AN INSIDER'S PERSPECTIVE

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Saturation Curves and Process Design

INTRODUCTION

I am afraid that I must start by sounding like that person I was hoping I would not become, the reminiscing old shot peener, but here we are! For those of us that have spent considerable time in this industry, there are several situations that require the use of kid gloves. To an auditor, it might be the delicate exercise of handing out multiple non-conformances resulting in a failed audit. For a sales engineer, it might be the daunting job of presenting a significantly higher priced revision 6 of the original proposal after the customer has changed the scope as many times. To an installation technician, it might be the tactful task of informing the customer that a spinner hanger would have been a better choice of work handling arrangement for their application than the fixed table that just got installed. For me, it has been the interesting journey of explaining the significance of saturation curves while carefully and non-offensively laying it down that their self-claimed 'peening' operation was doing no more than 'cleaning' components.

More recently, I have been conducting onsite shot peening training for Electronics Inc. and blast cleaning training for Ervin Industries more frequently than before. Each session continues to expose me to some of those gaps seen among novice and experienced users alike. Graphs and charts do little to help with the explanation or mitigate this pain. Therefore, I would like to discuss select fundamental concepts with the aim of making shot peening and blast cleaning more inviting and manageable to users. Just as I started thinking about the framework for this article, I attended the SAE/AMS semi-annual meeting in Troy, MI. Walter Beach, the Chair of both committees had started working on re-writing ARP 7488, Aerospace Recommended Practice – Peening Design and Process Control Guidance. This is intended for use as a reference document, with the OEM specification taking precedence. Walter has covered a variety of process aspects related to shot peening in this document that I wish to incorporate into our discussion. Though these are geared to aerospace users, they apply equally to other industries as well. (Note: Using this reference also adds to the credibility that this article is not AI generated!)

SATURATION CURVES

Process capability index (Cp and Cpk) is a statistical metric used to measure the ability of a manufacturing process to produce output that meets specific quality requirements or specifications. It provides a quantitative way to assess how well a process is performing compared to its tolerance limits. I like to think about saturation curves as accomplishing this purpose in shot peening. However, a few facts that are often misunderstood:

1. The Almen strip deflects/bends when impacted by a spray of peening media. When you measure the deflection of the strip with an Almen gage, you are measuring the arc height. This is not the intensity. You need a minimum of four such arc heights (datapoints), obtained by exposing a minimum of four distinct strips to media spray at different exposure times. The nature of exposure will depend on your machine. It could be number of passes, strokes, rotations, cycle etc. With those four data points, you will set about plotting your saturation curve. If you notice, I have not introduced the term 'intensity' yet. That is because, intensity is calculated from the saturation curve. In other words, 'arc height' is a measured value whereas 'intensity' is a calculated value from the saturation curve. SAE J443 has more details.
2. We often talk about the 10% rule when it comes to saturation curves. Unfortunately, this 10% rule has been subject to misinterpretation given its evolution over multiple versions of SAE J443. The current version of this document instructs the user to only accept 10% and nothing less for increase in arc height when the exposure time is doubled. Only then can the arc height be called the intensity of the process. The misunderstanding arises from the language in earlier versions of J443 which allowed upto 10% as acceptable validation. During our shot peening workshops, students are trained to manually plot saturation curves, and to accommodate a variety of drawing skills, we allow a tolerance of 9-11%. In real-world conditions, most of you use computerized curve solvers that help you get to an accurate intensity value at exactly 10%.

When plotted correctly, the saturation curve gives you the complete bill of health for your process. Let us consider some of the features of this curve:

- The saturation time 'T' (and 2T) times are specific to a set of process parameters. In other words, changing any of the critical parameters that affect the impact energy such as velocity (air pressure or wheel speed/diameter), media size, and media flow rate will require a new saturation curve resulting in a different intensity value. If using the same parameters during periodic plotting of a saturation curve (not to be confused with routine verification using a single strip) results in an intensity value different from the original, it signifies that your process is no longer stable due to a shift in those critical parameters.
- Media contamination is possible in shot peening machines, especially when operating with multiple sizes or hardnesses of peening media that are switched in the same machine. In addition to the possibility of an incorrect media size being accidentally added to a machine, damage to a classifier screen in the form of rips or blinding could result in contamination. In such cases, the emergence of a double knee in your saturation curve demonstrates the first knee for the smaller of the two shot sizes, followed by a second knee for the larger size. This is not an acceptable version of a saturation curve. Had you not attempted to plot a saturation curve, you would not have been able to identify this rather important issue.
- The 'T' time in a saturation curve is not a time measure of how long it will take to peen your actual part. Do not attempt to corelate the size of the Almen strip (3" x ¾") to the size of your part and arrive at an incorrect cycle time either. Times T and 2T are used to validate your peening process. Actual peening time will depend on the time it takes to achieve 100% denting on actual parts. An old, now corrected prime spec instructed the user to peen the part to the higher of the two – time T and time to achieve 100% coverage. When this instruction was to be used to peen aluminum parts, 100% coverage was achieved much faster than the T time on the saturation curve. The exact opposite can be expected if this instruction were to be followed when peening case hardened parts. Review your spec carefully and discuss such anomalies with your end user.
- Data used to plot the saturation curve (velocity and media flow rate, shot size being constant) are to be transferred to your production process when peening parts, except for exposure time. Exposure or cycle time is dependent on the time it takes to achieve required coverage (min. 100%) on the part.

