IMPORTANCE OF CONTROLLING PARAMETERS IN SHOT PEENING PROCESS

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Abstract: The critical peening parameters for fatigue life improvement are: exposure time, shot flow rate, distance between shots throwing station (blast wheel or nozzle) and work surface, shot diameter and shot hardness. The objective of the present work is to investigate the effect of various controlling parameters of shot peening on the material properties of the product to be shot peened.

Keywords: Shot peening, Material properties, Process parameters

INTRODUCTION

The outcome of shot peening is the result of interaction between the following two sets of parameters [1]:
1. Material parameters.
2. Shot peening parameters.

4.1 Material Parameters

These include microstructure, hardness, surface condition and hardening characteristics of the work material. The result of their interaction with the shot peening parameters is:
1. Generation of residual stresses in the work material.
2. Strain hardening of the surface and sub-surface layers of the work material.
3. Changes in microstructure and substructure of work material.
4. Change in surface conditions of the work material.

4.2 Shot Peening Parameters

The shot peening treatment is characterized by the following parameters:
1. Shot material (grade, shape and hardness of shot; fraction of broken shot).
2. Peening parameters (shot velocity, mass-flow rate, peening time and impact angle).
3. Intensity and coverage of components (depending on the peening parameters).

These parameters have to be controlled carefully in order to constantly guarantee top quality shot peened components [2]. The parameters that affect the shot peening process and its efficiency are discussed below.

4.2.1 Shot Material and Its Hardness

The shots used for peening are usually of cast steel with the hardness of 40-50 on the Rockwell C scale. Cast iron can also be used as the material. However, as it is brittle it breaks down quickly and causes difficulty in maintaining the effectiveness of the process of peening [3]. The majority of peening is undertaken using ferrous shots which have high impact energy and good durability. For the use on thin parts, the glass beads have been found to be the best option. They can be used when lower peening intensities are permitted. Using them avoids having to decontaminate nonferrous parts after processing, but glass has a higher breakdown rate and higher risk of irregular particles in the blast stream. Ceramic bead is very hard but with much lower density than ferrous shot. It is less prone to breakage than glass bead, but initial purchase costs are higher.

Shot must be at least as hard as the surface being peened. Standard peening shot has a hardness range of 45-55 RC but usually is furnished toward the low end of the hardness range. Consequently, when peening hard parts such as carburized and hardened gears at nominally 60 RC, while there will be some cold work effect on the part, it will not be as great as when a harder shot is used. For these applications, a special hard shot in the range of 55-65 RC should be used to maximize the effect of peening. In residual stress studies performed on steel in the 60 RC range, it was found that the residual compressive stress obtained by using special hard shot was roughly double that produced by using regular hardness shot [4].

4.2.2Shape and Size of Shots

The shots or beads should be free from sharp edges and deformed shapes. For ideal peening application, it is preferable that all shots be of perfectly round shape arid of same size and material properties. The size of the shots chosen depends on the thickness of the work. Small shots give better coverage while large size shots give smoother finish.

It has been demonstrated both in the laboratory and in the field that if the shot striking the work is not uniform in size, the gain in fatigue strength is likely to be less than that obtained with uniformly sized shot, even though the arc height and coverage specifications have been met [5].

Using steel balls, higher deformation energy is obtained at the same impact velocity than with lighter glass or ceramic spheres. 1-lowever, the maximum size of the balls is limited by technical restrictions. If the ball diameter is increased, the component surface roughness will become greater and there are certain machine operating restrictions. A ball size of 0.05 to 1 mm diameter is commonly used.

Since the shots break down due to the repeated usage, there is the need for the maintenance of the shots. The metallic shots should be checked once in an eight hour operation, glass beads once in two hour operation to ensure that not more than 10 % of the shots or beads are deformed. Shot for fatigue life enhancement is typically 1mm or less in diameter, depending on the smallest radius to he peened and the required depth and intensity of processing. Cut wire shot is made from wrought steel wire which is chopped into short cylindrical shape. When the edges are rounded-off, or conditioned, this provides top quality peening shot with uniform size and very low break-down rate. Understandably, cut wire has a much higher initial cost than cast steel shot.

