



## ACADEMIC STUDY

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# J443 An Evolutionary Guide to Shot Peening Intensity Measurement

## INTRODUCTION

J443 – Procedures for Using Standard Shot-Peening Test Strip, was first approved in January, 1952. As an SAE Recommended Practice document the principles that it enshrined were widely adopted by the then emerging shot peening industry. With accumulated experience and technological advancements several revisions became necessary. These were made in 1961, 1984, 2003 and 2010. A further revision is a “Work In Progress.” J443 is an important, definitive, guide to shot peening intensity measurement.

This article attempts to trace the influence that the evolution of J443 has had on shot peening intensity measurement. Future developments will have to take into account new technology and a more universal input of ideas.

## J443 1952

This original version was produced in radically different times from those that we have at present. The accumulated quantitative knowledge was, at that stage, limited and ideas were at a formative stage. These were the days of slide rules, logarithmic tables, stencils for lettering and graph paper. Statistical analysis, using manual procedures, was very laborious and therefore had limited application.

Two alternative procedures for peening intensity measurement were recommended – “*Procedure Based on Arc-height Exposure Time Relationship*” and “*Alternative Procedure Based on Coverage Measurement*.”

### *Procedure Based on Arc-height Exposure Time Relationship*

This currently-familiar procedure is based on a graph of Almen arc height versus peening exposure time. The definitive graph was its Fig.1 which is reproduced here (as Fig.1 for this article).

Graph-drawing principles reigning in 1952 give an insight as to why Fig.1 appears today to be somewhat strange. Flexicurves and French Curves were readily available for producing segmented curves. There are six marked points that all lie exactly on a curve. Curves then were normally pencil-sketched by hand and often transposed in ink onto tracing paper. The curve in Fig.1 has a significantly-different shape

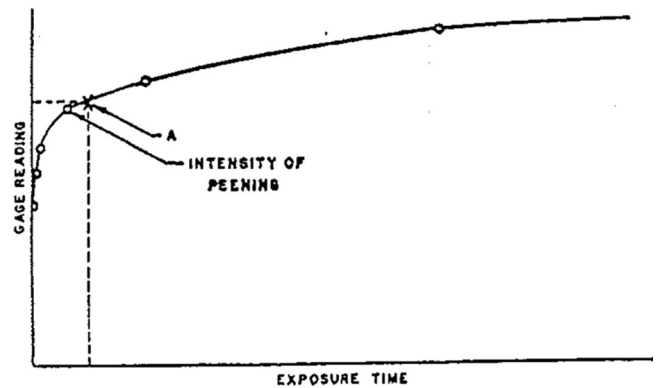


FIG. 1—INTENSITY DETERMINATION CURVE

from any that are normally encountered when using real data points – the initial rate of increase being far too steep. The exposure times indicated for the six graphed points are in the ratios 1 to 2.5 to 5 to 20 to 60 to 220. It seems unlikely that real exposures would have ranged by a factor of 220. For Fig.1 it therefore appears that six ‘virtual’ points were added to a previously-drawn curve – perhaps involving overlaying the traced curve onto graph paper. It is almost impossible to conceive that the six points were actual Almen strip data points. Curve-fitting, to allow for variability of real data points, has not been employed for Fig.1. One interpretation is that the curve was deliberately simplified – avoiding the complication of data point variability and the need to allow for that variability.

“Intensity of peening” and a point “A” appear in Fig.1. The “Intensity of peening” is the fourth of the six ‘virtual’ points that lie exactly on the curve. This fourth point happens to be the first for which doubling the peening time results in less than a 10% increase in arc height. It may be that an implicit, rather than an explicit, 10% concept was being considered as early as 1952. Point “A” is a point of the curve (not a ‘virtual’ point) and has no defined location, other than by a vague reference to the curve flattening out, which it doesn’t, and it is hard to justify.

The actual text in J443 1952 reads “*The gage reading corresponding with the point A where the curve flattens out*

is generally taken as the measurement of the intensity of that particular peening. In some cases the point is difficult to pick out and requires some judgment." The indicated "intensity of peening" point, which is a 'virtual' point, is not mentioned anywhere in the text. This gives rise to ambiguity, to say the least.

