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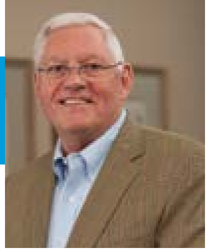
The Shot Peener

Sharing Information and Expanding Global Markets for Shot Peening and Blast Cleaning Industries

Celebrating Continuous Improvement

THE SHOT PEENER

Sharing Information and Expanding Global Markets for Shot Peening and Blast Cleaning Industries



OPENING SHOT
Jack Champaigne | Editor | The Shot Peener

Continuous Improvement

ELECTRONICS INC. - ISO CERTIFICATION

In our 50 years of operation, Electronics Inc. has been dedicated to providing our customers with quality products and services on which they can depend. So when customers inquired whether we were certified under a quality management system, we were eager to prove ourselves. ISO's emphasis on continual improvement resonated with our staff. We have always focused on innovation in the industry and improving our understanding of shot peening.

While our implementation team worked through the certification process, we found that Electronics Inc. already met many of the requirements of ISO 9001. Now we have a structured framework for the daily actions that keep our operation running smoothly. We also learned new methods to monitor the quality of our products over time and to be proactive about potential disruptions. This guarantees that our products and services will always meet the high standards to which Electronics Inc. holds itself. By formalizing our quality management, we can ensure that our commitment to quality is not just a promise but a practiced reality.

In December of 2023, we passed our certification audit with flying colors.

THE SHOT PEENING INDUSTRY

In this magazine are several more examples of how our industry and academic institutions are continually seeking improvements in processes and products.

Kumar Balan
In every issue of *The Shot Peener*, Kumar explores ways to improve shot peening and blast cleaning processes and equipment. His insights are based on his own vast experience and the experience and advice from industry leaders. (Page 6)

Purdue University
Langdon Feltner, Mark Gruninger, and Paul Mort with Purdue University, School of Materials Engineering and Tod Canty with JM Canty are working together to develop industry-ready specifications for media size and shape distributions. (Page 12)

www.shotpeener.com
The Q & A forum at www.shotpeener.com is an ideal resource for those wanting advice on how to make improvements in shot peening, blast cleaning, media, specifications, equipment, and more. (Page 18)

Dr. David Kirk
Our readers rely on Dr. Kirk to explain the fundamental and not-so-basic elements of surface treatment. New and experienced members of our community have benefited from his articles. (Page 26)

sentenso
Determining Coverage on a peened part is a challenge, to say the least. sentenso has developed customized Coverage comparison samples to help reduce the time and personnel effort that has to be put in every part. (Page 34)

We hope you enjoy and benefit from the Spring issue of *The Shot Peener*.

THE SHOT PEENER

Editor
Jack Champaigne

Associate Editor
Kathy Levy

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Electronics Inc.

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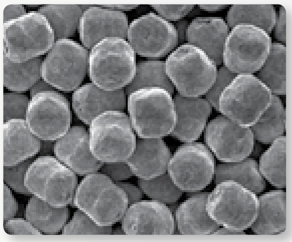
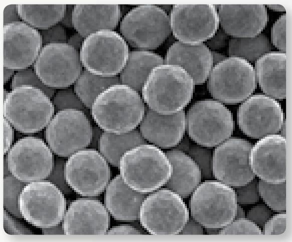


Normal Conditioning



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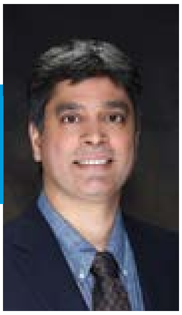

AN INSIDER'S PERSPECTIVE

Kumar Balan | Blast Cleaning and Shot Peening Specialist

More On Choice of Media Propulsion

INTRODUCTION

To err is human, to forgive was the kindness of my General Manager (thank you, Mr. Spratley)! For those of us that have spent our careers evaluating applications and suggesting viable solutions, the choice of media propulsion is almost always obvious. Afterall, it is frivolous picturing a batch of aircraft blades or engine components tumbling under blast wheels with the pretext of being shot peened. Similarly, cleaning a 10' wide plate in a roller conveyor type machine cannot be practically accomplished with a bank of suction blast guns. However, not all parts are as simply proportioned and the logic clear as the above examples.