4.2.3Shot Velocity and Impact Angle

The shot velocity is a very important parameter in the shot peening process. The kinetic energy of the shot is proportional to the square of the velocity. Hence, higher the shot velocity more will be the work done, and more will be the effect of the shot peening process resulting in the development of higher compressive stresses in the part. For a shot of mass **in** and velocity *v*, its kinetic energy or impact power is equal to ½ mv^2.

In the case of air blast method, the shots are introduced into the stream of compressed air and directed by the nozzle on to the work piece. The compressed air pressure determines the shot velocity and so the pressure is a critical control parameter. Due to the direction of the compressed air in the nozzle, low-pressure high velocity airflow is obtained in the suction line that conveys the shots. As there is no need to raise the shots, this system is less expensive and is suitable for low intensity peening applications. For high intensity pressure applications, gravity feed system is required. The main drawback of the air blast method for feeding the shots is that compressed air has to be produced, and there should be monitoring to ensure that the air pressure does not fluctuate due to the use of the air at some other place in the plant. Also, the system requires oil traps and air dryers.

Only those shots traveling at correct velocity produce the proper peening intensity. If the velocity is less, it takes more time to reach the saturation. An intensity monitoring can be carried out by drawing the saturation curve for the initial process development. Saturation is achieved when the exposure time, when doubled, does not increase the arc height by more than 10 %. In addition to shot velocity, the angle of impact also plays an important role. The energy absorbed by the work varies as per the sine of the angle between the plane of the work and the line of motion of the shot.

4.2.4 Surface Coverage

Coverage can be measured by means of a polished Almen strip as described in AGMA 101.05 [6]. This method is used primarily as a means of setting up the machine conditions to obtain a given coverage. Once the desired coverage is established for a given setup, it is a matter of maintaining the shot size, shot velocity, shot flow rate, exposure time (or conveyor speed) and the position of the work in the blast. If these conditions are duplicated in a given machine the arc height and coverage should consistently fall within the specifications. Coverage is sometimes specified as visual, which implies that the surface of the part as inspected with a magnifying glass shows no visible surface that has not been indented by the blast. This is adequate when 98 % coverage is required. It is the measure of how much area of the part has been uniformly dented by the shot peening process. Surface coverage is usually determined by the visual method with the help of ten-power magnifying glass together with a visual examination using a liquid tracer system. Under this system, the specimen consisting of a test strip is coated by the tracer liquid and the liquid is allowed to dry. The specimen is then shot peened under the specified parameters and then examined under the ultraviolet light. If all the tracer liquid coating has been removed it indicates full coverage has been done.

The peened specimen is magnified to 50 times in the field of a metallurgical camera and using a sharp pencil, the indented areas are traced on a piece of transparent paper. The area of the indentations is then measured and the ratio of the indented area to the total area is determined. This method is very time consuming and assumes that the test strip represents the work piece.

In order to increase durability and to avoid stress corrosion cracking it is imperative that the critical surfaces are completely shot peened, i.e., a complete coverage is achieved. The complete coverage ratio is defined as the equal and complete indentation of the original surface of the parts to be shot peened. The sample parts are shot peened until the necessary intensity and coverage is achieved. Another check is then made under UV lighting as to whether the film has been completely removed. Complete coverage is characterized by the complete removal of the film during peening. Surfaces, which are not completely covered, have a yellow - green fluorescent color under UV lighting.

4.2.5 Shot Peening Intensity

The most important parameter of the shot peening treatment is the intensity of the shot. A simple measure to characterize this peening parameter is given by the so called Almen intensity. In order to determine the peening or Almen intensity, a thin steel strip from standard steel is fixed with four screws onto a metal block and is then peened with the same peening conditions as the component. Due to peening of one side only the thin plate will show a deflection after being removed from the metal block. This deflection is an integral measure of the resulting compressive residual stress-field as a function of the peening parameters used. The Almen intensity, given in deflection height, is now used in practical applications to control the machine parameters such as shot velocity, peening time, flow rate and shot size. The Almen value does not depend on one parameter only, but gives an integral value for a given peening treatment. These Almen values are used by the engineers to define the intensity of the desired peening treatment of a given component.