Fig.2 is reproduced here. Data point variability is now indicated, though not mentioned in the text. The intention was to indicate how the production setup of a given peening machine could be varied to achieve the desired peening intensity. Three curves are shown involving nine, eight and seven points per curve. Each curve again involves a tremendous range of apparent exposure times.

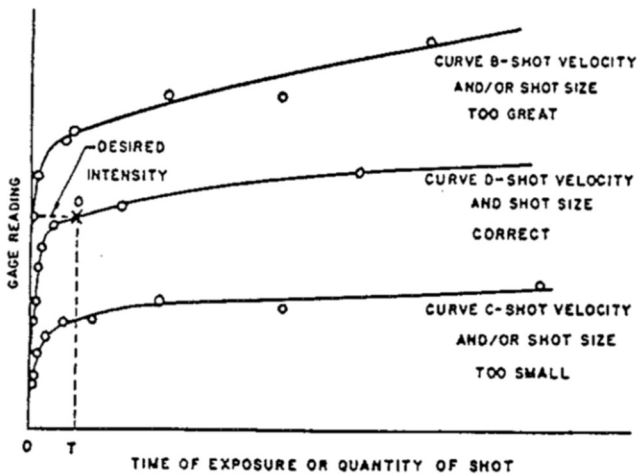


FIG. 2—INTENSITY DETERMINATION CURVES B, C, AND D

**Alternative Procedure Based on Coverage Measurement**

The mere presence of an alternative procedure indicates that peening intensity definition was in its formative stages. This alternative procedure assumes that a required peening intensity could be specified in three parts: Strip Type, Arc Height and Percentage Coverage for that arc height, e.g. "0.010, A-2 and 98% Coverage."

The recommended procedure may be summarized as follows:

- (1) - One strip to be polished, peened to a known, reasonably-low, level of exposure and the coverage measured for that strip. Coverage measurement to be achieved by placing the strip in the field of a metallurgical camera, tracing the indented areas using a sharp pencil and tracing paper, measuring the indented areas within a circle of known diameter, using a planimeter, and finally calculating the ratio of indented areas to total area of the circle.
- (2) - The measured coverage and known level of exposure to be used to determine the exposure required to meet the specification, e.g. 98%.
- (3) - An unpolished strip to be peened for the exposure determined in (2), arc height measured and compared with the specified arc height requirement.

- (4) - If the measured arc height does not meet the requirements then the machine settings must be changed and steps (1) to (4) repeated.

The relationship between coverage and peening exposure time was expressed as:

$$C_2 = 1 - (1 - C_1)^n$$

Where C1 = % coverage (decimal) after 1 cycle

C<sub>2</sub> = % coverage (decimal) after n cycles

n = number of cycles

A chart, Fig.3, was provided "plotted to a convenient time scale."

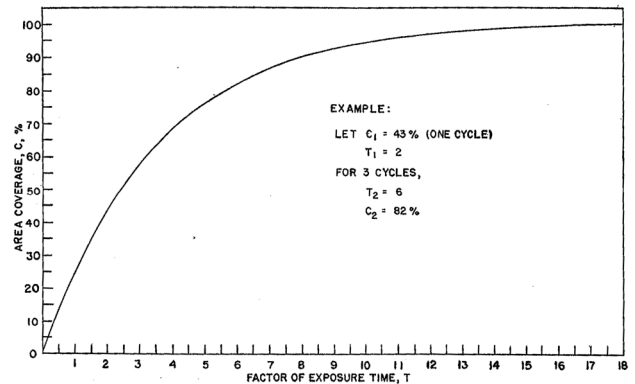


Fig.3. Relationship of Coverage to Exposure Time.

The chart, Fig.3, actually follows the exponential function:

$$C\% = 100(1 - 0.756^n)$$

An example of using Fig.3 was given in section 7 as: "Suppose, for example, the desired conditions are 0.010, A-2 and 98% coverage. Suppose further that the coverage measured in the first trial was 76%. Referring to the chart of Fig.3 the exposure time used in this test is equivalent to five units. At fourteen units, 98% would be obtained. Therefore, the exposure time must be increased in the ratio of fourteen to five, or 2.8 times the exposure used in the first trial. This is the exposure to be used in determining the arc height."

This procedure seems to be rather inappropriate for everyday shop-floor use. It does, however, have the advantage that a point does not have to be (vaguely) selected from an arc height versus exposure graph.

