Shot Peening Coverage– the Real Deal

Dr. John Cammett

In an article in **The Shot Peener** Spring 2007 (Shot Peening – Getting It Right), I stated that coverage is the least understood and least appreciated concept in peening. It is often the least observed in terms of meeting coverage requirements in practice. My statements stem from many years of observation of company specifications, conversations with practitioners and contact with attendees at workshops and onsite training classes. With regard to the latter, often one of the principal barriers to overcome is to uncouple the concepts of peening intensity and peening coverage which, though separate and distinct, are often traditionally and curiously commingled in practice. I will come back to this later in the article, but for now, I will say that the confusion usually centers on the use of exposure times in deriving peening intensity from Almen saturation curves to gage component coverage. Coverage and exposure time of an Almen strip, in general, have nothing whatever to do with peening coverage on a component. Let me leave it at that for now with a promise to return to the subject in later discussion. Before doing that, I will present some of the basics in coverage, then make good on my promise while offering some highlights and arguments concerning the importance of coverage as regards to component performance and peening process economics.

Coverage Basics

What do we mean by coverage?

Coverage or coverage percent up to 100% is defined as the percentage of a given surface area obliterated by shot peening impressions, commonly referred to as dents or dimples. Coverage beyond 100% is defined as multiples of the time to achieve 100% or full coverage. Thus, 200% coverage requires twice the time for full coverage, 150% coverage requires one and one-half the time for full coverage, etc. For practical purposes, full coverage and 100% coverage may be considered synonymous. In detail, however, they are slightly different whereby convention is that full coverage is slightly less (98%) than 100% coverage. This subtle difference arises from recognition that coverage percentages are difficult to discern as 100% coverage is approached and that the rate of coverage in this range is quite low. Further explanation of the latter point is offered later in discussion of how coverage develops.

The time to achieve a given coverage percentage is influenced by media size, peening intensity and media flow rate. Media size and velocity as related to peening intensity dictate the size of peening dents (diameter and depth) presuming spherical media. It should also be noted that media hardness will have a minor effect on coverage. This is because the media hardness relative to component material hardness, for a given velocity, will determine how much energy is transferred into making the impression versus how much energy is consumed in deforming the media particle. Media flow rate (how much media we throw per unit of time) will thus determine the rate at which coverage is achieved. ***It cannot be overemphasized that coverage control cannot be achieved or maintained unless media flow rate is also positively controlled and maintained.***

How does one determine coverage?

Before delving into methods of coverage measurement, I must stress that coverage percentage must be determined by observations on the component. Unless the component material is the same as the Almen strip (AISI 1070 spring steel) or a steel of the same hardness and microstructure, component coverage at given exposure times will not be the same as observed on Almen strips. Moreover, impact angle and component geometry, in addition to hardness, will also influence coverage. In some cases, Almen strip coverage may provide an approximate guide to component coverage, but in the final analysis, coverage must be determined by observations on the component. Exposure times on Almen strips and exposure times on components, in general, have no relationship to each other. For given peening conditions, peening dimple size is a function of material hardness. Softer component materials will achieve coverage more quickly than Almen strips (~45 HRC) while harder component materials will take longer. ***Leave Almen strips to do their one job and that alone is to determine intensity—not coverage.***

As detailed in SAE J2277[1], the most common and usual means for determining component coverage is by optically-aided observation at 10-30X magnification. This can be conveniently accomplished by use of commercially available magnifiers. If component size or geometry precludes direct observation of an area in question, then replicas of the surface may be made and then examined optically to determine coverage. Figure 1 shows two photographic examples of areas peened under the same conditions, but for different exposure times. The exact coverage percentage associated with the peening time for the partial coverage example is argumentative, but it was obviously insufficient to yield full coverage. Peening time was cumulatively increased until full coverage was achieved as evidenced by complete dimpling as in the full coverage example. Viewing replicas of peened surfaces is greatly facilitated by use of a top-lighted stereo microscope. Determining coverage by optical observation may also be facilitated by use of coupons with a ground or sanded finish, particularly for