Let us consider some aerospace applications—landing gear components could be peened in airblast as well as wheelblast machines and the same with aircraft structures. Peening auto transmission gears follows the same logic. Though my industry colleagues that work exclusively with wheel or air machines will make a convincing argument about the efficacy of one over the other, they will also agree that there are several other considerations before a determination can be made. This brings me to explain my first act of acknowledging my boss' kindness.

At an earlier stage in my career, I was presented with an opportunity to design a machine to clean tubes to remove mold residue from its outside diameter. At the suggestion of a salesperson that sold aluminum oxide, the customer had decided on a nozzle/airblast machine to clean these tubes. Traditional solution for this application would have been a centrifugal wheel machine cleaning with steel shot. The customer being always right, I went along with the airblast solution, and the result was less than optimal!

Salient aspects of this application that I overlooked were (a) rapid breakdown of AlOx and subsequent generation of dust, (b) insufficient impact energy given the lower specific weight of AlOx as compared to steel shot or grit, (c) increased compressed air consumption due to the need for high pressure, multiple nozzles, and finally, (d) embedment of AlOx particles on the tube surface making it difficult to distinguish between mold residue and broken abrasive.

An expensive correction ensued, and a new wheelblast machine was supplied to blast the tubes with steel shot. Aside from the classic consideration that blast wheels are better suited for higher productivity and those listed above, end-users also consider commonality of machines in their facility, spares, compressed air availability, space and a variety of less critical features when evaluating their choice.

BLAST PATTERN EVALUATION

For those of you that are new to our industry and wish to learn more, I suggest you refer to a short series of articles relevant to the topic[1]. Our current discussion will continue from where we left off in 2017 in the previous articles. I have learnt that besides productivity concerns, the prime driver for our choice of nozzles over wheels is the blast pattern.

Blast pattern with nozzles are portable when automated (and to a less accurate extent in manual systems). The target in airblast is focused, causing minimal to no damage to the surrounding areas. Airblast machines have also experienced a rapid rate of development in this aspect as compared to wheelblast which has progressed from fixed to oscillating wheels yet confined to its location on the walls of the blast cabinet.

Degradation or deflection of this blast pattern is the second point of consideration. As nozzles wear, it leads to increased compressed air consumption and a corresponding drop in intensity in shot peening applications. Useful life of a nozzle is predictable, and timely replacement puts the process back on rails. With wheels, the wear is more elaborate. Blast pattern degradation could be from wear of control cage, impeller, and blades.

It starts from the control cage, whose opening when worn, could shift the pattern by several inches inside the machine. The illusion of blasting or peening the parts in the required areas could easily be shattered when inadequate coverage is observed on the part, and uncommon wear noticed in the inside of the cabinet.

In our discussions in 2018[2], I reported on an innovative tool that Wheelabrator had designed to detect wear in a blast wheel control cage. This device automatically adjusts/corrects the control cage setting based on wear so that the part can continue to receive expected coverage in required areas.

1"The Role of Wheelblast in Shot Peening", Parts 1 and 2, Spring and Summer editions of *The Shot Peener.*

2"Emerging Technologies and Blast Machines", *The Shot Peener*, Summer 2018.

Though I cannot attest to the popularity of this innovation, it is possible that there is some end-user pensiveness in relying on electronics in an abrasive environment. A similar innovation involved automatically targeting the control cage to shift the blast pattern. The adoption of this device may also have been marred due to moving parts and wear concerns.

COMPARABLE PARAMETERS

Whether your work involves peening or cleaning, the underlying principle is about the transfer of impact energy. Energy can neither be created nor destroyed, only transferred from one medium to another. In our blast machines, this transfer takes place from the media/abrasive to the component being processed with the aid of compressed air or electricity (wheel motor). This energy then either pulverizes and cleans the scale or imparts residual compressive stress on to the component being processed. To demonstrate my non-partisan attitude to both types of media propulsion systems, I list here comparable parameters that we aim to control during the transfer of this energy, typically in shot peening and sometimes in cleaning.

