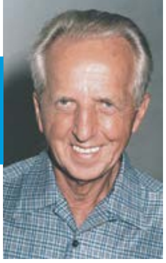

ACADEMIC STUDY

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Back to Basics:
Peening Intensity

INTRODUCTION

Peening Intensity and Coverage are our two main shot-peening parameters. As such, they cover separate aspects of shot peening. Coverage will be the subject of the next article in this mini-series.

Peening intensity, aka Almen intensity and saturation intensity, is currently unambiguously defined—thanks to the adoption and availability of dedicated computer programs and a precise definition. This definition states that "Peening intensity is the arc height of a point on an Almen curve such that doubling the peening time increases the arc height by 10%." Fig.1 illustrates the definition applied using a computer program.

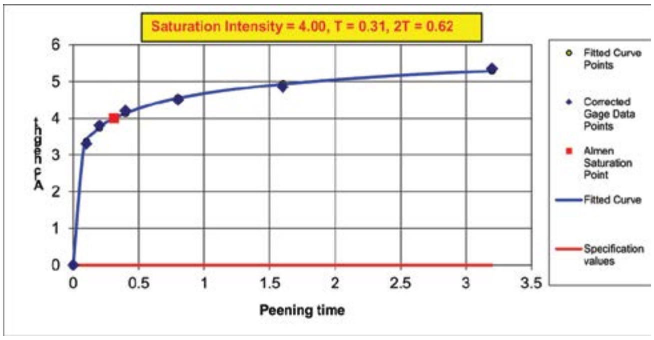

Fig.1. Peening intensity (saturation intensity) as arc height satisfying definition.

The most important feature of peening intensity is that it is directly related to the thickness of the work-hardened, compressively stressed "magic skin." This is illustrated schematically by fig.2.

As the peening intensity increases so does the thickness of the "magic skin." For a given peening intensity the skin thickness also increases with the softness of the component. The optimum skin thickness generally increases with the thickness of the component. An analogy from the animal world is that elephants have thick skins whereas mice have relatively thin skins. It follows that peening intensity is a very important, basic parameter. The level of peening intensity must be measured with reasonable accuracy and then related to process parameters such as shot size and velocity.

The mechanics of peening intensity measurement are familiar to all shot peeners and are amply explained in J442. This article therefore concentrates on the basic principles involved.

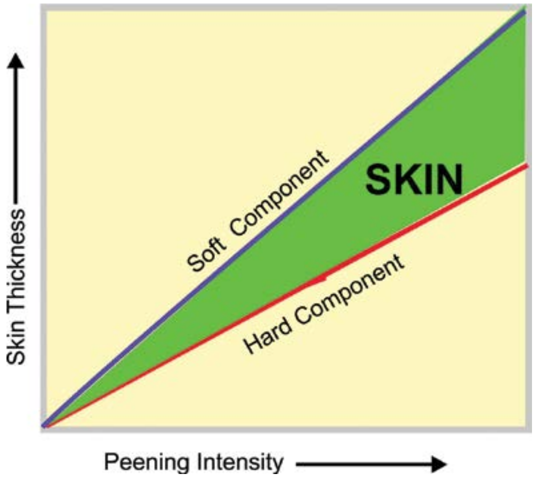

Fig.2. Relationship between peening intensity and skin thickness.

PEENING INTENSITY VERSUS SHOT SIZE

The thickness of the "magic skin" is also directly proportional to the size of shot being used. Small shot is used to produce a thin skin whereas large shot is used to produce a thick skin. Fig.3 shows the effects induced by a single indentation. Each individual indentation makes a contribution to the curvature of a peened Almen strip. The greater the radius, **r**, of the impacting spherical particle the greater will be the depth, **h**, of the indentation and hence the greater the contribution to the depth, **t**, of the "magic skin." The indent material, shaded yellow, has to go sideways thereby producing an outflow of the surface and hence curvature.