In shot peening process, the spherical particles leave a blast nozzle or a centrifugal blasting machine and strike a metal surface. The work done to the surface depends on a number of factors. Size and material of the spherical shot is important, as is its velocity, the rate, and angle at which the blast pattern sweeps across the surface. The relative work done to the surface is called the *Peening intensity.*

If a flat strip of metal is shot peened on one side only, it slightly curls away from the side which has been treated and produces a convex surface. If a standard strip is used, the degree of curvature is a measure of the peening intensity. Higher is the strip curling, higher is the peening intensity. The standard strip is called an *Almen Strip* after the person who first formalized this method. It is made from spring steel of carefully controlled quality to a size within close tolerances. It is used in three thickness - *C, A* and *N*. The *C* strip is the thickest and *N* strip the thinnest. All the three are produced to a single size and the specifications for thickness and flatness are given in Table 1.

Table 1: Specifications of Almen Strips

Strip	Thickness (in.)	Flatness (in.)
N	0.031 ± 0.001	± 0.001
A	0.051 ± 0.001	± 0.001
C	0.094 ± 0.001	± 0.001

The curvature or arc height of the strip is measured with the aid of a dial gauge after the strip is placed and retained magnetically against two pairs of ball contacts a fixed distance apart. The gauge is zeroed with the unpeened strip in position. After peening, the strip is replaced against the contacts with the unpeened side towards the dial gauge and the Almen arc height is read directly in thousandths of an inch or mm. The three different strip thicknesses are to cater for different extremes of peening intensity. For most applications an *A* strip is used, and if it gives a deflection after peening of 0.015”, this is expressed as 0.015” *A*. For lighter peening, giving less than 0.006” *A*, an *N* strip is used. The *C* strip is for heavy peening of intensity greater than 0.23” *A*. Table 2 shows the arc height obtained for different peening intensities on the three scales. When peening intensity is measured, it is important to subject one side of the Almen strip to exactly the same blast conditions as the object to be peened. To do this the strip is clamped by the heads of four screws to a heavy flat block of hardened tool steel, called an Almen block. The assembly is then passed through the blast stream in the same manner and relative position as the part to be peened. On irregularly shaped components, often more than one strip is used, each one positioned on a different face requiring treatment.

Table 2: Scales of Shot Peening Intensity [7]

Peening Intensity (Almen Degree)	Type of Test piece	Are Height (mm)
4 N	N (0.1 mm N = 4N)	0.10
6 N		0.15
8 N		0.20
16 N		0.40
18 N		0.45
6 A	A (0.1 mm A = 4A)	0.15
8 A		0.20
10 A		0.25
10 A		0.50
24 A		0.60
7 C	A (0.1 mm C = 4C)	0.18
9 C		0.23
11 C		0.28
21 C		0.53
23 C		0.58

The intensity is expressed as the arc height of an Almen test strip. The curvature formed in the test strip is a function of the mass of the shot, shot hardness, shot velocity, angle of impingement and the exposure time to the shot stream. The intensity measurement is necessary for process control [7].

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.

1. Almen *N* scale for low intensity of shot peening usually below 6 *A.*
2. Almen A scale for medium intensity of shot peening usually 6 *A* to 24 *A.*
3. Almen *C* scale for high intensity of shot peening above 24 *A* [8].

4.2.6 Peening Saturation

The term *saturation* refers to the condition where peening has essentially reached its maximum effect. More precisely, for a specified arc height, saturation is said to be reached at the time T required to achieve that height when continued peening to 2Twould not increase the height by more than 10%. Arc height can be termed Almen intensity only when saturation has been achieved [9].

