ACADEMIC STUDY
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Coverage Variability

INTRODUCTION
Coverage is one of the most important parameters in shot peening. It is specified in J2277 to be the "Percentage of a surface that has been impacted at least once by the peening media." It is, however, impossible to avoid coverage variability. Measured coverage values vary because we cannot apply peening uniformly and also because the measurement technique itself is a variable. The topic is so important that it merits different approaches. Coverage variability was the subject of a previous article (TSP, Summer, 2009) using a largely mathematical approach. This article is much more descriptive, avoiding mathematical derivations.

Fig.1 is a schematic representation of the simplest type of peening. It assumes that a conical jet stream is moved steadily and linearly across a flat plate sample (colored green). As it passes across the sample, dents are created (colored gray). The result is that we have a pattern of dents with maximum coverage occurring along the centerline and zero coverage occurring at both edges. This represents the most extreme type of coverage variation. The maximum coverage level on the centerline will depend on several factors including shot flow, shot size, shot velocity, traverse rate and sample hardness.

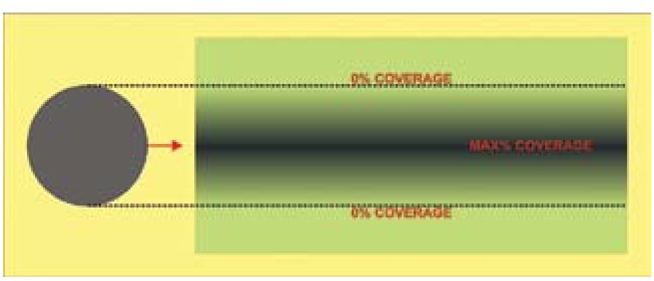

Fig.1. Extreme coverage variation induced by a single pass across a flat plate specimen.

This article concentrates on explaining the reasons for unavoidable coverage variation and suggesting methods for minimizing its effect. A substantial section has been included that compares the problems associated with paint spray and shot peening coverage.

LINEAR SINGLE-PASS COVERAGE GENERATION ON FLAT SURFACES
The transverse variation of coverage indicated in fig.1 is of considerable importance in shot peening operations. The following assessment starts by using an analogy. Imagine a five-soldier squad being ordered to march across three strips of soft ground, A, B and C. The three-soldier column marching across the central strip, B, would obviously leave three sets of boot prints as compared to the single sets for strips A and C. Boot-print coverage is three times as great for the central strip.

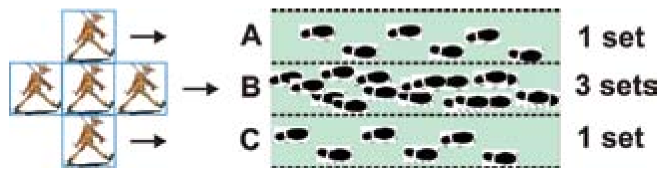

Fig.2. Five-soldier squad leaving boot prints on soft ground.

A five-soldier squad is not a good representation of a circular peening area. Fig.3 extends the analogy using 346 soldiers arranged in 20 columns. This arrangement is much nearer to that of a circle but makes mental picturing in terms of boot-print coverage more difficult. The implied coverage variation (top to bottom in fig.3) is also not very accurate. For the top and bottom columns there would be six sets of boot prints as compared with twenty for the six central columns.

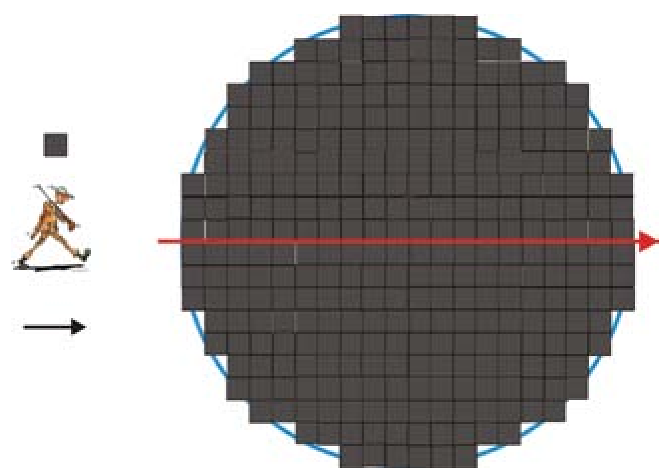

Fig.3. 346-soldier platoon representation of coverage generation.