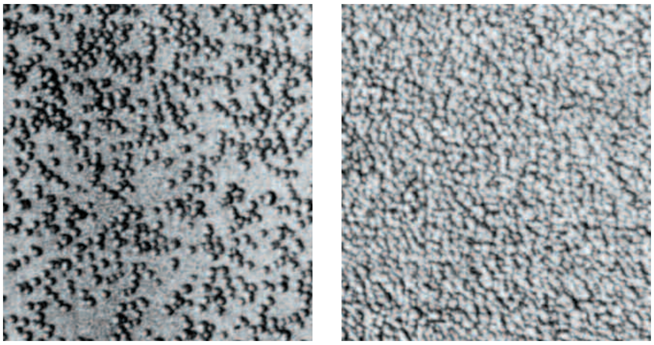

Figure 1. Coverage Examples
(Magnification altered from original 10X in reproduction.)

Continued on page 10

THE REAL DEAL
Continued from page 8

hard materials as the striated surface appearance will provide good contrast for observing peening dents.

There are methods other than optically-aided observation that may be used to determine coverage. These include video imaging which is a special form of optically-aided observation. This technique requires skill and relatively expensive equipment. Another technique is scanning electron microscopy, either on small components, sections cut from components or on replicas of component surfaces. Because of expense and time, this is not a favored technique, but it can be useful when dimples are difficult to resolve optically as on components of very hard materials. There are also methods involving coating a component and observing relative removal of the coating after peening. This practice most often employs a fluorescent coating observed under black light or the blue dye commonly used in machine shops. These methods require care to either ensure that there is a one-to-one relationship between media impacts and the amount of coating removed or a means to correlate coverage percentage with coating removal.

How does coverage develop?

When considering how coverage develops in peening, one must first realize that coverage is not linearly related to exposure time. Certainly the number of media impacts is linearly related to exposure time; however, peening is a random process and not every media particle impacts a new site. Rather many sites are repeatedly impacted by particles as the process proceeds. As modeled by Lombardo[2], after 90% coverage eighty percent of sites have been struck twice or more with five percent of sites struck five times or more. At 99% coverage, eighty-five percent of sites have been struck twice or more with fifty percent of sites struck five times or more. At 99.9% coverage, more than ninety-five percent of sites have been struck twice or more with eighty percent struck five times or more. In the latter case, more than twelve percent of sites have been struck ten times or more. Figure 2 schematically illustrates the effect of a media impact on a metal surface.

As illustrated in cross-section, a particle impact creates a visible dent in the surface and an associated zone of plastic flow beneath the surface. This plastic zone is often up to three times the diameter of the dent. Thus, it is not necessary for surface dents to overlap in order that subsurface plastic zones overlap as illustrated in Figure 3. Here in cross-section, the plastic zones associated with separated dents overlap.

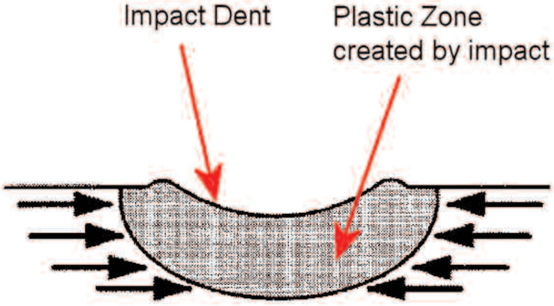

Figure 2. Schematic of Media Particle Impact and Resulting Plastic Zone

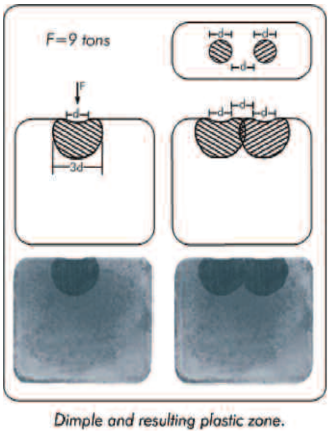

Figure 3. Superposition of Plastic Zones Associated with Adjacent but Separated Dents

In the above figure, the lower images were produced by metallographic etching of cross-sections through a plastic zone created by pressing a hardened ball into the metal surface.