Parameter	Wheelblast	Airblast
Velocity	Variable frequency drives or inverters	Air pressure with closed feedback (PID) loops
Media flow rate	Flow control valves	Flow control valves and orifice (suction blast)
Media size	Classifiers with two screens, limited to a single size by way of sampling (a fraction of total flow)	Classifiers with two or more screens, operable to classify multiple sizes (100% flow)
Media shape	Spiralator	Spiralator
Exposure	Reliant on the work handling arrangement Adjustment of media flow rate will impact coverage	Variability in work handling as well as through nozzle movement Adjustment of media flow rate will affect the intensity and coverage. Consider this adjustment carefully.

PROMINENCE OF WHEELBLAST

Outside of Aerospace, it is common to see wheelblast machines for shot peening applications. Their absence in aerospace is in part due to the complexity involved in peening aircraft parts, the need to target specific areas and unacceptance of overspray, the requirement to use multiple media sizes in the same machine and the extent of sophistication expected in a peening machine. Though I do not wish to mislead readers in thinking that wheelblast machines are not sophisticated, a large concentration of them are found outside of aerospace.

Some popular, high-throughout automotive applications include shot peening leaf and coil springs and connecting rods. These components are traditionally processed in wheelblast machines. For example, a six-wheel machine peens both sides of a connecting rod every three seconds. A three-wheel machine shot peens one coil spring every 4.5 seconds. When designed well, these machines are built with process control components such as closed-loop flow control valves, frequency drives for blast wheels (to vary shot velocity), classifiers to accept a sampling of peening media, spiral separators for shape control and arrangements to control and monitor part movement (since wheels are typically in fixed locations).

The Mining and Oil & Gas industries also use wheelblast machines for peening applications. Sucker rods that travel deep into the earth are peened in skew roll machines that spin and move the rods through the blast zone. As we know, peening process is agnostic to the machine being used as long as proper process control is maintained.

Those that are familiar with Roll Etching using blast wheels are familiar with the reclaim system in such machines. Roll etching involves preparing mill rolls that are used in various stages of reducing thickness of cold rolled coils of steel sheets.

This requires varied sizes of high hardness grit. These machines were one of the first with sophisticated process control. Given the capacity of standard classifiers and their inability to process 100% of the media flow, such machines were equipped with multiple levels of classifiers and dedicated storage hoppers so that the blast wheel always received the same size of grit to achieve a consistent and repeatable etch profile on the mill roll being blasted.

So, what does one do when applications can be addressed with either media propulsion system? In addition to some of the considerations discussed above, examine the part being peened. Will the inundating flow of media from a blast wheel flood tight areas in your part (example: planetary gears) and result in media-media instead of media-part surface impact?

Is your process likely to be scaled upwards in the near future? Would a future part design require only certain areas

of the component to be peened? At some point in the future, will be you required to use a different media size in your machine (airblast is your answer)?

THE FUTURE OF WHEELBLAST IN PEENING

The Shot Peener magazine presents a wealth of information in these columns on automated, robotic, computer-controlled airblast machines for shot peening. I would like to explore the possibilities in a wheelblast machine that could transform them into a more acceptable choice for peening when suited for the application. Some of those possibilities include:

Cleaning of peening media

Shot peening does not generate a lot of dust (peening is best accomplished with clean parts). However, the dust that is generated during peening should be separated out from the peening media that is circulated through the machine. Wheelblast machines are commonly fitted with an airwash separator that functions as the "lung" of the blast machine. When adjusted optimally, this unit separates dust and fines from the working mix.