An actual shot stream generates a vast number of indents as it passes over a component. Consider first a circular area within which peening indents are being uniformly generated. As such an area passes over a flat surface the relative coverage rate variation is as represented in fig.4. This type of variation has a semi-circular shape.

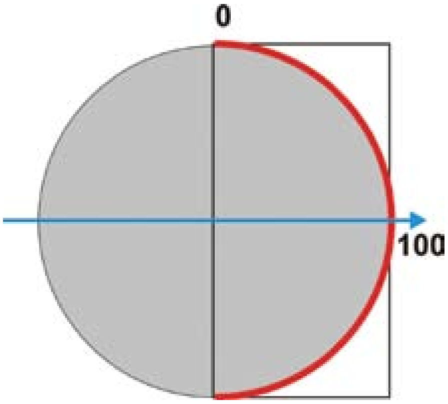

Fig.4. Variation of coverage for a uniform shot stream.

Commonly, however, the shot flow rate is not uniform—it is greater towards the center of the shot stream than it is on the outside limit. This gives an even greater variability than does a uniform shot stream.

Fig.5 indicates the variation of coverage for a non-uniform shot stream. The type of variation, shown in red, resembles a parabola rather than a semi-circle.

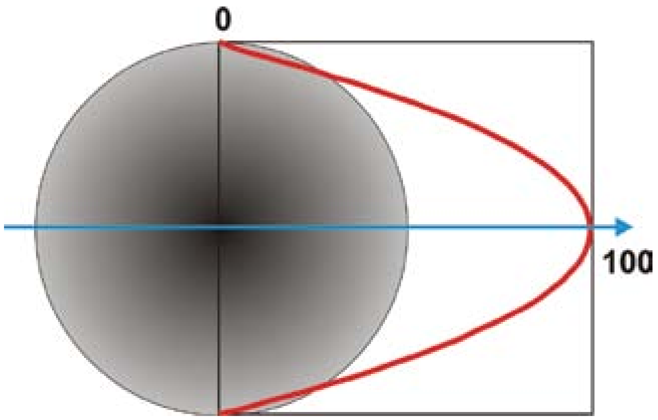

Fig.5. Variation of coverage for a non-uniform shot stream.

Figs.4 and 5 represent model situations where the edges of the shot streams are sharply defined. Real shot streams are not sharply defined—there is a "blurring" of the edges.

The variability of coverage is made worse if the shot stream is angled relative to the surface being peened. Fig.6 is a diagrammatic representation of this effect. When the stream is angled, the stream/surface area becomes elliptical. The rate of coverage is much greater at A than it is at B. A simple analogy is to shine a torch at an angle to a flat surface and observe the variation in brightness.

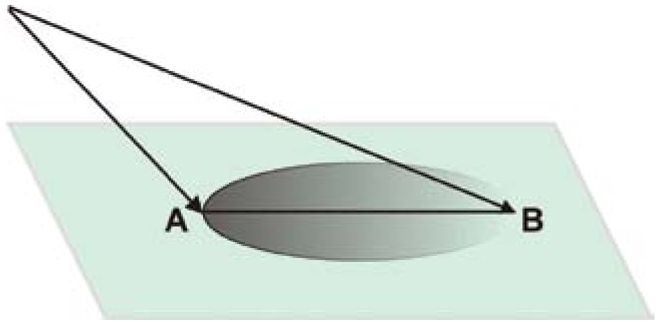

Fig.6. Effect of projected angle on coverage.