The development of coverage may be expressed graphically as a coverage curve with an actual example from work by Cammett and Prevey[3] shown in Figure 4. The straight line relationship with triangles as data points represents the accumulation of media impacts with time. The decelerating curve with squares as data points represent coverage accumulation with time as given by the model of Kirk and Abanyeh[4]. The open circles, in good agreement with the coverage model, represent actual coverage observations up to the point at which some individual dents could be resolved. The shape of the coverage curve is typical of that for all other cases I have observed.

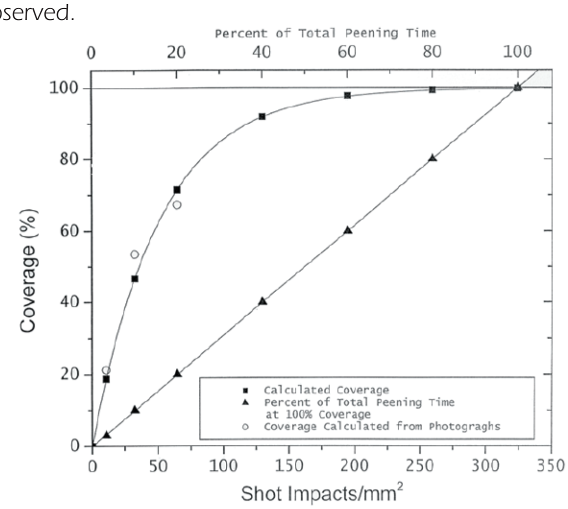

Figure 4. Coverage Curve (4340 Steel, 38 HRC, 9A Intensity, S280 shot)

Some interesting observations may be made from the coverage curve in Figure 4. The initial rate of coverage was high, but decreased markedly as 100% coverage was approached. In fact the time to achieve the final 10% of coverage was 1.5 times that to achieve the first 90%. The final 1% of coverage required 20% of the total time to 100% coverage while the final 2% of coverage required nearly 40% of the total time. The latter fact highlights the significance of considering 98% rather than 100% as full coverage. Hitting 98% on the button isn't easy, but significant cycle time savings could result from excellent and reproducible coverage control.

Continued on page 12

THE REAL DEAL
Continued from page 10

Certainly the Kirk-Abanyeh model, (details not shown here), is an excellent portrayer of coverage development. Application of the model, however, among other things requires measurement of peening dent diameters. This is beyond the practical capability of most peening practitioners. There is yet a much simpler method that may be used for estimating coverage development. Expressed mathematically, the relation is:

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

Here C_n is the coverage percentage (expressed as a decimal) after n peening cycles, C_1 is the coverage observed after one peening cycle and n represents the number of peening cycles (or n units of peening time). It must be recognized that this relationship becomes non-physical as one approaches 100% coverage because n approaches infinity as C_1 closely approaches a value of 1. As a practical matter, nonetheless, one will find it useful to estimate the number of cycles (or time) to achieve 98% (0.98) coverage deemed as full coverage. A log-log plot based upon the above relationship of coverage achieved in one pass vs. passes required for 98% coverage will readily permit full coverage estimation. An example of this is shown below in Figure 5. In this example, after observation of 39% coverage in one peening pass (cycle), an estimate of 8 cycles was made to achieve 98% coverage. Of course, the result is just an estimate and must be checked by actual observation.