**J443 1961**

The only changes from the 1952 version appeared in the two introductory paragraphs where J442 was first mentioned together with suggested intensity ranges for N, A and C strips. The rest of the specification was identical so that this version was not to be regarded as superseding the 1952 version. Only minor improvements in graphical and computational aids

had occurred between 1952 and 1961. Pocket calculators had not yet appeared.

**J443 1984**

This version was issued with the declaration that it was to supersede the 1952 version.

A considerable expansion was involved – the document becoming six pages in length compared with the two of the 1952/1961 versions. Quite apart from being expanded to six pages this version included the requirement that “Applicable Publications” formed a part of the specification to the extent specified. These publications were SAE J442, SAE J784a and SAE J808a. A “Related Publication,” SP181, was stated to be for information only and was not to be a required part of the document.

The figures from the previous versions have simply been copied. An enormous change in availability of computational aids had, however, taken place since 1961. Science-driven procedures, such as x-ray diffraction were routinely deriving best-fitting curves in order to pinpoint diffraction peak location. These employed devices, such as PCs and even programmable pocket calculators, to eliminate the tedium of manual procedures. Older readers may remember the launch of the Commodore 64 which became the largest-selling computer of all time.

Fig.1 is reproduced here as Fig.1/1984. The curve in Fig.1/1984 has exactly the same six points and shape as in the previous versions. A dashed portion of the curve is included beyond the sixth point reflecting projection (rather than knowledge) of its location. All six points are still shown as lying on a hand-drawn curve – however improbable that might be for real data points. The double intensity indicators of “intensity of peening” and point “A” were also preserved.

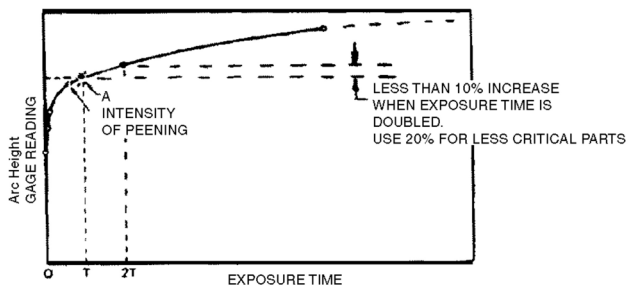


Fig.1/1984. Intensity Determination Curve.

A notable addition to Fig.1/1984 is that relating to “Less than 10% increase when exposure is doubled” together with “Use 20% for less critical parts.” This definitely refers to the point marked as “A” - which is not one of the six ‘data’ points but has to be selected as a point on the curve itself. There is no mention of computerized curve-fitting, which was becoming commonplace in other technologies.

A different attempt was made to specify and define ‘intensity’ - as illustrated by the following extract:

“Specification of an intensity (for instance, 12A) implies an arc measured when saturation has been obtained, as explained below:

A plot of peening time versus arc height can be used to define saturation. By peening a series of test strips, using increasingly longer peening times, with all other conditions maintained constant, and plotting the series of points on a graph of time versus arc height, a curve will develop. These points define a curve with a general shape as shown by Figure 1. Saturation has been attained when the “knee” of the curve is passed and increasingly longer periods of peening time are required for a measurable increase in test strip arc height. The location of the knee, point A shown in Figure 1 can be defined as that point on the curve beyond which the arc height does not increase more than “X” percent when the peening time is doubled.”

A crucial omission in this well-intentioned definition was of the one word “first” in the last sentence. If it had read: “The location of the knee, point A shown in Figure 1, can be defined as that **first** point of the curve beyond which the arc height does not increase more than “X” percent when the peening time is doubled” subsequent misinterpretation would have been avoided. With “first” added then a single point is being defined. Without it then the definition is satisfied by a region (not a point) of a curve.

Having defined peening intensity in terms of ‘saturation’ having been achieved, later parts of the text employ the phrase “saturation curve” to describe the general shape shown as Fig.1. This phrase is somewhat ambiguous since what is generally understood by the word “saturation” does not occur. “Saturation” is generally employed to describe any situation that has reached its absolute maximum – which does not happen at any stage of shot peening. It would, perhaps, have been better to stay with “Intensity determination curve.”