I spoke to an old friend and industry colleague—Bob Schoen who is the Field Training Manager for Blast Cleaning Technologies (BCT) in West Allis, Wisconsin. "At BCT, we place great emphasis on clean abrasive/peening media in our cleaning and peening machines. Our R & D efforts have led to a highly effective design of airwash which allows us to monitor and automatically adjust (a) the thickness of the abrasive curtain, and (b) generation of a full length of this curtain along the lip length." To explain the importance of this concept, the ideal thickness of the airwash separator curtain is between ¼" and 3/8" to allow effective passage of clean air. A full length of curtain allows fresh air to pass through the curtain and carry the fines/dust along with it to the dust collector. Both techniques result in less wastage of peening media and wear of wheel components.

Analysis of work mix

Efficient blast cleaning relies on a healthy work mix of small and large abrasive particles. This is not the case for peening applications which rely on uniformity of shot size. A mix of particle sizes helps pulverize heavy scale (large particles) and scour tight geometries (small particles) in the part being cleaned. An effective means of automatically checking the health of the abrasive work mix, realtime in wheelblast machines will enhance their cleaning efficacy.

Automated drop test arrangement

Mike Langtry of Langtry Blast Technologies explains their company's innovation in this field. "Drop tests are easy when you are flowing peening media in tens (airblast) and not hundreds of pounds as in a wheelblast machine. For this purpose, we designed an automated arrangement that diverts the discharge of the infeed hose to the blast wheel into a calibrated hopper mounted over a weigh scale. A simple selection on the system HMI allows collection of shot for a pre-determined time period to accurately weigh the pounds-per-minute to that blast wheel. This allows calibration of the flow control valve (typically a MagnaValve) connected to that blast wheel. Collected media is then discharged into the blast cabinet after the drop test."

SUMMARY

Several other opportunities exist in the wheelblast world to bring it closer to accuracy and repeatability that peening specifications dictate. Also, data collected through such initiatives is digital, which could help build that predictability engine that AI models hungrily await—gradually carrying us into the next generation of blast machines. I am confident of being able to report more on that in the future.

Characterization of Particle Size and Shape Distributions for Shot Peening Media

Langdon Feltner,[a] Mark Gruninger,[a] Tod Canty,[b] Paul Mort[a]
[a] Purdue University, School of Materials Engineering, West Lafayette, Indiana, USA
[b] JM Canty, Lockport, New York, USA

ABSTRACT
Characterizing and controlling particle size and shape distributions of shot media are fundamental to ensuring the success of the peening process. A combination of material knowledge, process expertise, and quality control measures are required to achieve consistent and reliable results. Technical advances in dynamic imaging of particulate matter have enabled routine sampling and analysis of particle size and shape distributions. This article discusses progress toward developing industry-ready specifications for media size and shape distributions.

1. INTRODUCTION
The relationship between the size distribution of steel shot and the residual stress field generated by shot peening is a critical aspect of the process. The residual stress field contributes to mechanical properties and performance of treated parts such as springs, axles, and gears. Size and shape distributions of shot media directly affect the impact energy and contact stress in the peening process. This paper discusses measurement and specification of size and shape characteristics as they apply to as-manufactured and in-use media. Further opportunities include the use of size and shape descriptors in model-based process control and optimization.

In addition to the support of the Purdue Center for Surface Engineering and Enhancement (CSEE), the work covered in this paper includes the efforts of several teams of students who participated in Materials Processing and Design, a capstone course for MSE Seniors at the Purdue University School of Materials Engineering. Samples of as-manufactured and in-use media used in these studies were provided by Toyo Seiko NA, Ervin Industries, and American Axle Manufacturing. The objective was to establish a robust statistical basis for size and shape characterization and specification (Section 3). Dynamic image analysis (DIA) was used to collect large numbers of particle images comprising randomly-oriented 2D projections of 3D shot particles, as illustrated in Figures 1 and 2.[1]

Detailed analysis and graphical representation of the image data was done at Purdue using specialized software for analysis of size and shape distributions (PD23[2]). The software is suitable for size and shape analysis of image data collected over a range of applications, i.e., it is not specific to particle scale, material, or method of dispersion. A statistical approach to characterization using geometric means and standard deviations (d_g, σ_g) along with distribution moments (number, area, volume) is described in [1]. Other recent publications discuss DIA in context of shot peening [2] and metal powder additive manufacturing [3]. More broadly, industrial adoption of DIA continues to expand, for example ranging from pharmaceutics to geotechnics.