LINEAR MULTI-PASS COVERAGE GENERATION ON FLAT SURFACES

Fig.7 is a representation of the variation in coverage caused by overlapping of parallel linear passes. This "stripe effect" can only be observed directly on peened components if low coverage values have been applied. That is because we cannot normally distinguish between a "high degree of coverage" and a "very high degree of coverage." An established alternative for detecting coverage variation is to use a commercial fluorescent tracer.

Fig.7. "Stripe" effect of coverage induced by overlapping linear passes.

Quantitative analysis of coverage variation by overlapping passes has been described in a previous article (TSP, Summer, 2009). Figs. 8 and 9 are schematic depictions of zero and 50% overlap of linear passes.

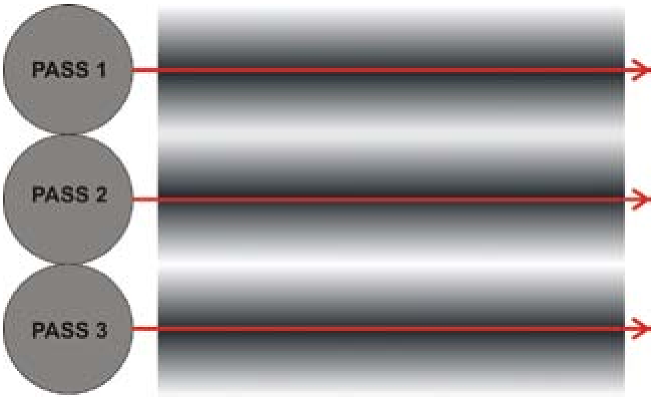

Fig.8. Coverage variation for zero overlapping linear passes.

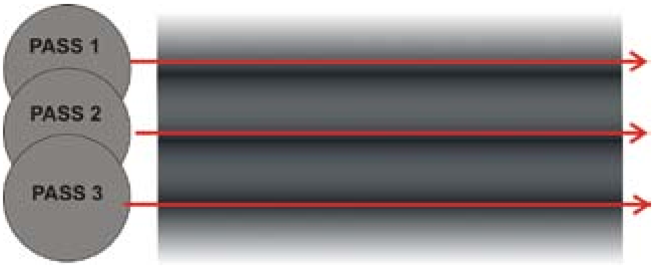

Fig.9. Coverage variation for 50% overlapping of linear passes.

COVERAGE VARIABILITY ILLUSTRATED USING PAINT SPRAY COMPARISON

An interesting parallel can be drawn between coverage variation in spray painting and in peening. Commercial spray painting is a multi-billion dollar industry that has therefore attracted huge research and development attention, especially for the automotive industry. At low paint coverages the variability is obvious. Current optimization techniques are based on employing ERBA (Electrostatic Rotating Bell Atomization). Paint enters a bell that is rotated at thousands of rpm in order to atomize it into tiny particles that are then ionized before being attracted to the component by potential differences of thousands of volts. The primary objective with spray painting is to achieve coverage within a required thickness range. A much simpler technique employs aerosol cans of paint.

Experiments using a simple aerosol paint spray can indicate procedures that are useful for highlighting shot peening coverage variations. These involved using a can of auto primer paint sprayed onto sheets of white A4 80 g paper from a distance of about 300 mm.

Fig.10 shows a very close similarity to the non-uniformity of shot stream coverage indicated in fig.5.

Fig.11 is a photograph of the author's attempt to simulate the situations shown in figs.8 and 9. This involved employing horizontal "strokes." The observed effect simulates a peening situation intermediate between those of figs. 8 and 9.

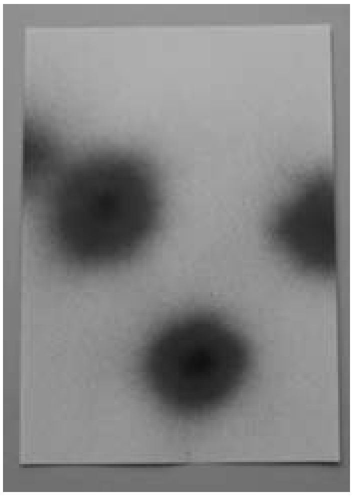

Fig.10. Static spray patterns showing coverage variation.

