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Understanding the Peening Time Paradox

The Key to Uncoupling Intensity and Coverage

WHAT I REFER to as a time paradox is only a seeming paradox. Time is used in the standard protocol for determining peening intensity, yet intensity itself is independent of time during peening provided that machine settings or other key parameters are not altered during the process. This may seem paradoxical though in reality it is not. Coverage certainly is time dependent because an increase in exposure time during peening results in more impact dents on the surface of the part. One of the continuing challenges encountered in my twenty-plus years of teaching shot peening in training and workshop sessions has been to get students to grasp the difference between intensity and coverage concepts and their separate relationship to time. If you truly understand the conceptual independence of intensity and coverage in peening, then you need not read the remainder of this article. On the other hand, if you believe there is a fundamental relationship between the two, or even worse, attempt to relate them in practice, then I invite you to read on. You are belabored by a misconception. As the saying goes, we really must talk about this.

An Analogy

Let us begin discussion in a semi-technical vein and defer matters more technical to later. A useful analogy is that of a garden hose delivering a stream of water under pressure. If the water is delivered into the hose by the utility provider at constant pressure and the hose nozzle meters at a constant flow rate, then the force of the water is analogous to peening intensity. It matters not how long the time, whether for a second, a minute or an hour, the force of the flow remains the same and so does the intensity provided by the media stream in peening. Both the force of water flow and peening intensity are independent of time. There is, however, a time dependence of the water flow and this is the amount of moisture delivered to the ground or plants that are being watered—more time, more wetting. This is analogous to coverage in peening—more time, more coverage. Indeed, a certain degree of wetting from the hose on a given area can be achieved by passing the hose back and forth over the area at any constant rate. All that matters is that the wetting occurs over the necessary total time. And so it is with peening. The desired coverage will be achieved in the necessary total time irrespective of the speed of passes over the given area of the part.

An Example

To illustrate the uncoupling of intensity and coverage, consider that a job shop company involved in shot peening for a variety of customers employs two people on a part-time basis. One individual is responsible for doing intensity determinations and establishing machine settings to achieve intensities according to customer requirements. The first person does this in the mornings for the peening jobs that the second individual performs in the afternoons. The two individuals are on separate work schedules and communicate only by computer records in the company system. The lack of additional communication is not problematic since the first employee provides the machine settings appropriate to the intensity levels that the second employee must use in peening parts. Usually, the second employee must verify that the given machine settings will produce the desired intensity for each part by performing an intensity verification. Then the second employee must also determine the peening cycle time for each part according to customer coverage requirements. Let us suppose now that the parts to be peened include materials of different hardness, soft, medium and hard, but that the intensity required by customers for each is the same and the coverage requirement is also the same. Clearly, the typical sizes of dents in the each of the different parts will be different given that the media is the same and the impact energy is the same. The soft part will have larger impact dents than the medium hard part and much larger dents than the hard part. Because of the differences in dent size, the soft part will achieve the desired coverage much sooner in time than either the medium hard and hard parts under the imposed condition of equal intensity and media flow rates for each. Despite this contrived but plausible scenario, two very important points may be posed. The peening cycle times for the parts will be quite different and thereby, there is no correspondence of cycle times to the Almen strip peening exposures or even the saturation times for each intensity determination. Note that, because the intensities sought were the same, the Almen strip exposure times and saturation times would have been the same for each. Indeed, since the same intensity was being sought, irrespective of part hardness, it may have been necessary to do only one intensity determination and not three.

Intensity: Some Technical Considerations

Now, let us consider the concept of intensity in peening on a somewhat more technical level and in a bit more detail than that presented above. Conceptually, intensity in shot peening is simply a measure of how hard we hit a work piece with media propelled via air or wheel. This involves the transfer of kinetic energy of the media into deformation of the surface layers of the work piece. Not all of the media kinetic energy is transferred. Some is lost as the kinetic energy of rebounding media. Some is lost as elastic energy of deformation of the media particles and some is lost as elastic energy of recovery of the work piece deformed layers. The remainder of the media kinetic energy is retained as plastic deformation of the work piece surface layers. Hopefully, we propelled the media with sufficient total energy to cause some plastic deformation; otherwise, we will not have achieved anything useful from the bombardment. It is the amount or degree of plastic deformation that matters as far as producing the desired effects of peening. As a practical matter, we do not concern ourselves with the partitioning of media kinetic energy thus, but simply want to have a measure of the effect of peening (the relative amount of plastic deformation produced). The measure that we call intensity is an analog quantity expressed as a specific property of a saturation curve. Please read on for further explanation.