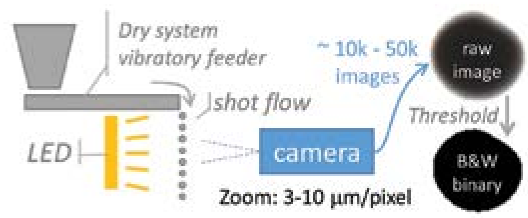

Figure 1. Dynamic Image Analysis (DIA) schematic.

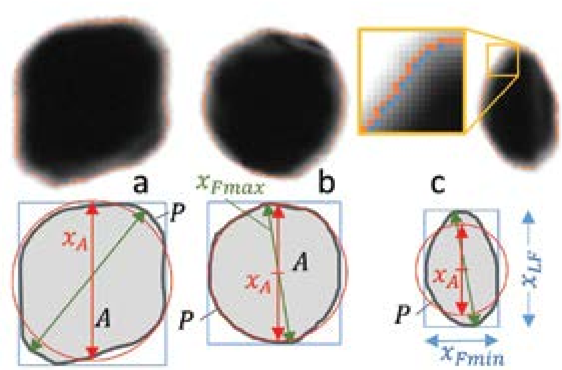

Figure 2. Analysis of images representing modes in the working mix: a) sub-conditioned CW; b) conditioned CW; c) worn media. Orange pixels in grayscale images show thresholding. Bounding boxes (blue) and equivalent-area circles (red) illustrate size features.

Many studies on particle image analysis are available in the literature. With advances in digital imaging technologies, size and shape analyses are becoming more routine for many applications. However, given the long history of the field, there is some ambiguity in the terminology of shape descriptors and analysis methodologies for same. For

[1] The DIA equipment used in this work, Solidsizer, was provided by JM Canty, Lockport, NY.

[2] PD23 analysis of raw image data uses NI Vision, National Instruments Corp., Austin, TX.

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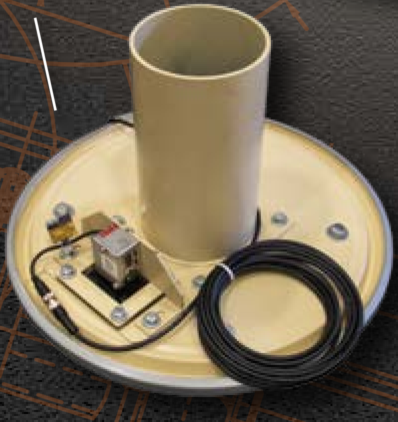
Pneumatic Vacuum Assembly

Adjustable Feed 2" Carburetor Pick-up Probe

30 Gallon Drum Lid



*Empire's **Pro-Loader** is designed for bulk media transfer in an Empire blast system, with no lifting and minimal attention by an operator.*

example, there is considerable ambiguity associated with "sphericity", "roundness" and "circularity".

As a starting point, this study references the guidance and terminology of the International Standards Organization [4] including Feret lengths (x_{Fmin}, x_{LF}, x_{Fmax}) area-equivalent diameter ($x_A=\sqrt{(4A/\pi)}$) and form factor ($FF=4\pi A/P^2$), where A is the projected area and P is the perimeter.

2. DISTRIBUTED VARIABILITY IN PEENING MEDIA

In the current study, we consider a combined dataset having a mix of as-manufactured, conditioned and worn media, all using CW32 media. The wear threshold was determined using a multi-modal analysis of in-use media sampled at three different times (Figure 3). A transition from conditioned to worn media was consistently observed at about 780 µm. Above this threshold, media are in states of conditioning or preliminary wear, initially increasing sphericity with peening, and then gradually decreasing in size by surface erosion. Below the threshold, media have a distribution of shapes including a portion that is evenly worn and well-rounded, and a portion having more severe wear with breakage and shape degradation, e.g., Figure 2c.