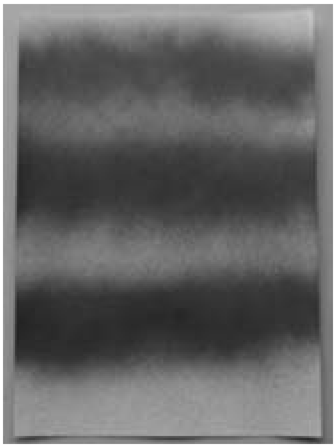

Fig.11. Paint spray patterns showing 'stripe' coverage variation.

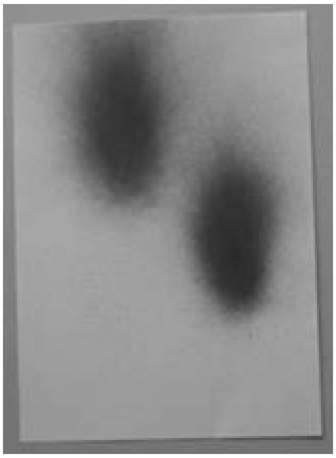

Fig.12. Angled spray paint patterns.

Fig.12 emulates the effects of angling a peening stream relative to a component's surface. The predicted shape and coverage variation are very similar to those given in fig.6. Finally, fig.13 illustrates the author's attempt to achieve uniform coverage by waving the spray over the surface. Uniformity was not achieved!

Fig.13. Random paint spray.

DETECTABILITY AND EFFECTS OF COVERAGE VARIABILITY

It is generally recognized that 98% is the maximum level of coverage that can be measured with any degree of accuracy. Variability of coverage levels below 98% can therefore be detected, but not for higher levels. It has also been suggested that 98% should be regarded as "Full Coverage."

The minimum level of coverage on a peened component that displays detectable variation is of critical importance. Assume, for example, that coverage with a single pass varies as shown in fig.14. The problem now is to estimate how many further passes would be needed to satisfy a client's specified coverage level. For the example shown, the minimum observed coverage level is 60%.

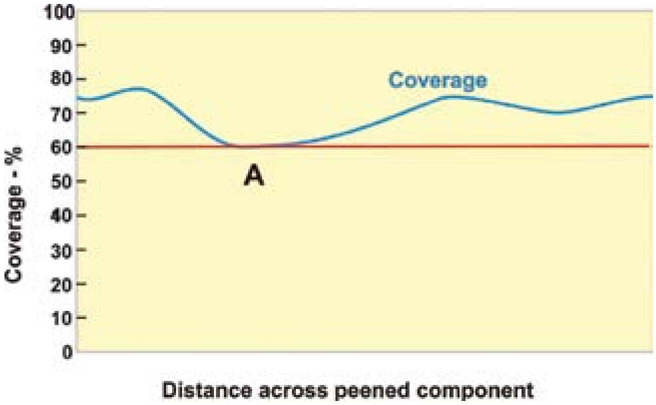

Fig.14. Representation of possible coverage variation across a peened component.

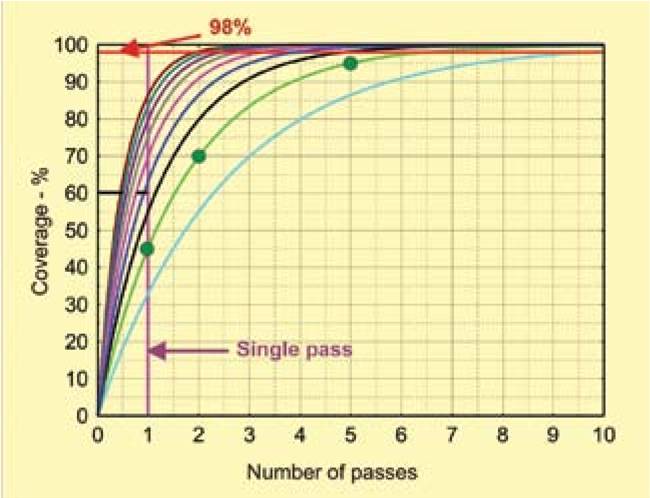

Fig.15. Prediction curves for estimating number of passes to achieve required coverage level.