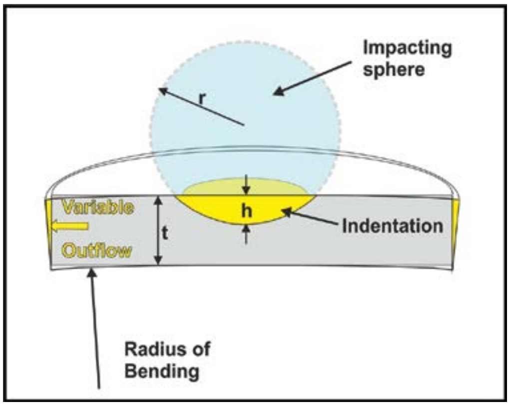

Fig.3. Single indentation causing outflow and thereby contributing to Almen strip curvature.

A single indentation makes only a tiny contribution to Almen strip curvature. This tiny contribution depends on the size of the indentation. Numerous indentations are needed to induce the arc height that we measure. Interestingly there is a linear relationship between declared peening intensity and shot size provided that we keep all other peening parameters constant. This is illustrated in fig.4 which is based on actual data produced for wheel-blasting when all other peening parameters were kept constant.

Fig.4. Peening intensity versus shot size.

DATA

Data is an essential feature of shot peening. Without it shot peening would not exist. Peening intensity estimation requires data points. Each data point consists of the deflection measured on an Almen strip peened for a known time (or its equivalent). A set of these points is then used to derive a peening intensity curve (aka saturation curve). This curve is then analysed to assign a peening intensity value.

It cannot be emphasised too strongly that shot peening data has real value. Think of each data point as being worth at least a dollar. For a complete set of data points, saturation curve and derived intensity value, we have at least a double figure's worth in dollars. Data should be stored in a database (aka data bank). The term "bank" properly emphasises the value of data. Microsoft's Excel allows creation of a database. Stored data can then be accessed using the sorting feature. A parallel is a Google search, which involves entering words as a sorting mechanism for its vast database. The main value of peening data also lies in being able to access it at any future date. This accessibility has many advantages, e.g., saving time when having to achieve the same peening intensity with the same peening parameters (shot type and size, air pressure, nozzle size, required peening intensity, etc.).

A shot peener's basic database should include the peening parameters, peening date and a copy of the data set and curve-fitting used to estimate the peening intensity. Armed with such a database, sorting can be used to answer such questions as "When and how did we last achieve a 5 - 7 peening intensity using S170 shot?" This avoids guesswork as to what parameters to employ for a current job.

PEENING INTENSITY ESTIMATION CURVES

Peening intensity is estimated using curves computer-fitted to the arc heights of a number of Almen strips that have been peened for different lengths of time using the same shot stream. Basic questions are "How many strips and which curve should I use?"

Number of Almen Strips in a Data Set

Specifications require that at least four Almen strips should be used. One or two of these should give arc heights less than the subsequently derived peening intensity and one must exceed the time, 2T, where T is the time associated with the peening intensity point.

The most economical answer to the question "How many strips should I use?" is obviously four. This does not mean that four is the best choice. There are two reasons why more than four could be a better choice. The first reason is that each individual data point is subject to variability—repeating the exposure for the same peening time yields slightly different arc heights. Using extra data points helps to iron out this variability. The second reason is that the larger the number of data points in a set, the closer will be the computer-fit to the true shape of a saturation curve. Table 1 is an actual data set that is used in this article.

Table 1. Six-point data set

Strip No.	Peening Time	Arc Height
1	0.25	10.8
2	0.50	12.9
3	0.75	13.7
4	1	14.4
5	2	15.7
6	4	16.4

Selecting the Equation of Computer-Fitted Curve

Computers use a program that finds the parameters of a pre-selected equation. The program best-fits the data that it is supplied with. Users may or may not be in a position to pre-select the equation employed. The author's Solver Suite does offer several choices. Any program used must, however, satisfy specification requirements.