Recognizing the principles involved, John Almen in his early work on shot peening patented a scheme for determining peening intensity using standard test strips (Almen strips) made from SAE 1070 spring steel with the standard dimensions of 3" x 0.75" x Thickness and heat treated to a specified hardness range (44-50 HRc). A key feature of Almen strips is that they are thin enough to bend when subjected to peening on one side because of plastic deformation produced at surface and in near-surface layers. Three thicknesses of Almen strips are used today to give appropriate amounts of bending depending upon the intensity range being used for peening. Almen also patented a gage (Almen gage) for measuring the degree of curvature produced in Almen strips after being impacted by media. The successor to Almen's patented gage, in use today, determines arc-heights. An arc-height is the chordal elevation of the unpeened surface of the test strip above a reference plane defined by the positioning of the strip on the gage. Almen also introduced the concept of saturation, recognizing that the bending of strips increases with peening exposure time until no further increase occurs after sufficiently long exposure. It may have been fortuitous that Almen chose 1070 spring steel as the Almen strip material because another material, such as aluminum or other austenitic alloy, would not have exhibited saturation behavior as observed with the SAE 1070 steel. More information on Almen strips (including saturation behavior and intensity determination) and Almen gage characteristics are available in SAE specification J442.

A typical Almen saturation curve is shown in Figure 1 from SAE J443. The curve is a plot of Amen strip arc-height on the Y-axis versus peening exposure time on the X-axis. To generate a saturation curve, a minimum of four Almen strips must be used and each is peened for a different exposure using the same machine settings. Note that the time scale need not actually be time itself, but may be any uniform time-based unit such as machine cycles or inverse velocity of part or nozzle motion. Each of the four or more Almen arc-heights produced is exactly that, an arc-height and not an intensity. Intensity is derived from the saturation curve by invoking what is termed the ten-percent rule. The saturation curve is a best-fit curve representing the Almen strip data and not a point-to-point fit to the data points themselves. The intensity is defined as the first point on the best-fit curve (not generally at a data point itself) whereby the arc-height increases by only 10% when the exposure time is doubled. Deriving the intensity value can be done satisfactorily by manual calculation, but it is most effectively done by use of computerized algorithms validated per SAE J2597. The time at which intensity is thus declared is called the saturation time.

Some very important points involved in the process of intensity determination include:

- The time scale of a saturation curve can be in terms of any time-based unit provided that the units are uniform.

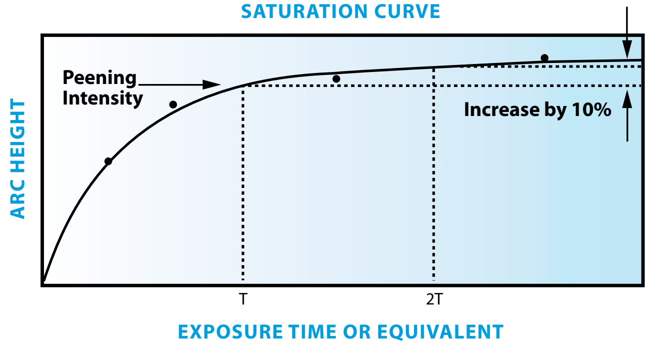

Figure 1. Almen Saturation Curve

- The Almen strip has only one function and that is intensity determination. Almen strips are not intended, nor were ever intended (except erroneously), to be used in any way to establish peening time for parts.
- The intensity value obtained by analysis of a saturation curve represents the entire curve. It is absolutely important to note that the derived intensity is independent of time. Further, It is vitally important to understand that the saturation curve is a plot of arc-height versus time and is NOT a plot of intensity versus time.
- The exposure times for Almen strips are only that and these bear no relationship to times for peening of parts, which are usually made of different material than Almen strips and respond to peening differently.
- The saturation time obtained during intensity determination is neither an independent nor a fundamental quantity and has no further use after intensity determination, except possibly as an exposure time for intensity confirmation when required.
- The time of peening, or the velocity of part/nozzle travel, is not dictated nor is it even influenced by anything done in intensity determination. Of course the same machine settings must be employed to ensure peening continuously at the desired intensity, but the peening time for a part is related independently only to peening coverage considerations.

