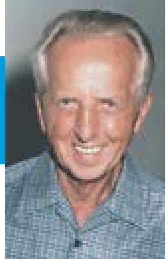

ACADEMIC STUDY
Dr. David Kirk | Coventry University

Estimating Peening Intensity

INTRODUCTION

The estimation of peening intensity is an essential tool for shot peeners. Its magnitude is normally estimated using an Almen strip data set. This data set comprises the arc heights of several Almen strips that have been shot peened for different periods of time using the same shot stream. Plotted as arc height versus peening time then yields a curve. The curve, commonly known as a "Saturation Curve", is used to estimate the peening intensity. Specifications generally require the determination of a point on the curve such that "A doubling of the peening time corresponds to a 10% increase in the arc height." Computer-based techniques enable this determination to be obtained objectively. Fig.1 illustrates one such technique in action, deriving 14.24 as being the peening intensity.

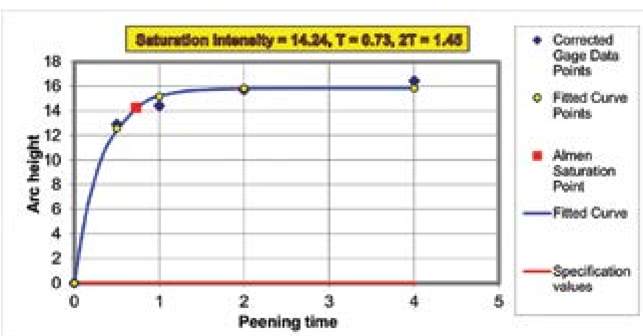

Fig.1. Computer-based derivation of Peening Intensity value.

Computer-based curve fitting requires prior knowledge of an appropriate equation. Initial studies indicated that exponential equations were appropriate, with either 2, 3 or 4 parameters, giving increasingly close fits to data. This led to the "Solver Suite" of programs. A later equation has been introduced via a French specification.

It is very important to note that the peening intensity of a shot stream varies within the stream. This feature is illustrated by fig.2 showing variation within a cross-section.

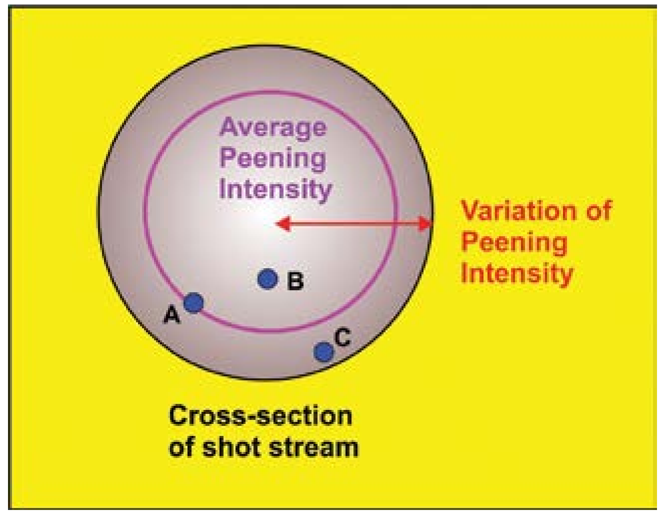

Fig.2. Variation of peening intensity across a shot stream.

VARIATION OF A SHOT STREAM'S PEENING INTENSITY

Shot peening intensity is proportional to shot velocity. Emerging shot particles are being blasted out of the nozzle by the conical air stream (colored blue) in fig.3. The edges of the cone experience a retarding effect due to the almost static surrounding air (colored yellow). This slows down the

