable surface enhancement. Key parameters such as shot size, material, velocity, impact angle, coverage, and peening time directly influence the development of compressive residual stresses, surface integrity, and fatigue life of the component. Any deviation can result in under-peening or over-peening, leading to insufficient stress improvement or surface damage. Therefore, systematic monitoring and control of these variables are essential to ensure product quality, performance, and durability in demanding applications.

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