Although peening intensity depends on factors concerned with the equipment (pressure, shot size, etc.), the time of exposure is also very important. Generally, the peening intensity (arc height) increases with exposure time until a saturation points is reached where any increase in exposure time of the samples to the blast only results in a marginal increase in peening intensity. If continued blasting for a long period of time does not produced a required arc height, then saturation point has been reached and either a larger shot size or a higher shot velocity is required. In practice, specifications of peening intensity should always be for saturation values.

If the Almen strips are shot peened at constant peening pressure for various peening times and the Almen intensity is plotted as a function of time, a characteristic curve for the shot peening process is obtained (Fig. 1). This curve is usually correlated with the coverage of the peened strips. A degree of coverage of 98 % is by definition given as that peening time at which doubling the peening time leads to an additional increase of the Almen intensity by 10 %. The characteristic curve basically serves to monitor the influence of the most important machine parameters.

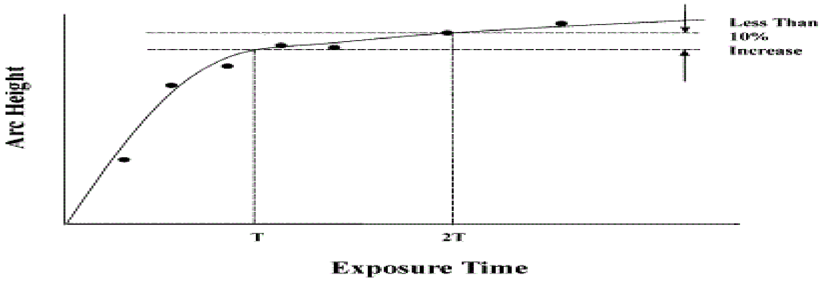

Fig. 1: Saturation Curve Indicating Intensity and Exposure Time [10]

Steel parts are harder than aluminum and therefore the peening dimple, for a given intensity, will be smaller for steel than for aluminum. For same intensity, steel would require more dimples, thus a longer peening time would be required. Peening time should be based upon the time required to achieve complete surface dimpling of the part.

4.2.7 Selective Treatment

It is not always necessary to peen an article all over, This is particularly true where **a** component has an area of particularly high stress that needs peening (Fig 2). Another case in point is a motor vehicle leaf spring, where one side is constantly under tension which is always fluctuating during use. In this case, fatigue failure could still occur, but only form the tension side and peening need only be carried out on the tension side to produce a layer under compressive stress. If one visualizes the loaded spring, the other side is always under compressive stress.

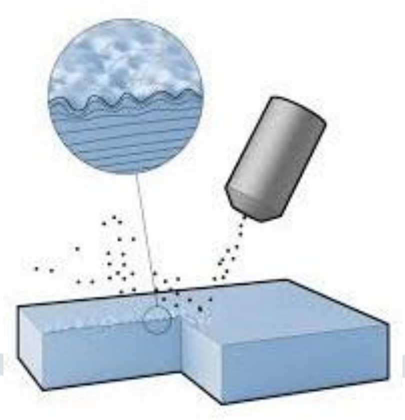

Fig. 2: Selective Shot Peening

Shot peening increases the surface roughness of gear teeth, which may cause problems in applications requiring extremely smooth operation. This roughness can be avoided by masking the tooth flanks and peening only the root area.

4.2.8 Relevance of Shot Peening Trials

To meet the customer's requirements, extensive shot peening trials are performed over the workpieces. In these tests, the aim is to determine the position of the blast wheel or nozzle as well as blasting intensity, abrasive quantity and blasting time. The shot peening programs are to be tailored to the specific production process required and the process reliability is to be guaranteed. The information derived from such tests indicates the machine most suitable for specific requirement. Due to the test results the machine construction is adapted to the customer's requirements and thus to the specific applications [11].

Process reliability is the decisive factor in shot peening,. The blasting intensity can be controlled by determining the Almen value and coverage. Due to the fact that all parameters (speed, blasting time, discharge speed, shot sizes and distribution) in shot peening systems are defined exactly, it is possible to adjust and examine the Almeri intensity and coverage. The process reliability is supervised in periodic intervals and must be guaranteed at all times.

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