Fig.2 in 1984 is again copied from that of the original versions - but with some modifications. These include the

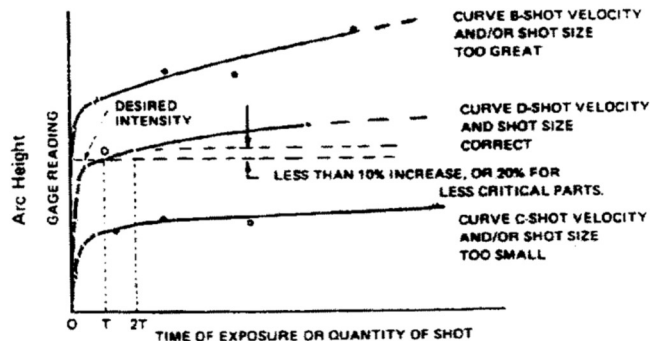


Fig.2/1984. Intensity determination curves B, C, and D.

removal of some 'data points' below the indicated peening intensity, with a corresponding dashing of the curves, together with the addition of the "Less than 10% increase, etc." concept. The general instructions as to how to change the stream's peening intensity remain very similar to those of previous versions.

Determination of surface area coverage was expanded but not presented as an "Alternative Procedure Based on Coverage Measurement." Five methods of coverage determination were allowed, singly or in combination. These included the one method allowed in the 1961 version.

**J443 2003**

This version was mistakenly declared as "Superseding J443 OCT 1997" – which was never issued - officially it may be regarded as superseding J443 JAN84. The revised version has only four pages - coverage measurement procedures now being incorporated into 'J2277 Shot Peening Coverage' as an "Applicable Publication." The second 'applicable publication' was J442.

The curve in Fig.1 was changed (for the first time in over fifty years) and is reproduced here as Fig.1/2003. In terms of shape it is quite different from the previous version. It has, in fact, exactly the same shape as the coverage curve, Fig.3, of the original 1952 version of J443. It is labeled as being a "Saturation Curve" rather than "Peening Intensity Curve". An identical figure to Fig.1/2003 appears in the 2001 edition of the SAE Manual on Shot Peening, HS-84.

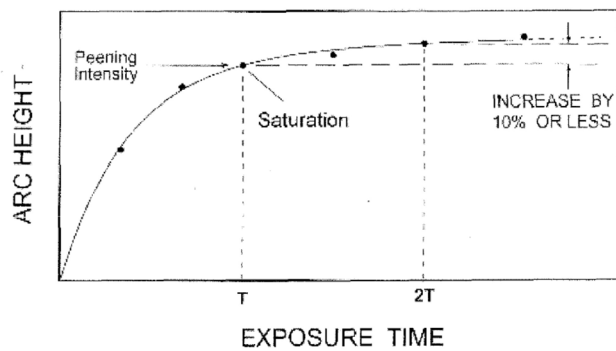


Fig.1/2003. Saturation Curve.

Six points are marked on Fig.1, all six being very close to the drawn curve. The small differences follow a sequence 'just below, on, just above, just below, on, just above' the curve. This sequence is statistically unlikely to occur with a set of six real data points.

The revised definition of peening intensity was encapsulated in the following extract:

*"Saturation has been attained when the "knee" of the curve is passed and increasingly longer periods of peening time are required for a measurable increase in test strip arc height. The location of the knee, saturation point shown*

*in Figure 1, can be defined as the first point on the curve beyond which the arc height increases by 10% or less when the peening time is doubled."*

The word "first" has, fortunately, been added but other problems now attend the definition. These are (1) that the simple exponential shape of curve shown does not have a "knee" and (2) that "first point on the curve" is ambiguous. "Saturation" in Fig.1 now coincides with a marked point – which it did not in previous versions. This ambiguity has led to different interpretations of the definition e.g. selecting the first data point from a set for which doubling the exposure time gives 10% or less increase in arc height. The critical exposure times marked on Fig.1, T and 2T, also appear to indicate data points.

Fig.2 of previous versions (indicating how machine settings affect peening intensity) has not been included. It may be concluded that users did not now need to be made aware of how to influence peening intensity by modifying machine parameters.

**J443 2010**

This latest version is declared as "Superseding J443 JAN2003". Six pages in length the document has three "Applicable Publications":

SAE J442 Test Strip, Holder and Gage for Shot Peening, SAE J2277 Shot Peening Coverage Determination and SAE Computer Generated Shot Peening Saturation Curves.