A factor analysis of size and shape variables reveals two critical features, one describing size (x_A), and the other shape (FF), together explaining about 73% of the sample variance (Figure 4). The grayscale contours representing the volume-based density of the working mix are overlayed by a quadrant grid that illustrates the media lifecycle (I through IV) in the peening process. Combining statistical, graphical, and mechanistic perspectives provides a path toward updated size and shape specifications proposed in Section 3.

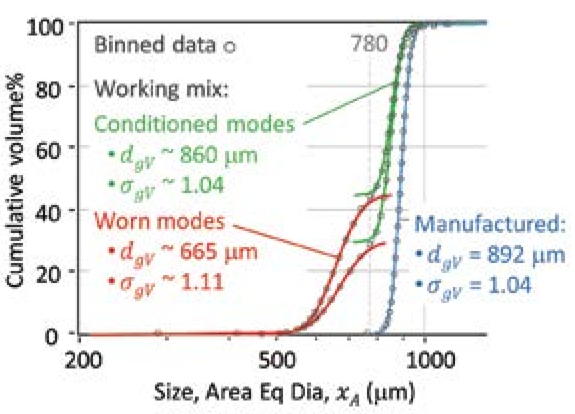


Figure 3. Size distributions of as-manufactured and working-mix CW32 samples. Bimodal working mix data show the range of three samples: conditioned modes > 780, worn modes < 780 µm.

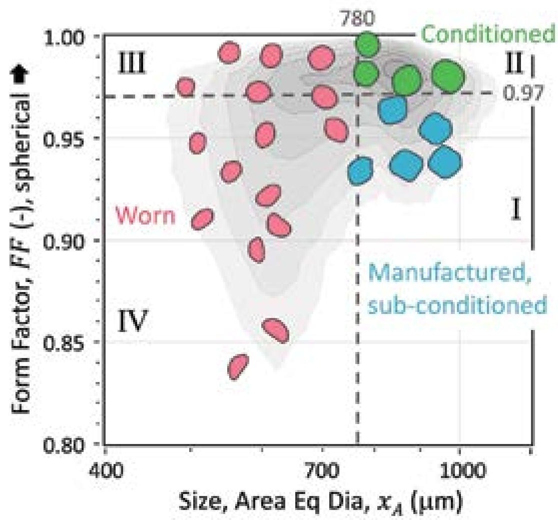


Figure 4. Size/shape quadrant map: I) as-manufactured, sub-conditioned; II) conditioned; III) worn and well rounded; IV) worn with shape distortion. Quadrant boundary thresholds (x_A = 780 µm; FF = 0.97) are based on multimodal size and shape analyses.

3. MEDIA SIZE AND SHAPE SPECIFICATIONS - DIA

A definitive step has been taken to create a guideline for media size & shape specification using Dynamic Image Analysis (DIA) as an alternative to existing sieving and manual inspection procedures. Example guidelines are illustrated using DIA data for as-manufactured S110 and CW14 media.

Figure 5 illustrates the equivalent area diameter (most relevant to peening) in context of a two-sided specification limits based on SAE J2441 [5]. Note the size distribution considers the full 2D projection area of the media rather than the minimum dimension obtained by sieving.

Shape archetypes that are provided for the purpose of visual inspection in AMS2341 [6] were quantified using orthogonal image analysis shape factors, AR_{box} and EFF, with the Form Factor contours overlaid. Figure 6 provides an illustrative reference between legacy shape specifications which required manual inspection, and proposed shape specifications using automated image analysis.

Figure 7 illustrates form factor limits using the same two examples of as-manufactured media that are shown in Figure 5. The Form Factor provides a quantitative measure of shape that combines the effects of elongation and angularity illustrated in Figure 6.

Compared to the CW32 working mix media discussed in the body of the paper, shape control of finer media (e.g., CW14 and S110) is more challenging. In this example, the Q50 limit is a challenge for conditioning of as-manufactured CW; and the Q5 limit is a challenge for shape classification of cast media. Further refinement of Form Factor quantile limits can be developed for specific peening applications.