DESIGNING THE PEENING PROCESS

(adapted from suggested revisions to ARP7488A)

If you are at the vantage point of instructing your peening service provider, drafting specifications, or creating notes on the drawing for your own organization to use in internal process design, consider the following issues faced by shot peeners when evaluating a peening project. Though instructions will be more elaborate than those listed here, the purpose of this list is to identify only those that tend to get ignored or remain ambiguous.

- Does the drawing clearly specify areas to be peened. If there are areas to be masked, are they clearly identified in the drawing? Have locations to determine / verify intensity been identified on the drawing? Are such locations sufficiently open to receive direct impacts from nozzles or blast wheels? Are there areas on your part where peening is optional (and, is overspray permitted)? If any of these instructions are not clear, is there an expectation established with the service provider where you will be provided documentation on their methods and alternate techniques to conform to your requirements?
- Does you part have sharp edges? Edge rollover is undesirable and could result in part failure due to a stress riser. In such situations, consider reducing the intensity requirement in such areas – with approval, of course.
- Are there any thin sections in your part that could potentially warp with the impact of peening media? Thin sections also get peened. However, they may need to be fixtured differently and perhaps peened to a lower intensity. Another option would be to peen simultaneously from both sides of this section.
- Are there sealing areas where dimensional changes due to shot peening are a concern? If so, have they been identified and noted in the drawing?
- Are you specifying a post-peening process?
- Is there a surface roughness value that you would like maintained after peening? If so, are you providing instructions on the permissible finishing process, post-peening?
- Have you specified the sequence requirements? An example could be, 'Shot peen after final heat treat and before coating'.
- Unless you require your peening service provider to take care of some or all of these, parts should be presented to them in a condition that is ready for peening. They

should be free of grease, dirt, oil, corrosion, burrs, sharp edges, any coatings, plating, or paint.

- Are there specific requirements for chemically cleaning prior to peening?
- Are there specific requirements for chemically cleaning post-peening or is there an added requirement of glass bead peening?
- Processes that could induce tensile stress such as heat treatment and non-destructive testing must be completed prior to peening. When peening, the part dimensions and finish requirements must have already been met.

MACHINE TYPE

The process designer must be cognizant of machine limitations (airblast – suction/pressure and centrifugal wheelblast). Generally, airblast type media propulsion is suited for rotating engine components whereas structural components can be processed in wheel or air machines. Wheelblast machines are commonly used when your peening media is metallic. Peening requirements in holes and slots are met with nozzles and deflector tips, not with blast wheels.

MEDIA TYPE AND SIZE

Four types of peening media are used in shot peening – cast steel shot, conditioned cut wire, glass bead, and ceramic. Cast steel shot and conditioned cut wire, in the metallic type, are both capable of delivering the required intensity with the choice being left to the process designer. In certain cases, the drawing might allow the flexibility to use one or the other to the service provider. When such flexibility is not provided, the service provider is not permitted to choose the media type.

When not specified, the default media hardness is regular (R) at 45 to 52 HRC. However, this may not be suited for hard parts (e.g., case hardened transmission gears) with hardness over 55 HRC. When such hard parts are peened with regular hardness media, the surface will resemble that of a burnished or polished surface posing challenges in visual inspection. It is important to know that high hardness media will achieve the same intensity as regular hardness media when the former is applied at a lower velocity. This knowledge allows you to take advantage of the same particles per lb. and thereby maintaining coverage rate while achieving higher intensity (e.g., going from ASR230 to ASH230).

Media size considerations are several such as:

- Intensity, with the following additional criteria
    - Shape of parts
    - Size of fillets (shot diameter vs smallest fillet on part)
- Finish – at equal intensities, larger media will produce a finer surface finish
- Avoid specifying small media at high intensity on aluminum or magnesium (soft metals). This increases the possibility of damage to the part.

OTHER CONSIDERATIONS

Almen test strips: after settling on a specific manufacturer of Almen test strips that conform to SAE J442, continue using the same strips for the duration of the project. Changing to a different manufacturer, even if the alternative conforms to J442 is likely to yield different results with intensity getting out of range. If a change must be made for uncontrollable reasons, you will need to plot a new saturation curve.

Target arc height: This is the desired measured arc height within the approved intensity range that the process should produce at saturation. Target height selection should be such that it is close to the center of the intensity range, for example, a practical target arc height for an intensity range of 0.012-0.016A might be 0.014A. This will allow normal process variation without drifting out of tolerance during verification.

Verification arc height: This is the measured arc height when in production (verified at least every 8 hours or with new batch of parts). Each verification location will be run to its Target arc height time; the resulting number shall be within 0.0015" of its original value and within the engineering drawing specification range.

Example: If the intensity range is 0.012 – 0.016A and the target arc height is 0.014A, each time this process is verified, the result must be between 0.0125 and 0.0155A.

With multiple intensity verification locations, generally a single target arc height is chosen by selecting the location that has the longest time (T) to reach saturation.

Finally, closing our discussion with the initial topic – saturation curves. Practical considerations might require you to change suppliers, process parameters, machine types etc. With the importance placed on results of the saturation curves, remember that any such change will require plotting a new curve, not just for specification conformance, but also to maintain the validity of your established peening process.