The three major changes may be summarized by the following extracts from page 1 of the document:

*"Figure 1 – Eliminate "or less" from the arc height criteria so one and only one numeric answer can be derived from a given saturation curve."*

*"Figure 2 – Demonstrates that special cases exist where... the Almen strip is saturated ... at the least amount of exposure available."*

*"Section 7.3 – It is common to use a fixture with multiple Almen holders for intensity tests. The peening intensity at each holder position must meet the requested values. The saturation times for each holder will be unique...."*

**Figure 1**

The latest version of Fig.1 is reproduced here as Fig.1/2010. The curve itself is a direct copy of the simple exponential curve used in 2003. Both sources of ambiguity (in the 2003 version) have, however, been removed. Two of the four points have been removed; those that previously were marked at exposure times of T and 2T. This, in turn, removed the ambiguity that these points might/should be data points. "Increase by 10%" is used to specify the unique point of the curve that is to be used to identify the level of peening intensity. This

removes the second source of ambiguity. The shape of the “typical curve” is now defined as “Type 1” – in order to distinguish it from a newly-introduced shape “Type 2.” Computers are mentioned for the first time with the sentence: “The use of computer generated saturation curves which comply with SAE J2597 is recommended.”

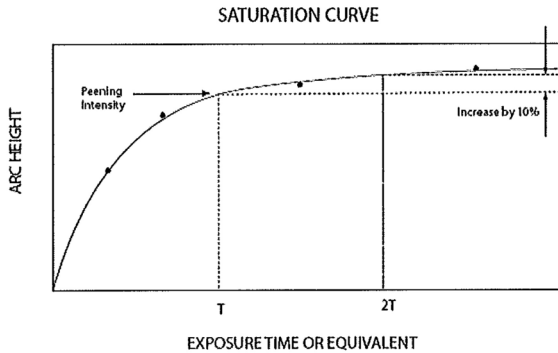


Fig.1/2010. Time Based Saturation Curve.

**Figure 2**

A different shape of saturation curve (from that in Fig.1) is specified - as shown here as Fig.2/2010. This is again an idealized shape, being based on ‘virtual’ points that show no variability. The different shape is intended to accommodate situations where even a single pass would exceed the previously-defined peening intensity point. Measured arc height after one pass is to be used as the peening intensity - provided that none of the multi-pass points have an arc height that exceeds it by more than 10%.

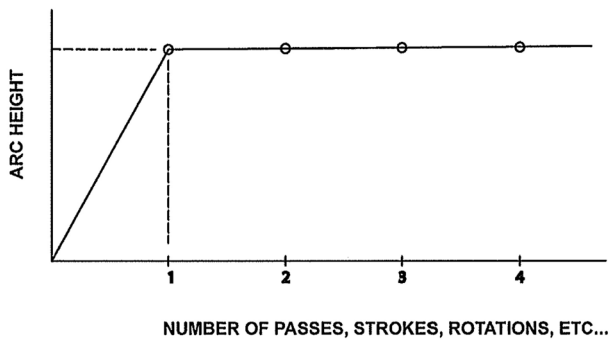


Fig.2/2010. Schematic Representation of Special Cases.

The peening intensity estimated using this “special case” method must normally be higher than that which would have been derived using the standard approach indicated in Fig.1. No guidance, however, is given as to any ‘correction’ that should be applied.

**Section 7.3 Verification of Intensity when using Multiple Holders**

This is another new topic, which needed specifying, as many

operations involve multiple holders. The saturation time, T, will be different for each holder. For subsequent verification, involving only one strip per holder, it is therefore recommended that a single verification exposure time may be selected. This should be the longest of the previously-derived saturation times for the group of holders – or other value acceptable to the customer. For each verification strip a “target arc height” has to be derived from the corresponding saturation curve using the agreed single verification time. Each peened strip must repeat the corresponding derived value to within  $\pm 0.038$  mm ( $\pm 0.0015$  inch).

**DISCUSSION**

J443 plays a central role in controlled shot peening. Its evolution from 1952 to date has several fascinating aspects. It is easy to be critical with the benefit of hindsight. Any implied criticisms in this article were not, however, intentional. Every committee in every sphere of activity meets problems caused by the disparate viewpoints of its members. Nevertheless the J443 Committee has succeeded in refining and improving intensity measurement procedures and accommodating new analytical techniques. ●




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