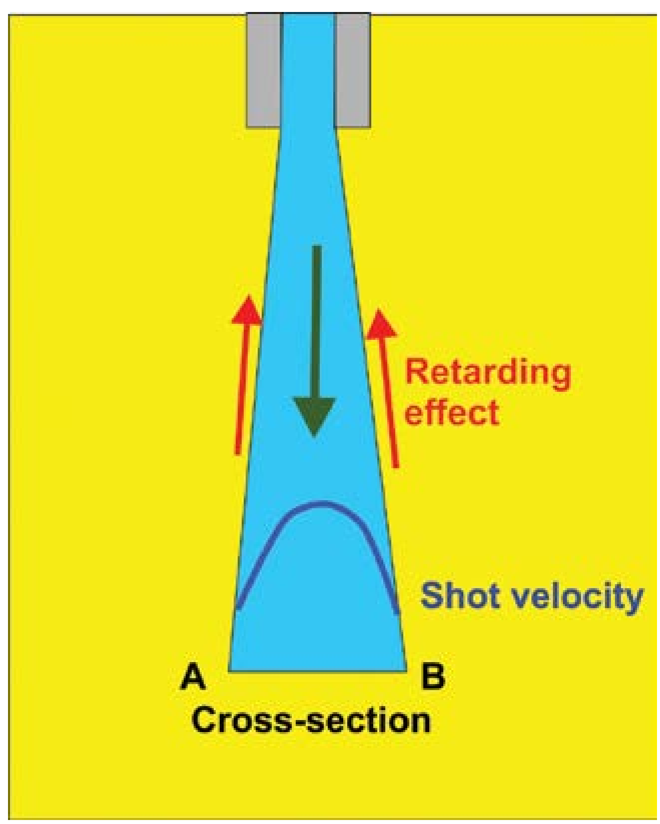

Fig.3. Shot velocity variation within shot stream.

velocity of the air stream at its edges. Consequently the shot velocity (colored blue) becomes higher at the center of the cone than it is at its edges. This means that the shot peening intensity is greater at the center of the cross-section, AB, than it is at its edges. Overall there will be an average peening intensity as at A in fig.2. Intensity will be higher inside the circle of average peening intensity, as at B. Intensity outside the average circle will be lower as at C.

Estimation of peening intensity should take account of the known shot stream variation. This is effected when using Almen strips because they are exposed to most of the shot stream cross-section.

VARIABILITY OF ALMEN PEENING DATA

Peening intensity estimation when using Almen strips requires a data set. Each point in the data set has coordinates of arc height and peening time. Because only two factors are involved we can plot peening intensity data points graphically, as arc height against peening time, giving us the so-called "Saturation Curve". Normally, between 4 and 6 data points are involved. However, every data point has its own variability—meaning that if we repeated the time of peening for a given point we would not get exactly the same arc height deflection. This begs the question "How can we cope with data point variability?" The standard answer is to employ the "Least Squares" method. This technique minimizes the squares of the differences between the data point values and the selected model equation. The following is an explanation of this technique.

Least-squares Curve-fitting

"Least-squares" means minimizing the sum of the squares of differences between data point values and the value lying on an assumed curve equation. This concept is illustrated in fig.4.

For simplicity of mental arithmetic, arbitrary units are used in fig.4. For point 1 the difference between the data point and the curve point is 1. 1 squared is also 1. For point 2 the square of the difference is also 1. For points 3 and 4 the difference between the data point and the curve point is 0.5 whose square is 0.25. The sum of the squares for the four points is therefore 2.5 (1 + 1 + 0.25 + 0.25). Consider next the dashed curve. For point 1 the difference between the data point and the curve point is 3 which squared is 9 — much larger on its own than the all-point sum of 2.5 for the much better-fitting continuous curve. The dashed curve is obviously not a good fit!

Least-squares curve fitting involves altering the parameters of the equation being used time and time again until a minimum value is reached.

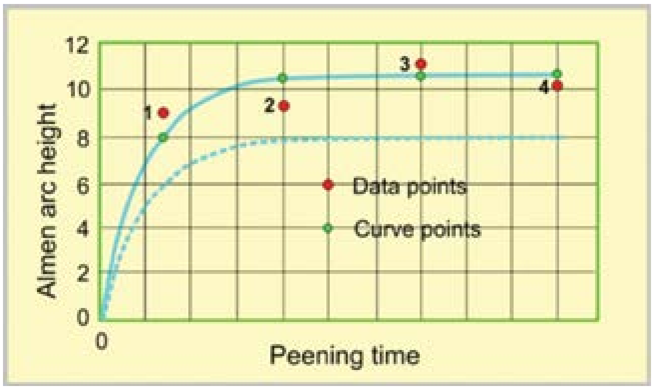

Fig.4. "Least-squares" curve-fitting applied to shot peening data points.

Several factors influence the variability of individual Almen data points. These include:

(1) Almen strip quality. As a general rule the higher the quality of the Almen strips the less will be data point variability.

(2) Almen gauge quality and maintenance. Again the higher the quality of the gauge the less will be data point variability. Routine maintenance is required in order to preserve gauge quality.