A basic question is "Does it matter which equation I use, if I have a choice?" Different equations will produce slightly different values for the peening intensity that it derives from a given set of data points. This difference is illustrated by figs. 5 and 6 which were created using the same data set (Table 1).

Fig.5 poses a basic question: "Why is the two-parameter fitted curve such a poor fit?" The answer lies in what the computer program has been told to do. It has been told, in effect, that the data points are supposed to have the shape of a simple exponential equation that has only two parameters, a and b. This is incorrect! The proper shape of a saturation

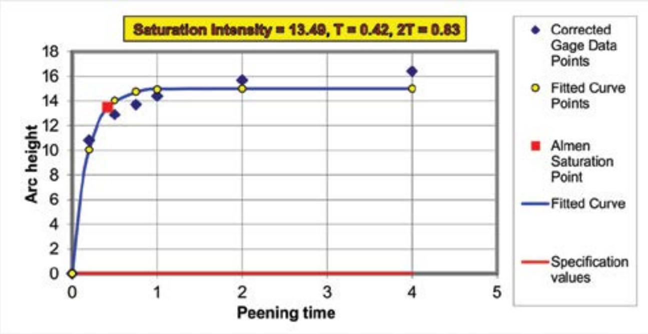

Fig.5. Intensity derivation using a Solver Suite two-parameter equation.

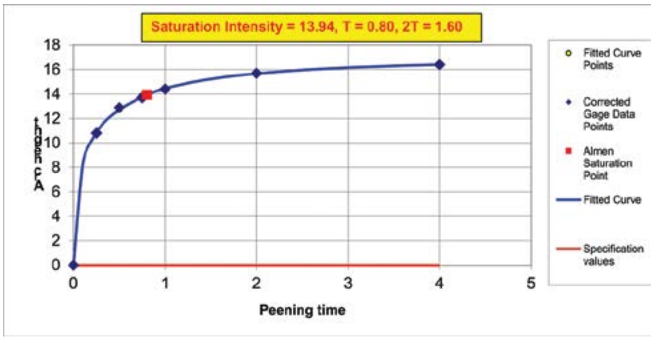

Fig.6. Intensity derivation using a Solver Suite three-parameter equation.

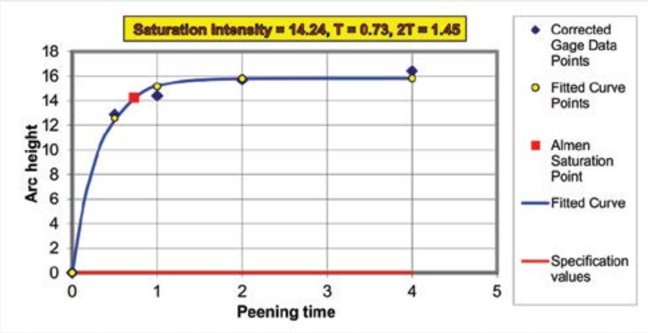

Fig.7. Intensity derivation using a Solver Suite two-parameter equation on reduced data.

curve is much nearer to that of a more complex exponential equation—one that has three parameters, a, b and c. That is why fig.6 presents a good fit.

Comparing the derived intensity values in figs.5 and 6 is interesting. Although the derived intensity-point times differ by a factor of 2, the intensity values are very similar—13.49 and 13.94. Fig.7 is included as an educational exercise. It uses just 4 of the 6 data points from Table 1. The derived peening intensity,14.24, is similar to the 13.49 and 13.94 of figs.5 and 6.

Computer Specification

A very sensible specification, J2597, requires that a computer program must derive peening intensity from all of their table of data sets to within stated limits. In a previous article (TSP Summer 2016) three different computer programs fitted to the same data set gave values of 5.38, 5.47 and 5.49—all well within SAE's stated limits of 4.4 to 6.4.