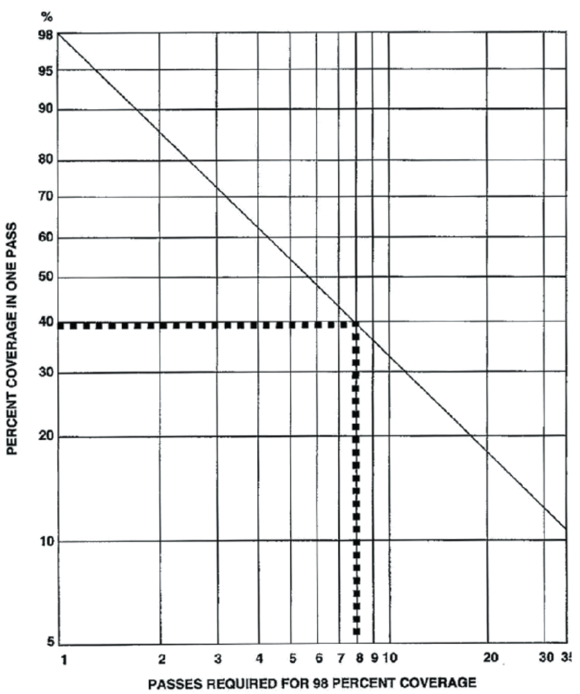

Figure 5. Graph for Estimating Coverage

The Importance of Coverage

Coverage is important first because of its impact on product quality and performance. Insufficient coverage may permit premature component failure by not overcoming tensile residual stresses from prior component processing or by not sufficiently counteracting applied tensile stresses in service. This is widely recognized, but the recognition often results in overdoing coverage. This is not a good thing since excessive coverage, in some cases, may permit premature component failure because excessive coverage creates surface damage. Peening involves a competition between the beneficial effects on component performance of subsurface compressive residual stresses and surface damage created by peening that tends to reduce component performance. Examples of surface damage that may be created by excessive coverage in peening include burrs, microcracks and microlaps which have sometimes been called peened surface extrusion folds (PSEF). Such defects are created by surface plastic deformation associated with multiple overlapping media particle impacts at and near the same site. Examples of such surface damage features are seen in the metallographically-prepared section through the peened surface of a steel component (42 HRC) in Figure 6 from work by Cammett[5]. Cracks in these photomicrographs are fatigue cracks whose initiation was favored by the presence of the defects created by peening.

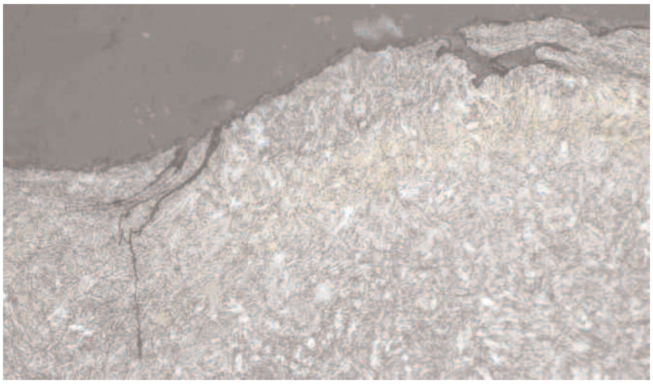

Figure 6. Fatigue Cracks Emanating from Peening-Induced Surface Defects

Continued on page 14

Continued from page 12

Further evidence for the adverse effect of excessive coverage on component performance is highlighted by the fatigue S-N curves for 4340 steel shown in Figure 7 from the work of Cammett and Prevey[3]. Some readers may note that this is the same figure used in my previous article. It clearly shows that fatigue strength and life were degraded by coverage in excess of 100%. Moreover, the apparent fatigue strength for 80% coverage was the same as for 100% coverage. Along with this was the observation that full development of surface and subsurface compressive residual stresses was achieved at 70-80% coverage. This is not to be construed as general advocacy for partial rather than full coverage in peening although there is potential for doing so after careful study and invocation of excellent peening control in terms of both intensity and media flow. It is advocacy for not exceeding full coverage or nearly full coverage in peening. Undershooting full coverage by a small margin is probably not harmful given the logic that overlapping dents on a peened surface are not required for overlapping of subsurface plastic zones as illustrated previously.