(3) User technique. Using an Almen gauge requires high levels of both skill and care. A fair analogy would be that the technique is that required from a surgeon rather than simply that required from a butcher.

(4) Shot stream stability. No-one's shot stream can be exactly constant. Air pressure, average shot size and shot velocity fluctuate. Control measures can minimize these fluctuations but cannot eliminate them completely.

Measuring data point variability is rarely carried out because it is tedious, time-consuming and expensive. Variability can sometimes, however, be obvious. For example, in fig.4 point 3 is higher than point 4. This could only occur due to the presence of one or more variability factors.

CHOICE OF CURVE-FITTING EQUATION

A variety of curve-fitting programs are available either free or propriety. An acid test for suitability is described in SAE J2597. Its ten data sets are as shown in Table 1 (page 30). Each data set contains values for exposure times and test strip arc heights and a corresponding intensity answer. To be satisfactory, a computer program must generate a saturation curve and numerical declaration of intensity which is within the tolerance band for each data set.

Note: Target answers are shown in bold print. Candidate programs must reach all ten target answers to within ± 0.001.

Table 1
Saturation Curve Data Sets

1		2		3		4		5	
time	arc height	time	arc height	time	arc height	time	arc height	time	arc height
4	0.0060	2.5	0.0030	3	0.0065	1	0.0038	4	0.0062
6	0.0069	5	0.0036	6	0.0081	2	0.0051	6	0.0070
8	0.0070	10	0.0044	12	0.0088	3	0.0052	8	0.0072
12	0.0070	20	0.0044	24	0.0090	4	0.0053	12	0.0072
	0.0064		**0.0040**		**0.0080**		**0.0048**		**0.0066**

6		7		8		9		10	
time	arc height	time	arc height	K/Feed	arc height	K/Feed	arc height	K/Feed	arc height
1.1	0.0046	2	0.0055	0.25	0.0081	0.25	0.0108	0.25	0.0045
2.3	0.0087	3	0.0066	0.50	0.0096	0.50	0.0129	0.50	0.0054
4.5	0.0101	4	0.0067	0.75	0.0100	0.75	0.0137	0.75	0.0059
9	0.0107	6	0.0068	1	0.0103	1	0.0144	1	0.0058
	0.0098		**0.0063**	2	0.0108	2	0.0157	2	0.0062
				4	0.0113	4	0.0164	4	0.0064
					0.0093		**0.0137**		**0.0054**

For example, an acceptable derived intensity for data set 1 would be within the range 0.0054 to 0.0074. The arc height values in Table 1 are in inches for illustration purposes only. Some curve solver programs will not function properly with such small values. It is therefore acceptable for the data in Table 1 to be converted into thousandths of an inch for computational purposes. For example: use 12 instead of 0.012".

The pragmatic solution to deciding choice of program is that "Any program will do provided that it satisfies SAE J2597." That said, the author's Solver Suite provides convenient modifications that allow for a variety of factors such as:

- Pre-bow correction
- Flapper peening correction
- Data set comparison and
- Number of parameters in the fitting equation (the greater the number of parameters the more precise is the fit).

Tests can be carried out to compare the suitability of different equations. One such test is illustrated by fig.5. Each of the ten SAE J2597 data sets given in Table 1 has been fed into two different curve-fitting equations—Solver EXP2P and Solver 2PF. For this particular test Solver EXP2P gives peening intensity values that are well within the maximum allowed deviation. Solver 2PF also satisfies the requirement but the Data Set 6 value is close to the allowed maximum deviation.

Two-Point Peening Intensity Verification

Shot peeners are required to verify at regular intervals that the shot stream's peening intensity continues to be within the

