Shot Peening… Getting It Right

by Dr. John Cammett

Reflections and Insights

Many readers know me as the guy who does the academic presentation on background and theory at the annual EI shot peening workshops. Indeed I have been doing this for more than fifteen years consecutively. If you consider that subject too abstract for your taste, please do not turn the page and avoid reading this article because you may think it is in the same vein. Instead, this is an appeal to consider the basic aspects of the shot peening process and the importance of doing it right. Lest I be judged overly sensitive or defensive about my workshop presentations, let me say that doing shot peening right is best served when the folks doing it understand the basics of how the process works and especially if they know why it is performed. Looking back over my forty-year professional career, I can claim to have been always interested in shot peening. This interest has held throughout, but is increasing even more now with passing time. The volume is increasing, yet has not yet passed or even reached full crescendo. I trust that the beat will go on for a long time to come. There is yet much to learn and I am well determined to continue the quest.

Through much of my career, I have been a failure analyst. My first experience in failure analysis was a very poignant one. It involved a fatigue failure of a helicopter rotor drive shaft. I hasten to add that this did not involve a military helicopter because it occurred long before my career with the U.S. Navy. While I was with Metcut in Cincinnati, a lawyer brought me the shaft to examine after it had already been examined by the National Transportation Safety Board (NTSB). The lawyer was seeking corroboration of findings by the NTSB metallurgist from examination of the failed component.

I had no disagreement that the failure mode was torsional fatigue. Further, there was no evidence of corrosion or other in-service degradation of the shaft. Also, there were no apparent manufacturing defects. This failure did not involve shot peening quality as an issue because the shaft had not been peened and peening was not called for in its manufacture or design. I claim no knowledge that the helicopter operation was always within its prescribed flight regime; however, my firm belief at that time and since was that the shaft should have been peened. Had it been peened, the helicopter pilot may well be still alive today. In other words, peening could have prevented the fatigue failure of the shaft and the resulting fatal crash.

This matter had personal significance because the pilot was a local physician and father of a high school friend and classmate of my younger daughter. I did not make the connection at the time of my involvement because of the time between the crash and my involvement. I was not called to testify in any legal action which presumably involved suit by the physician's heirs and estate against the helicopter designer and manufacturer. Had that occurred, I would have recused myself when I realized the personal connection. Please note that I am at liberty to discuss this matter because the legal issues of the incident have long since been settled.

Since that most unfortunate helicopter rotor shaft failure, I have examined more than a few aircraft component failures in which shot peening or lack thereof was an issue. I am not at liberty to divulge details, but fortunately I can say that none involved loss of life. Nonetheless, in all such cases, monetary losses were not trivial because aircraft, aircraft components and aircraft component systems are inherently very expensive. Failures of critical aircraft structural and engine components in flight can have disastrous consequences in terms of property loss and loss of life. Even failures on the ground can be very serious.

Let's not overlook the potential serious consequences of failures in ground vehicle components. Loss of use in a racing vehicle may involve great financial loss. Further, if failure occurs in a critical component at critical moments of operation, the consequences could be life-threatening to operators and passengers and result in total loss of the vehicle as well.

Components are not designed to fail, but are often designed to function for infinite life under presumed service conditions. In some cases, particularly in weight critical applications, components are designed only for a prescribed safe service life. In all cases, designers apply design rules and protocols conservatively to achieve desired service lives of components. Skilled designers of aerospace and automotive vehicles and components recognize that manufacturing methods, particularly surface finishing methods and treatments, are critical to performance and life.

Shot peening is one mechanical surface enhancing treatment that can add fatigue life or fatigue strength margin to a component. Peening can do this very reliably if it is performed with due diligence and control. Yet shot peening suffers from an image problem and is not generally popular with designers. Many reluctantly apply it, seeking some margin in fatigue resistance, but do not give it design credit as a fully-reliable benefit. As I see it, this image problem for shot peening stems from two sources:

(1) This process had humble origins and grew out of blast cleaning, a relatively unrefined and "dirty" process in the U.S. automotive industry, and
(2) Shot peening is conceptually very simple. Its analogy with blast cleaning has too often led to lack of process control in practice which in turn has led to variable, unreliable process results.