Coverage: Some Technical Considerations

Until now, I haven't provided much technical discussion of coverage although it has been mentioned in passing. Coverage is defined as the relative amount of obliteration of or replacement of the original unpeened surface features by dents produced by media impacts. Most germane to this article is that coverage is time dependent as may be seen in the typical coverage curve shown in Figure 2. This is a plot of coverage percentage from 0 to 100% versus time of peening on the y-axis versus time (or time-related quantity such as passes) on the x-axis. The subject of coverage in peening is quite important and deserving of considerably more discussion than it is receiving here, but this is not necessary to current purposes. Here it is given limited mention because, in the current context, it is important to observe only that coverage is time dependent and that, under constant intensity and media flow rate, the progression of coverage from 0 to 100% with time occurs continuously but at a progressively declining rate. In other words, a coverage curve is a decelerating curve whereby the rate of coverage declines continuously with increasing time. Because of the subjectivity of coverage determination, normally done by optically aided visual technique and combined with the relatively slowness of rate approaching 100%, coverage is considered complete when at least 98% has been attained. This is assuming that each unimpacted area is comparable in size to a typical impact dent and that the unimpacted areas are randomly

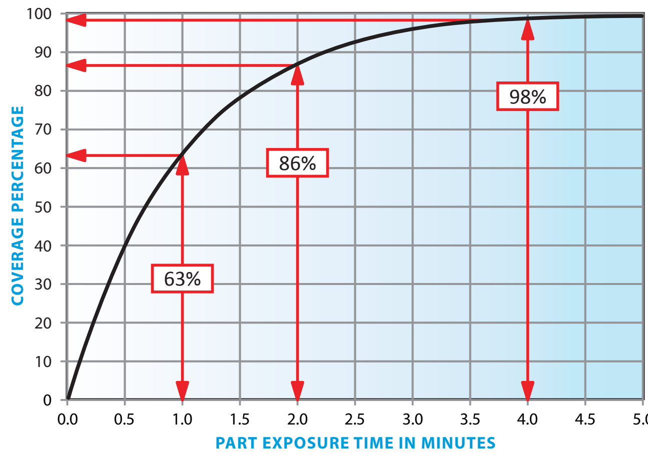

Figure 2. Coverage Curve

distributed. There are some individuals who believe that even small unimpacted areas can be deleterious to fatigue strength in peened parts, but this is not so. The reason is that the subsurface extent of plastic deformation associated with a peening impact dent is much greater than the size of the dent as seen on the surface. But I digress. The important aspect of coverage relative to this article is that it is time dependent and, of course, that the peening cycle time for a part depends upon attainment of a desired or required coverage amount.

Summary

I have presented some basic concepts on intensity and coverage in peening. Central to discussion presented is the argument that the two concepts are separate, independently determined, and are not related by time. Further, it has been demonstrated by argument that intensity is not time dependent whereas coverage is. A most significant corollary to this is that what is done during the performance of intensity determination and what results from it, has no bearing on subsequent peening of a part in terms of coverage or resulting cycle time.

TECHNOLOGY

by Kathy Levy | InfoProse | www.infoprose.com

3D Printing and the Metal Finishing Industry

3D printing creates a three-dimensional solid object of virtually any shape, using a laser beam to melt the raw material and laying horizontal cross sections to build the part based on information supplied by a digital model. 3D printing for industrial applications is commonly called *additive* manufacturing because of its additive process. Traditional machining techniques mostly rely on the removal of materials by methods such as cutting and drilling (*subtractive* manufacturing). 3D-printed parts tend to be lighter than traditionally forged parts because they don't require welding, and the process generates less scrap material. A 3D printer is a limited type of industrial robot that is capable of carrying out an additive process under computer control.

NOW THAT GE AVIATION and Pratt & Whitney are using 3D printing to make metal jet engine components, it's time to think about the impact 3D printing could have on the shot peening and blast cleaning industries.

If you're surprised to read that 3D printing has progressed this far into mainstream manufacturing—albeit aerospace is a leader in manufacturing innovation—here are few examples of how the futuristic technology is progressing.

Aerospace Components

In the spring of 2013, The University of Connecticut (UConn) and Pratt & Whitney announced the opening of the new Pratt & Whitney Additive Manufacturing Innovation Center at the university. A press release from UConn cited that it is the first additive manufacturing facility in the Northeast United States to work with metals rather than plastics. The press release quoted Paul Adams, Pratt & Whitney's chief operating officer, as saying, "Additive manufacturing is complementary to traditional methods by enabling new innovation in design, speed and affordability, and is necessary to build the next generation of jet engines. We are currently using additive manufacturing to build complex components with extreme precision for the flight-proven PurePower® commercial jet engine."