ACCURACY AND PRECISION OF INTENSITY MEASUREMENTS

Accuracy and precision of measurements are of basic importance in all fields of science and engineering. Although the procedure for intensity measurements is carefully laid out in publications, such as SAE's J442, it cannot prevent variations in both accuracy and precision. The following are definitions of the terms involved:

Accuracy: The difference between measured values and the true value of a particular strip's arc height.

Precision: The random spread of measured arc height values made on the same strip.

To illustrate accuracy and precision, consider the following hypothetical case study.

Case Study: Student Training in Use of Almen Gauge

Three students, Tom, Dick and Harry, were being instructed on the proper use of an Almen Gauge by Big Joe. Each student measured the same peened Almen strip three times using the same Almen gauge but recorded different values as follows:

Tom: 6.12, 6.12 and 6.11 • Dick: 6.10, 6.14 and 6.11
Harry: 5.92, 5.90 and 5.88

Tom piped up, "Dick and I got very similar values but they are very different from Harry's. He must have made a mistake." Big Joe sighed deeply before replying, "All three of you made at least one mistake. You and Dick forgot to zero the gauge before making measurements. Additionally, Dick was careless when replacing the strip on the gauge as was Harry. I can record that you, Tom, had the highest precision but had inaccurate values. Dick had a lower precision and was also inaccurate. Harry had the best accuracy but not the best precision. When I measured the same strip earlier today, I got values of 5.90, 5.90 and 5.89."

After lunch Harry came up to Big Joe with a problem. "Sir, my boss gave me a peened strip to measure that he had found to have a deflection of 7.52 as the average of 10 measurements. I did 10 measurements on the strip during the lunch break that gave an average of 7.19. Why is there such a difference?" "You are keen," said Big Joe. "When you get back, ask when was your firm's gauge last overhauled? It could be that the support balls have now got flats worn into them."

Accuracy and precision are commonly presented graphically as shown in figs.8 to 11. The random spread of measurements—precision—is shown as what statisticians call a "Normal Distribution." This a continuous curve, with individual measurements lying somewhere within the curve, usually between a range such as a-b. The range increases as precision decreases.

The four situations presented correspond to the type of findings of Tom, Dick, Harry and Big Joe given in the case study. As a quick exercise, associate Tom, Dick, Harry and Big Joe with the most appropriate figure from 8 to 11, (Big Joe as fig.11 would be wrong), answers at the end of the article.

Lack of precision is usually due to a combination of independent factors, e.g., strip thickness and strip placement. This combination is not simply quantitatively additive but has to conform to a definite rule. The range, a-b, is directly proportional to what statisticians call the curve's "standard deviation" and is assigned a value, s. Think about the effect of combining two independent variables that have standard deviations of 1 and 5 respectively. The rule tells us that the standard deviation for the combination is given by:

$$s^2 = 1^2 + 5^2$$

Expressed verbally, it is saying that the square of the standard deviation is the sum of the squares of the independent variables. For $s^2 = 1^2 + 5^2$ we have that $s^2 = 1 + 25$ giving **s = 5.1.** We might have thought that the relative contributions would have been in the ratio 5 to 1 but we would have been wrong. With the aid of the statisticians' rule we see that the second variable, value 5, dwarfs the first variable, 1. That does not mean that we can ignore the first variable. As an example, what if the 1 represented strip thickness variability and the 5 represented strip placement errors. Strip manufacturers would be ill-advised to relax their control of strip thickness. That could lead to having a much larger standard deviation, even larger than placement errors.

The Rule of Additive Deviations is very important in all aspects of shot peening.

PEENING INTENSITY CONTROL

The basic principle of peening intensity control is to control the size of the dents being produced. Several factors are involved, principally shot size, velocity and density, together with strip hardness. Each shot particle produces a dent that contributes to the induced strip curvature. A strip peened for a given time (or number of passes) acquires numerous dents. Measured strip curvature is therefore an example of integral calculus as it sums the individual contributions with the maths done for us!

Effective peening intensity control requires a combination of practical experience in the application of the basic principle of dent size control. Fig.12 is a pictorial representation of the principal control factors. These factors can only be considered individually provided that all other peening factors are kept constant.