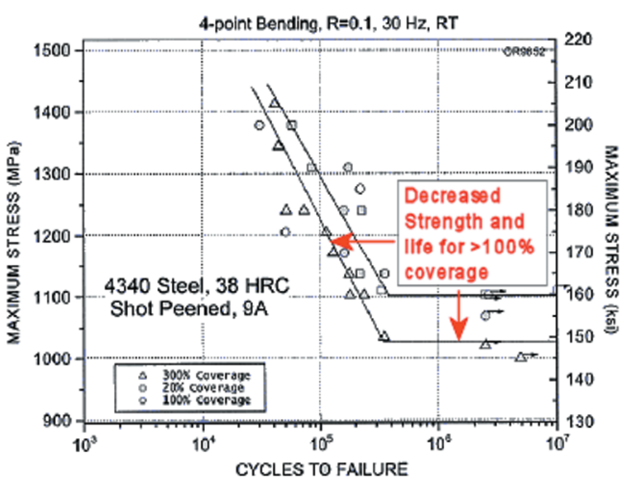

Figure 7. Effect of Coverage on Fatigue of 4340 Steel

As alluded to in the previous discussion, coverage is also important because of its influence on process economics. In the example offered, it was shown that the same fatigue strength in 4340 steel resulted after only about 80% coverage as was attained after 100% coverage. The peening time required for 80% coverage was only twenty percent of that required for 100% coverage. These facts are illustrated by the timelines in Figure 8. Thus, in this example, the full benefit of peening was realized in only one-fifth of the processing time needed to attain 100% coverage. Compared with greater requirements such as 150% or 200%, as are commonly called out, the opportunities for time and cost savings are concomitantly larger. The loss of fatigue strength resulting from peening coverage greater than 100% is further reason to control coverage. The concept of controlled coverage in peening is embodied in a recent patent authored by Prevey and Cammett[6]. I hasten to add again that proper coverage control demands excellent control of media flow.

Peen Lean! Do no more than is necessary to guarantee full process benefit.

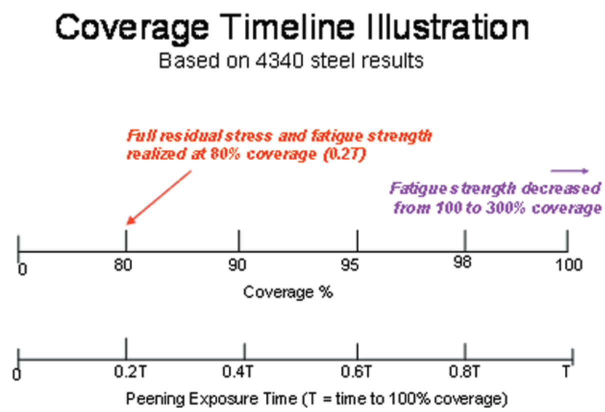

Figure 8. Timeline for Coverage in 4340 Steel

Summary Comments

In this article I have covered basic aspects of peening coverage while addressing and dispelling the erroneous linkage of component coverage with exposure time for Almen strips in saturation curve development and intensity determination. I also addressed the subject of how coverage develops and the matter of coverage curves and their fundamental nonlinearity. Coverage is far too important a consideration to ignore in peening practice as it has significant ramifications in both component quality and in process economics. This is why I have called it the real deal. I leave you with one parting shot... **Peen Lean!**

References
[1] SAE J2277, Shot Peening Coverage Determination
[2] Lombardo, ICSP6
[3] Cammett and Prevey, ICSP8
[4] Kirk and Abanyeh, ICSP5
[5] Cammett, unpublished work
[6] Prevey and Cammett, U.S. Patent 7,159,452

John Cammett Dr. John Cammett, Materials Engineer/ Metals Branch Chief, recently retired after more than 15 years service with the U.S. Navy (Navair) in the In Service Support Center to the Fleet Readiness Center East, Cherry Point, North Carolina. His more than forty-year professional career has also included materials engineering and management positions at the General Electric Company, Evendale, Ohio; Metcut Research Associates Inc. and Lambda Research Inc, Cincinnati, Ohio. His areas of expertise at Cherry Point included analysis of aircraft component failures, aircraft mishap investigations, development of repair/rework process methods and technical support of depot manufacturing/rework/repair operations, surface integrity investigations and metallurgical applications. A Registered Professional Engineer, Dr. Cammett is a fellow of ASTM, past Chairman of Committee E-9 on Fatigue, Life Member of ASM International and past chairman of the Cincinnati Chapter, also a member of the International Scientific Committee for Shot Peening and a conferee of the 2006 Shot Peener of the Year Award. In "retirement", Dr. Cammett is currently involved in training and consulting activities with Electronics Inc., Nadcap auditing plus other research and consulting activities in the private sector.
Dr. Cammett may be contacted via cell phone at 1-910-382-5771 or email at pcammett@ec.rr.com.