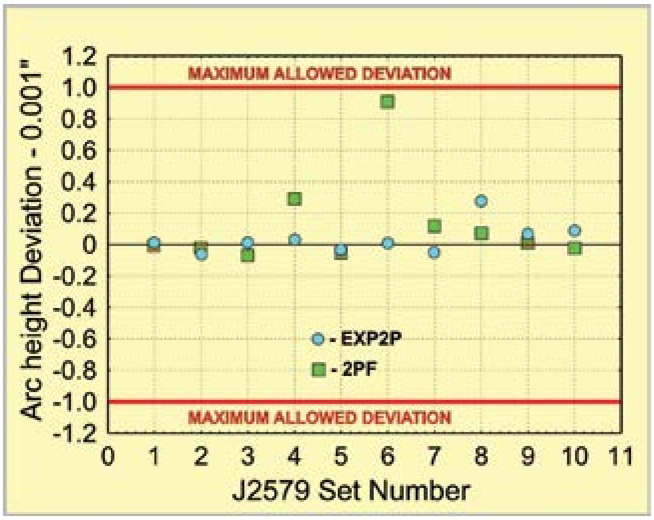

Fig.5. Deviations from the J2579 data set for EXP2P and 2PF programs.

specified range. A balance has to be struck between excessive and inadequate testing. The simplest verification test requires only one strip to be peened. Earlier specifications required that this strip be peened at the peening intensity time, **T**. This is clearly impossible if **T** is not an integral number of passes/strokes/table rotations. SAE J443 now addresses this problem and allows the single strip to be peened at the nearest practicable time to **T**. The arc height reading from the single strip "must repeat the value from the saturation curve plus or minus 0.038 mm (± 0.0015 in)."

A central problem with single-strip procedures is that they cannot verify that the shot stream's intensity is being maintained! That is because an infinite number of saturation curves can pass through any one point (and the origin 0,0). Fig.6 illustrates the phenomenon.

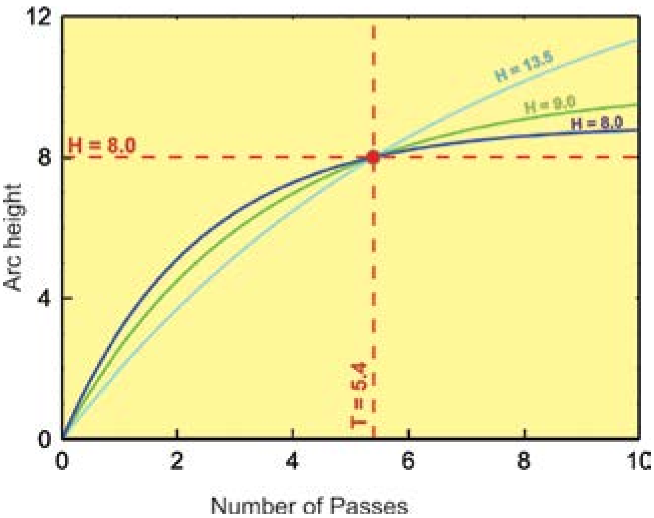

Fig.6. Different saturation curves passing through a notional peening intensity 8.0.

Two-point intensity verification avoids the multiplicity problem of one-point verification. Fig.7 illustrates the methodology involved. Two strips are peened for "times" t and 2t. The resulting arc heights are used to determine the values a and b of the equation. The arc height value at the previously determined critical peening time, T, is then determined. This is the value that should be close enough to that previously determined using the multi-point data set. If it is then the shot stream's peening intensity is verified.

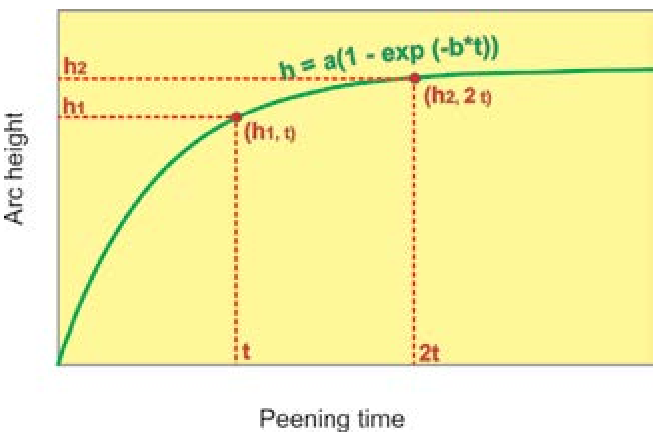

Fig.7. Two data points uniquely defining a saturation intensity curve.

A full description of two-point verification is given in a previous TSP article – Fall 2010.

DISCUSSION

Estimating peening intensity on a regular basis requires that a fixed control procedure is used. This must include:

- Regularly calibrated Almen gage,
- Same quality Almen strips,
- Properly trained operator, and
- Standardized measuring procedure.

The number and type of measurement is normally specified by customers.

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