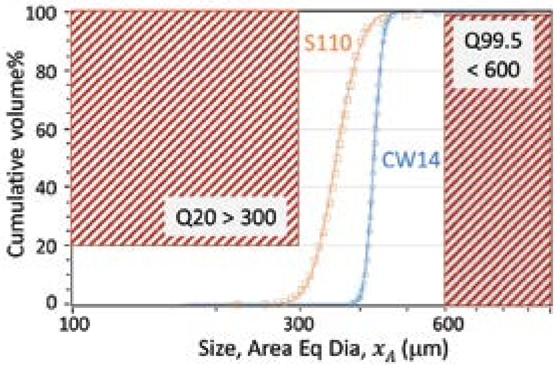


Figure 5. Size specification using J2441 adapted to equivalent area diameter. Quantile specifications (Q) describe the allowable size range (non-shaded).

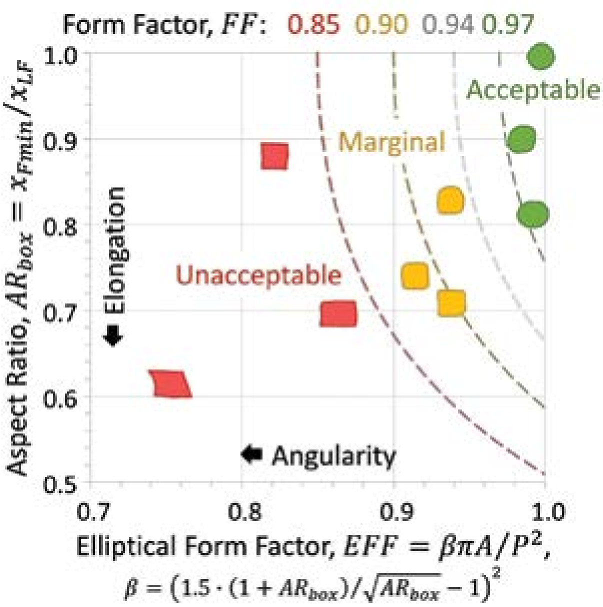


Figure 6. Mapping of legacy shape archetypes using orthogonal shape factors. Form factor contours (dashed lines) relate to the proposed limits shown in Figure 7.

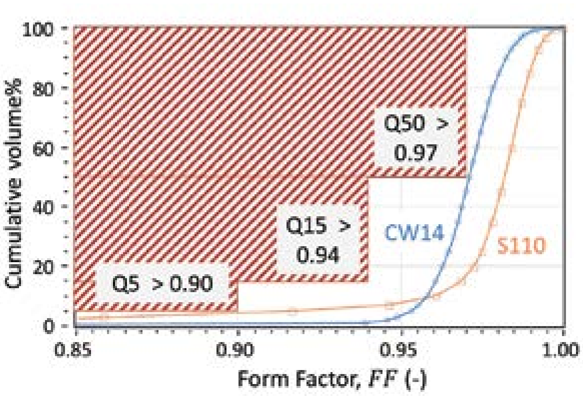


Figure 7. Proposed 1-sided shape specification format using form factor as a lumped-sum parameter. Quantile specifications (Q) describe the allowable shape range (non-shaded).

4. CONCLUSION

Dynamic Image Analysis (DIA) has proven to be a viable technology to measure the size and shape of particulate matter including, for the purpose of this paper, a variety of commercially relevant shot types. Two of the most developed and promising uses of DIA in shot peening are: 1) as an alternative to conventional "manual" measurement techniques for analysis and specification of as-manufactured and working-mix media; and 2) as input data to simulate the effects of working-mix dynamics over a variety of shot peening processes.

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Q & A

THE Q & A FORUM at www.shotpeener.com is the ideal place to get advice on a wide range of topics from industry leaders and colleagues from around the world that have tackled and solved your challenges. The topics include:

- Shot Peening Process, Intensity, Coverage
- Specifications
- Equipment, Machines, Accessories
- Abrasive Blast Cleaning Process
- Media, Shot, Beads, etc.
- Ask Dr. Peener

You don't need to register to browse the forum. If you would like to post a question or respond to a post, however, you need to register and it's very simple to do. The following are a sampling of the forum's posts. Maybe you will find an answer here to an issue you are facing.