Peening is neither a cleaning process nor is it merely a matter of propelling spherical media, rather than grit, against the surface of a component. My point is that shot peening, when performed optimally and correctly with due diligence, will produce reliable component life benefits which can be fully accounted for and countenanced in component design and life management.

Basic Aspects of Peening:

Let's look at the basics of what it takes to do shot peening right. Beyond the peening equipment itself, shot peening, when boiled down to its most basic aspects, has three main

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variables: **media, intensity** and **coverage**. In the simplest terms, **media** is what we throw, **intensity** is how hard we throw and **coverage** is how much we throw. "Where" we throw may be considered a fourth basic aspect, involving both media stream aiming and part masking. Where we throw considerations will not be discussed as they are much less often problematic than the what, how hard and how much we throw aspects of the process.

The best peening practice involves achieving an optimum balance of these three basic aspects. Such achievement may be attained only by systematic experimentation and analysis. These are all too often not done. Instead, peening recipes are often derived from experience, not necessarily a bad thing, or from imitating what someone else did. The latter is not synonymous with experience and often leads to less than optimum results. While recognizing that there are interactions among the three basic aspects, let us consider each of these individually and in turn explore their importance to the peening process.

Media:

Shot peening media are, first and foremost, a critical aspect of good practice. After all, media particles are truly the "tools of the trade" and, as for all tools of craftsmen, they must be well-chosen and well-maintained to perform well. Choice of media for shot peening involves considerations for type and characteristics that are suitable and appropriate to the application.

Types of media include four general categories:

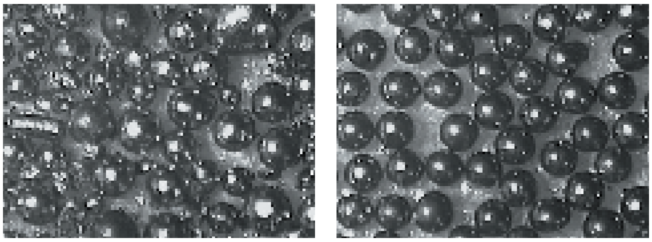
1. Cut wire media – The starting material for this is steel or stainless steel wire. The wire is cut into pieces of length equal to diameter and then, before use, the resulting cylindrical shape is made at least roughly spherical by a conditioning process that involves impingement against a hard surface.
2. Cast media (usually cast steel shot) – The majority of peening applications involve cast steel shot as the media. As the word cast implies, particles are made by solidification of molten liquid steel droplets. In earlier times, steel shot was used for munitions. It was made by pouring molten steel from a (shot) tower and breaking the molten metal into droplets by a stream of forced air. Free falling a sufficient distance through air allowed the droplets to take predominantly spherical shape and to solidify and become solid shot particles before reaching the ground at the bottom of the tower. Indeed this type of peening media, because of its historical roots, is the only type that can be truly called "shot" though we often refer to the other media types as shot also.
3. Ceramic bead media – This is an emerging and the newest media type for peening application. The most common ceramic bead material is zirconium oxide with a glassy-phase aluminum oxide binder. It is manufactured by compaction and sintering of the materials initially in powder form.
4. Glass bead media: - These media particles are also produced from the molten state. Interestingly, the major use of glass bead media is for reflectivity in paints used for highway and road surface markings. Glass beads are also used commonly in blast cleaning, but this is not to be confused with true peening.

My listing of media types above is in descending order of durability, particularly in regard to friability (i.e. ease of fracturing) because fractured media particles are detrimental to good peening. Rating the media types in order of durability is not a recommendation for use. Economics are another consideration. Media durability must be balanced against acquisition cost and whether or not media residue requires post-peening processing and of the processing cost.