When MIT Technology Review publicized additive manufacturing as one of the "10 Technology Breakthroughs of 2013," the magazine featured GE Aviation in the related article. GE made their top 10 list because "…the decision to mass produce a critical metal alloy part to be used in thousands of jet engines is a significant milestone for the technology."[1] The critical parts in the spotlight are 3D printed jet engine nozzles—GE Aviation is committed to supplying more than 85,000 3D-printed fuel nozzles for its new LEAP jet engines by late 2015 or early 2016. To help GE realize the potential of additive manufacturing, GE Aviation purchased Morris Technologies and Rapid Quality Manufacturing in 2012. Both companies specialize in additive manufacturing.

3D-printed components aren't earthbound: NASA and Aerojet Rocketdyne of West Palm Beach, Florida recently announced that they have finished testing a rocket engine injector made through 3D printing. "NASA recognizes that on Earth and potentially in space, additive manufacturing can be game changing for new mission opportunities, significantly reducing production time and cost by 'printing' tools, engine parts or even entire spacecraft," stated Michael Gazarik, NASA's associate administrator for space technology in Washington, D.C., in a press release. "3D manufacturing offers opportunities to optimize the fit, form and delivery systems of materials that will enable our space missions while directly benefiting American businesses here on Earth," said Mr. Gazarik.

Medical Implants

"3D printing is becoming more commonly used in the medical industry, specifically in product development as a way to create fast prototypes for design feasibility testing," said Scott Hatfield, Manufacturing Engineer with Medtronic. Mr. Hatfield added, "It is also used in the creation of prototype and custom manufacturing fixturing and gaging." Medtronic divisions—Medtronic-Diabetes for example—are already using 3D printing for rapid prototyping. Medtronic's new Customer Innovation Centre in Galway, Ireland has 3D printing facilities to prototype new ideas along with extensive training and education facilities.

3D printing is also developing rapidly in medical implant manufacturing. At Peking University Third Hospital in Beijing, Liu Zhongjun and his team of surgeons started clinical trials with 3D-printed titanium orthopedic implants last year. A typical usage is repairing a fractured pelvis with a titanium implant that fits perfectly with the anatomical structure of the pelvis. "3D printing technology has two very nice features: 1) It can print specific structures 2) It is capable of producing porous metal," Liu stated in article on his team's accomplishments. He explained that pre-clinical studies have indicated that bone can grow into the metal pores, and enhance the strength of the implant. "In the past we used clinical titanium mesh, but with the growth of bone, titanium mesh could easily stick to the bone and cause collapse. 3D printed implants fit the bone completely. And as a result, not only the pressure on the bone is reduced, but it also allows the bone to grow into the implants."[2]

Restoration of Worn Metal Parts

GE scientists have developed a 3D-printing technology they call "Cold Spray" that can rebuild worn parts without machining or welding. The additive technology is closer to 3D painting than 3D printing. According to a press release on www.worldindustrialreporter.com, metal powders are sprayed onto a worn part at high speeds to rebuild the worn elements of the parts. Spray technologies will be especially conducive to the repair of large components and have the potential to transform repair processes for industrial and aircraft components including rotors, blades, shafts, propellers and gearboxes. (You can watch a YouTube video on Cold Spray at tinyurl.com/coldspray.)

New Metal Alloys

Additive manufacturing will give product designers the ability to create new shapes and components because they won't be hampered by the limitations of today's casting and machining technology. They will need metal alloys to meet their design parameters. According to Martin LaMonica in his article on additive manufacturing for MIT Technology Review, "GE engineers are starting to explore how to use additive manufacturing with a wider range of metal alloys, including some materials specifically designed for 3D printing. GE Aviation, for one, is looking to use titanium, aluminum, and nickel-chromium alloys. A single part could be made of multiple alloys, letting designers tailor its material characteristics in a way that's not possible with casting. A blade for an engine or turbine, for example, could be made with different materials so that one end is optimized for strength and the other for heat resistance."

What Our Industry Experts Are Saying

Industry leaders share their opinions on 3D printing and its significance to the shot peening and blast cleaning fields.