It is neither practicable nor necessary to make enough quantitative measurements to replicate the complete curve of fig.14. In practice, peeners scan the surface using simple optical magnification. Experienced peeners can readily detect the "low point" region equivalent to A. Just one coverage measurement at, or near to, A is sufficient to estimate the required number of repeat passes. An experienced peener might say that "Four or five repeat passes will give 'full coverage' (98%) if one pass imposed a minimum of 60%." The basis of this judgement is illustrated by the coverage prediction curves shown in fig.15. The variation of coverage with amount of peening is well-established, having the exponential shape of the curves shown. For fig.15 several coverage/passes curves have been included, reflecting different peening rates.

Use of the prediction curves can be illustrated by the following example: three dots are shown on the green curve in fig.15. The first dot corresponds to coverage of 45% having been imposed by one pass. The second dot corresponds to coverage of 70% being predicted after a second pass. The third dot corresponds to coverage of 95% being achieved if three passes are applied. For the example of 60% imposed by one pass prediction is not quite as easy, because it doesn't happen to correspond exactly with any particular curve—we must interpolate between nearest curves.

Prediction curves are the graphical equivalent of mathematical prediction programs. One such prediction program was described in TSP Summer 2012, where entering the measured value of coverage for one pass yielded predictions of coverage for multiple passes. Copies of that program are available from Electronics Inc. at www.shotpeener.com.

MINIMIZATION OF COVERAGE VARIABILITY

Coverage variability can, of course, be rendered undetectable.

This occurs, for example, if "300%" coverage has been specified. This requires that peening is applied for three times as long as is needed to reach "full coverage". With that amount of peening it would not be possible to detect any variation in coverage.

"Uniform coverage" of less than 98% can be defined as coverage that does not exhibit detectable variation. Experienced industrial shot peeners have far more knowledge than has the author on how to approach such uniformity for complex component shapes. The basic principles are, however, common to those required for uniform spray painting.

One novel technique that could prove useful in improving uniformity is to incorporate dithering. "Dither" comes from the Middle English verb "didderen," meaning "to tremble." Small vibrating motors were built into the mechanical computers used in World War II bombers and the induced vibration was called "dither." Small vibrating motors could be attached to a peening nozzle in order to induce two-dimensional dithering. Experiments with an aerosol paint spray and physical hand trembling revealed that a much more uniform coverage could be achieved than when using a firm hand.

Another suggestion that could be used for large, flat, components is to employ a highly rectangular nozzle. This concept springs from the fact that high-pressure patio cleaners can have either circular or rectangular water jet streams. Personal experience indicates that the highly rectangular jet induces a much more uniform cleaning action than does the circular water jet.

DISCUSSION

The main objective for this article was to try and raise awareness of coverage variability. This important topic has produced very little attention in published work. Simple geometrical factors show some coverage variability is unavoidable. Steps should therefore be taken to minimize its extent.

There are very few occasions when coverage variation can be encouraged. One could be for concave fillets where maximum coverage may be required at the center of the fillet if this is the most highly stressed region.

Non-uniform peening can have an effect on measured peening intensity values. Almen strip deflection increases with the amount of peening (and hence the coverage) that has been applied. The more a moving shot stream is offset from the centerline of the strip the lower will be the average resulting coverage. This will, however, only be significant for small-diameter shot streams.

The paint spray analogy that has been included can be an economical way of making newcomers to shot peening aware of coverage variability.

The suggestions made of ways of reducing coverage variability are speculative. Progress requires, however, that new techniques evolve.