Other important criteria for media are size and size distribution, hardness, friability, shape, density and whether media residue left on parts after peening can be tolerated. These characteristics cannot be chosen either arbitrarily or independently because they may interact with each other and will have influences on the other basic aspects of peening—intensity and coverage.

For example, size and size distribution may affect friability since larger particles, particularly in cast steel media, will tend to fracture more readily than smaller particles. Choice of media size and media material density will affect the range of intensity that can be attained and, of course, smaller media will give more rapid coverage at the same mass flow rate than larger media. As with media size, higher hardness media of a given type and material is more friable than lower hardness media. Higher hardness media will also give greater intensity and somewhat more rapid coverage than softer media at the same peening conditions. Media shape is an important characteristic since fractured particles, misshaped particles or unconditioned cut wire with sharp edges or angular features will produce nonspherical impact dents or dimples. Finally, there is the matter of media residue on peened components. The most familiar example of this is ferrous contamination on aluminum components which must be removed post-peening due to rusting of the residue under moist service environmental conditions.

Notwithstanding all of the above, the best intentions and practice in media selection can be rendered ineffective if media isn't properly maintained. The left photogragh in Fig.1 is in-use cast steel media which was poorly maintained and the right photograph is well-maintained in-use media of the same type. The contrast between the two is dramatically obvious. In the right photograph, the spherical shot particles are about the same size. In the left photograph, we see widely disparate sizes of particles, misshaped particles, fractured particles and nonmedia contaminants. The well-maintained cast steel media has a better appearance than even new media which normally has misshaped particles to the extent allowed in applicable specifications. This brings into question the reason for specification requirements which allow more discrepant particles in used than in new media. If the only consequence of poor media maintenance were media with poor appearance, that would not be such a bad thing. Unfortunately, this is not the case. The truly bad consequences of poor media maintenance are inconsistency in peening results from dents of non-uniform size (confounding of intensity) and irregular shape as well as cushioning effects of dirt and nonmedia contaminants as they interfere with media impacts.



Poorly-maintained media *Well-maintained media*

Fig.1

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We can avoid these undesirable effects by properly maintaining the media. An inline screen separator/classifier apparatus is very important. It is my opinion that one cannot claim to have a good peening process without one. An inline separator/ classifier consists of vibrating screens appropriately sized to allow passage of the proper size media and their return to the reservoir supply while letting fractured and subsize media particles to pass through to a refuse container. As a practical matter, an inline separator will also remove a lot of nonmedia contamination as well as misshaped media particles, but removal of these can still more effectively be accomplished by an air wash device to remove low density contaminants and a spiral slide apparatus to remove misshaped (nonspherical) media.

Intensity:

The importance of selecting the best intensity for achieving a desired result of peening is illustrated in Fig.2. As easily seen from the data, an Almen intensity of 0.008A (in.) yielded greater fatigue life than peening either at lower or higher intensities. Usually the effect of intensity is not this marked, but there is generally a point reached with increasing intensity beyond which surface damage induced by peening begins to mitigate benefits attained by the induced subsurface compression. In other words, one can get too much of a good thing. Surface damage may take the form of micro laps or folds in soft materials to microcracking in hard materials. Such effects can be detected by metallographic sectioning and microscopic examination. Detection may also be possible via advanced nondestructive examination techniques which can also be employed to give intensity information. Such technology is not currently being applied to peening, but developments are occurring and may well find application in peening process control. As in the illustrated case, lower than optimum benefit may result when the peening intensity is too low. This may involve instances when intensity does not produce deep enough compression to overcome adverse residual stresses induced by prior processing or to overcome adverse applied stresses or stress gradients in service. These effects may be predicted and avoided through a judicious combination of residual stress measurement and finite element analysis based upon service loading.