Shot Size

It was shown in a previous article (TSP Spring 2004, "Prediction

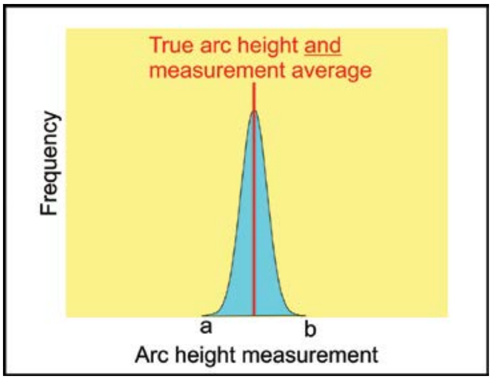

Fig.8. Good accuracy and precision.

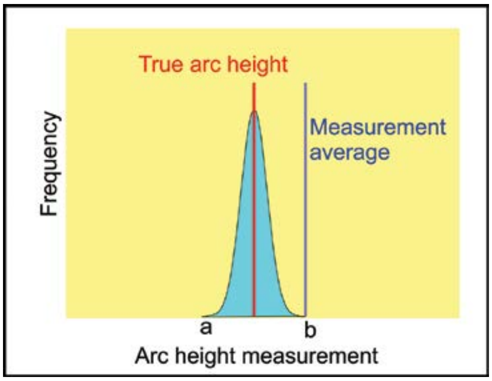

Fig.9. Poor accuracy but good precision.

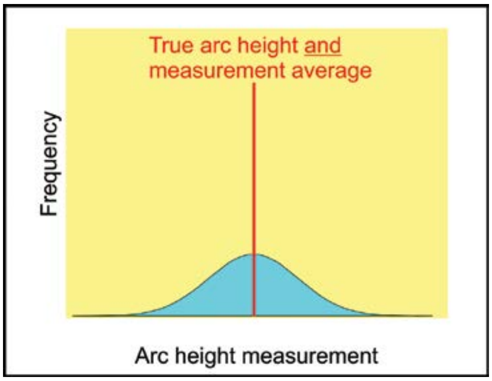

Fig.10. Good accuracy but poor precision.

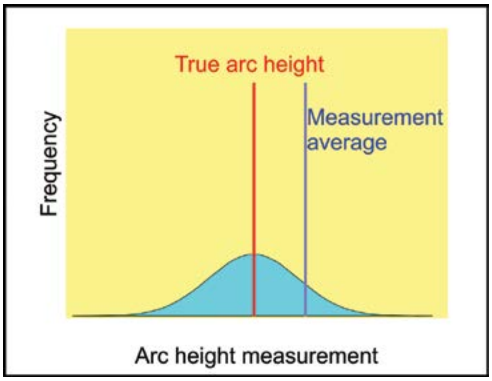

Fig.11. Poor accuracy and poor precision.

and Control of Indent Diameter") that dent diameter is directly proportional to the shot diameter provided all other factors are kept constant. Fig.4 of this article shows this linear relationship between peening intensity for a particular set of peening parameters. Basically, as shot size increases so does peening intensity. Hence, if we want a high peening intensity, we must specify a large shot size. Large dents can be smoothed by applying a second peen using smaller shot.

Cut wire and as-cast shot have different ranges of size within each grade. This is a consequence of the respective manufacturing methods.