Scott Hatfield, *Manufacturing Engineer for Medtronic*
If 3D printing makes shot peening obsolete on a medical implant, then that implant didn't need shot peening in the first place. Medical implants are shot peened to create a layer of residual compressive stress to increase fatigue strength. If this layer of residual compressive stress is needed to get the desired performance out of an implant, simply changing the method of manufacturing to 3D printing will not create a surface that is in a state of compression. It will still retain tensile stresses at the surface and will require the same secondary operations as they do now to facilitate the creation of residual compressive stresses to counter the inherent tensile stresses in the material.

Walter Beach, *Vice-President of Peening Technologies*
Peening Technologies is shot peening aerospace engine components manufactured with 3D printing. As far as blast cleaning, parts may still need post work to remove slag/residual material.

Kumar Balan, *Director, Global Sales for Empire Abrasive Equipment*
The threat to shot peening is minimal. At this stage, 3D printing is a complement to traditional manufacturing processes and together they increase efficiencies. If additive technology achieves the high production rates possible with current processes, it will be yet another type of manufacturing for the shot peening world. In other words, the tensile stresses produced by this manufacturing process will still have to be countered by compressive stresses provided through shot peening.

One could make an argument that being an "additive" process and not a "subtractive" process like current manufacturing, the tensile stresses created by 3D printing may not be a threat. I'm eager to see how our aerospace design engineers respond to that and will be very surprised if they eliminate a proven stress-countering process, especially given the time involved to update our stringent specifications and audits. It takes several years to approve the use of different and better peening media than established ones! In my mind, the larger threat to shot peening is alternative materials such as composites and exotic alloys of aluminum and titanium. That said, aerospace engineers that I've spoken with don't perceive these materials as replacing conventional materials.

Blast cleaning removes scale, rust and burrs and it etches, deflashes, and more. Although some 3D-printed parts may not require a step like deburring, blast cleaning is here to stay as long as the parts are metallic, especially because of heat treating. Metallic components go through heat treatment processes after forging, casting and other conventional manufacturing processes. A 3D-printed component will also have to be heat treated. Heat treatment produces scale, and components stored long enough oxidize to develop rust. These contaminants will have to be blast cleaned regardless of the upstream production process.

Blast cleaning is widely used in high-production automotive facilities. I don't see 3D printers advancing to the extent of being capable of producing large quantities; for example, 10-14 tons of brake drums or similar components an hour, much less at an operating cost that's competitive to a metal foundry. Given the amount of infrastructure and capacity being added to foundries and forge plants around the world today, and their constant search to reduce operating costs by adopting newer technologies, the limitations of 3D printing must be evident to experts in those industries. In addition, the large industry sector in raw sheet steel, structural steel and other weldment will still rely on blast cleaning to clean their stock before downstream fabrication processes. As a complementary process, however, I do see 3D printing shrinking the development time of tooling and patterns in foundries and forge plants.

Jörg Kaltmaier, *Project Planner with voxeljet AG*
Cast parts made from voxeljet models are like any cast parts. They need to be cleaned, blasted and machined. (voxeljet is a leading manufacturer of industrial 3D printing systems and operates what it believes to be one of Europe's largest service centers for the "on-demand production" of molds and models for metal casting.)

Are We Finished?
Not by a long shot…at least in the foreseeable future. While it's difficult to predict how emerging technologies will eventually impact us, for the most part, components that benefited from shot peening and/or blast cleaning after conventional subtractive manufacturing require metal finishing treatments after today's additive manufacturing. In addition, the new technology faces challenges before it will be widely accepted:

- High cost: The price of materials and equipment are out of reach for most manufacturers
- Slow speeds: The pace of 3D printing will need to increase a hundredfold to compete with conventional manufacturing in many applications[3]
- Lack of raw materials: Even though companies like GE are experimenting with new alloys specifically developed for additive manufacturing, only a few metals and plastics are currently suitable for the process
- Poor consistency: Parts are not always identical from machine to machine, or from day to day on the same machine[3]

Even more encouraging are the innovators in our industry that are already looking for ways to take advantage of additive manufacturing. "Peening Technologies is working with a 3D printer services supplier to develop polymer masks. The technology is very expensive now, but it will definitely have a place in creating very sophisticated and resilient polymer masks for aerospace components," said Walter Beach. "I can see purchasing a 3D printer in the future."

1. http://www.technologyreview.com/featuredstory/513716/additive-manufacturing
2. http://3dprinterplans.info/beijing-hospital-uses-3d-printed-titanium-orthopedic-implants-for-patients
3. Freedman, David H., "Layer by Layer," MIT Technology Review, December 19, 2011.