Media hardness affects peening intensity. Harder media propelled at the same velocity as softer media will yield higher intensity based upon energy transfer considerations because lesser deformation of harder media upon impact means greater energy transfer to the Almen strip. Another factor influencing intensity is impingement angle whereas energy transferred varies as the trigonometric sine function of the angle. Nozzle standoff distance can also affect intensity when it increases to the point that air resistance measurably affects media velocity. Another factor influencing intensity in direct air pressure peening, though secondarily, is media flow rate. Leaner flow rates permit higher media velocity, hence higher intensity.

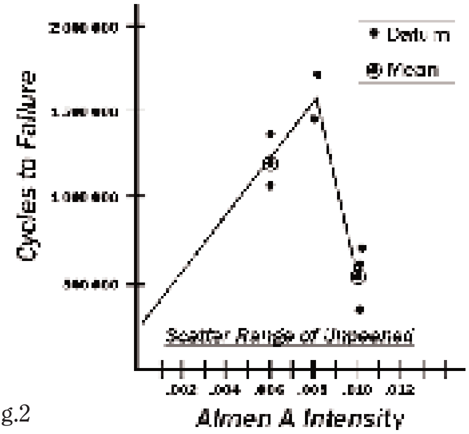

Fig.2

Finally, I must state the obvious regarding peening intensity because it is not recognized by all. All Almen intensities are arc heights, although special ones, but not all arc heights are intensities. Further, intensity can be determined only from an Almen saturation curve (arc height vs. exposure time or other time-based parameter) using multiple Almen strips (i.e. a minimum of four or five depending upon specification requirement). Almen intensity cannot be determined from a single Almen strip, and, indeed, one can easily be fooled when using one or two strips for intensity verification. Enough said on the subject of intensity!

Coverage:

From my experience in shot peening and shot peening training, I have reached two conclusions:

1. The concept of coverage, often confused with intensity, is the least understood and least appreciated aspect of peening, and
2. Most peening is performed with far too much coverage.

The former leads to misinterpretation of peening cycle times. The latter leads not only to the less than optimum benefit from peening, but also costs peening practitioners and component owners a lot of money. Peen Lean! Too much coverage may be hazardous to component health and to

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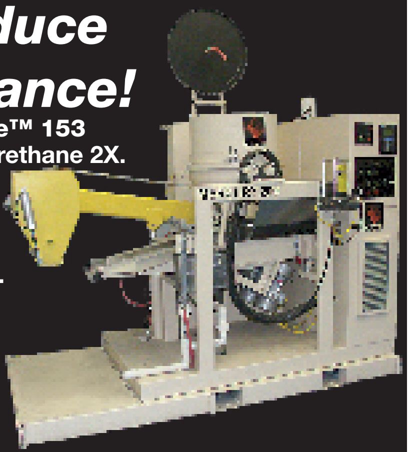

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your pocketbook. Do I have your attention? Within limits on page space, I will not be able to fully develop my arguments, but I plan to do so in a future article.

Coverage up to 100% is defined as the percentage of impacted area on a component surface (i.e. the fraction of the surface area obliterated by peening dents expressed as a percentage). Beyond 100%, coverage is expressed as a multiple of the time to achieve 100% coverage. How does one determine the latter? The customary means for doing this is to peen a surface for increasing time and examine it at intervals via 10-30X magnifier until no undented areas are seen.