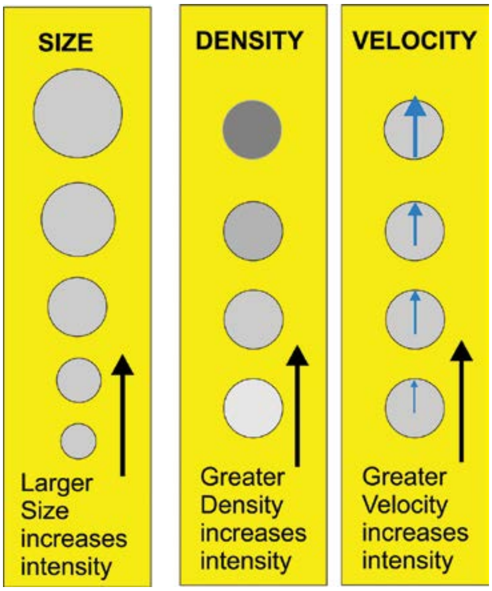

Fig.12. Principal control factors affecting peening intensity.

Density

The main effect of density is to increase the mass of a given size of shot particle thus increasing its kinetic energy and therefore the peening intensity. Steel shot, both ferritic and stainless, has a density of about $8 g/cm^3$ whereas ceramic shot can vary between 2 and $6 g/cm^3$. The lower the density, the higher the velocity that must be imparted in order induce a given peening intensity.

The enduring popularity of steel shot lies in its combination of properties (cost, hardness, density, etc.). Steel shot manufacture is a well-established industry, largely because of its massive use in engineering products.

Velocity

Shot velocity, v, is the simplest method of controlling peening intensity. This is because the kinetic energy of shot particles is $\frac{1}{2}mv^2$. Air blast and wheel blast peening provide us with quite different control mechanisms. With air blast peening the emergent air velocity is always constant at about the speed of sound. As the applied air pressure increases so does the density of the air. The greater the density of the air in the nozzle, the greater will be shot acceleration. Nozzle length is also important. Equations have been presented (TSP Winter, 2007 and Spring 2007) that allow prediction of shot velocity:

Air blast

$$\mathbf{v_s = (C_D.A.\rho_A.s/m)^{0.5}\,(v_a - v_s)}$$

where $\mathbf{C_D}$ is the "drag coefficient" (a dimensionless number that depends upon the shape of the object and for a smooth sphere $\mathbf{C_D} \approx 0.5$), **A** is the cross-sectional area of the object, $\boldsymbol{\rho_A}$ is the density of the **compressed** air ($1.2 kgm^{-3}$ times the compression ratio), **s** is the nozzle length, $\mathbf{v_a}$ is the velocity of the air stream, **m** is shot mass and $\mathbf{v_s}$ is the velocity of the shot particle. ($\mathbf{v_a} - \mathbf{v_s}$) is termed the "relative velocity" of the particle compared with that of the air stream.

Wheel blast

$$\mathbf{V_S = 2.\pi.N(R^2 + 2.R.L - L^2)^{0.5}}$$

where **N** is wheel speed, **R** is blade tip radius and **L** is blade length.

CONCLUSIONS

The measurement of peening intensity poses an almost unique chain of problems for shot peeners. At times they must feel as if they are jugglers having to handle so many factors—from choice of strip, choice and maintenance of gauge facility, care in measurement technique and using stored data to facilitate successful intensity aims. A great deal depends on prior experience and careful attention to detail.

It cannot be stressed too highly the importance of maintaining a data bank of previous measurements.

Appendix

What is meant by the term "peening intensity"? Of itself, the term is misleading! The word "intensity" implies both magnitude and frequency. Think of a lightning storm. We associate lightning storm intensity with a combination of flash magnitude and flash frequency. Similarly for a hailstorm we associate intensity with a combination of both size and frequency of hailstones. Think of enduring a hailstorm whilst sitting in a stationary car. Hailstones hitting the car's roof will cause a pinging noise. This noise has two components: (1) loudness of individual pings and (2) frequency of pings. The loudness of the individual pings will increase with hailstone size and hailstone velocity. For peening, we can associate intensity with a combination of shot size and shot velocity but not frequency—which affects coverage. That said, we must endure the misleading name as it is so firmly fixed in our vocabulary. A better name would have been "Arcivity"—ability to induce arc height.

Problem Answers
Tom: Fig.9
Dick: Fig.11
Harry: Fig.10
Big Joe: Fig.8