The really important point here is that coverage must be determined by observation of the component surface. Coverage is related to peening exposure time of the component. In general, this has absolutely no relationship to peening exposure time on Almen strips or to Almen strip saturation time. For any such relationship to exist, the component material must have the same hardness and plasticity characteristics as the Almen strip material, AISI 1070 steel. Peening specifications and methods that mathematically express component exposure time to Almen exposure or saturation time are fundamentally wrong. Coverage may be determined correctly only by observation on the component.For constant flow rate, the number of impacts in peening is linearly proportional to peening exposure time; however, coverage is not proportional. The reason is that impacts are random and each media particle does not necessarily strike a new site. Indeed, many of the sites are struck multiple times before full coverage is achieved. A plot of coverage percentage versus exposure time is a decelerating curve. In work on a medium hardness alloy steel performed by the author and Prevey, 80% coverage was attained in about 0.20 fractional time and 90% coverage in about 0.40 fractional time[1]. The residual stress distributions shown in Fig.3 indicated that the full residual stress benefit from peening was attained after 0.20 fractional time and did not change much from that point up to 400% coverage. Moreover, as shown by the S-N curves in Fig.4, the fatigue strength for 0.20T coverage was the same as for full coverage and was less for 300% coverage. The absolute differences in coverage time from 80% coverage to full coverage was more than three minutes and to 300% coverage was about 11 minutes. Similar results were obtained in work on nickel-base alloy Inconel 718 by the author and Jayaraman[2]. A U.S. patent was recently granted based upon the referenced results.[3]

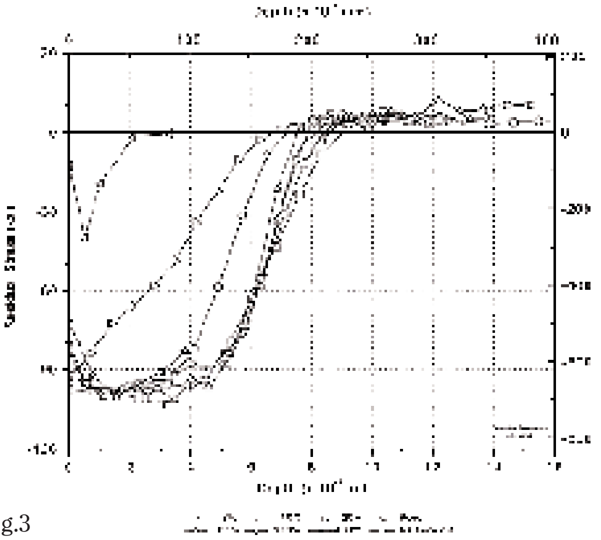

Fig.3

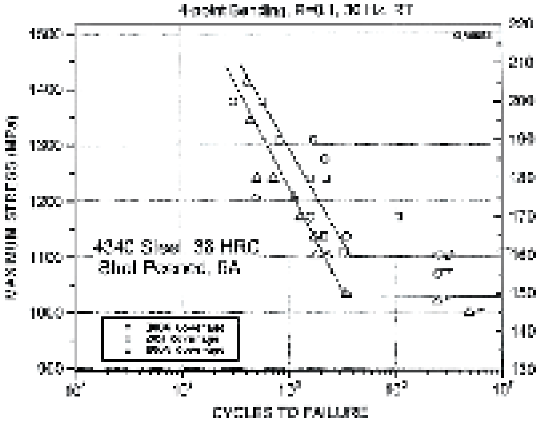

Fig.4

My presentation of these results doesn't mean that I'm pushing peening at coverage levels significantly less than full coverage, though it is possible with care and good process control in general and excellent flow control specifically. The associated cost benefit in reduction of cycle time in a production environment is obvious. For others, I recommend that full coverage or approximately so is all the coverage needed. Peening to coverage greater than 100% is not only a waste of time and money, it is also destructive of equipment and produces no benefit. It may also be detrimental to component quality and durability. I am planning a future article that will treat the subject in much greater detail. In the interim, I urge you to **Peen Lean**!

Summary:

Peening performed correctly with due heed for the basics will provide reliable benefits to components, mitigate risk of component failure and save money in doing so. **Peen Lean**! Do you need more argument than this? If you agree with me, then get on with things with my best wishes for your success. If you do not agree, then we need to talk. Call or email me; contact information is provided below.

References:

1) P. Prevey & J Cammett, ICSP8:
2) J. Cammett & N. Jayaraman, ICSP9
3) P. Prevey and J. Cammett, Patent US 7,159,425, B2, Jan 9, 2007.

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/r ework/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.