Shot Peening Process, Intensity, Coverage

Peening Parameters

Questioner: Hello every one. My question is which parameter should remain the same as the parameters at the intensity point to apply on peening the actual part:

1. Shot type and size (sure)
2. Impact angle (sure)
3. Stand off distance (sure)
4. Shot feed rate (not sure)
5. Nozzle size (sure)
6. Translation speed of nozzle (not sure)
7. Blasting pressure (not sure)
8. Rotary speed of part (not sure)

I want to change some parameters above to control the required coverage. Thank you for your support.

Answerer #1: Once you set the machine parameters and achieve the correct intensity, you must continue with these settings and no more changes. If you make any changes you must repeat the saturation curve test.

Questioner: Thanks for your feedback. But I have one confusion. If I continue with these settings and no more changes, the coverage of actual peening part seems over the coverage that I expect. In this case, what should I do? Please advise.

Answerer #2: After your machine is set to peen to the correct intensity, the only parameter you can change is the time it takes to peen the part. Understand that the amount of time you peen the part does not affect intensity. The peening time ONLY affects the coverage.

With that in mind, you can change the peening time of the actual part. I want to re-visit a couple of your parameters from above: *6. Translation speed of nozzle and 8. Rotary speed of part.* These will not affect intensity as long as the nozzle distance and media impingement angle in relation to the part surface remains the same as it was in the positive intensity test/verifications.

Answerer #1: There are two aspects to peening parameters: intensity and coverage. Intensity is established using a saturation curve. Once you have the correct intensity you must lock down all parameters of machine settings.

Coverage is only determined by observation of dent accumulation onto the part. You must peen your part long enough to dent the entire surface.

Questioner: Thank you and appreciate your support. My concern is clear now.

Surface Damage After Peening

Questioner: Has anyone ever experienced this phenomenon? A part appears to be free of defects prior to peening, then after peening a scratch or nick becomes visible.

Answerer #1: There appears to be two alternatives as to scratch origin. Either the scratch was present before peening or it was imposed after peening. If it was present before peening then the scratch cannot be sharp and must have appear to have been "blurred" by the action of peening. If the scratch appears to be sharp, then it must have occurred after peening as a result of part handling. A blurred scratch is rare but can be the result of a scratch having been smoothed over by a burnishing type of process applied prior to peening. During burnishing metal flows over the scratch hiding it from view. Subsequent peening then stretches the surface revealing a (blurred) scratch.

Answerer #2: Could it be that something has gotten into the working mix of shot that is being cycled through and shot at the part causing damage when it hits? Maybe a bit of metal or something? This would be applicable on a system without classifier screens to take out stuff like that, of course.

Questioner: The damage looks like a long scratch or groove that's been peened over. Problem is we are 100% sure it was not visible to the naked eye prior to peening. Answerer #1 seems to have hit the nail on the head.

Shot-Peened Part Warpage

Questioner: Is it possible to correct a part that has been warped post shot peen and be acceptable? The part was only shot peened on one side of the part. The other side was completely masked off.

Answerer #1: I think the first option would be to peen the other side, but the other side was masked off for a reason. Even if allowed, the part may not return to its original shape.

More important is learning why it warped. Was it peened with too high of an intensity? If so, that would be the larger issue and cannot be undone. If the peening procedure allowed for the intensity used, then the process design is in question.

Since that is often not the case you should verify the part was dimensionally correct—was it too thin?—before being peened. Next, double-check that your arc height measurements and intensity calculation are correct.

In the end, any corrective action would need approval from the part owner and/or design authority. Please let us know your findings, or additional information. I would appreciate reading a follow-up.

Questioner: Exactly what we did...peened the other side. It was optional but it did not return to the original shape. The intensity was within the allowable range as was the arc height measurements and calculations.

The part was too thin and that is why masking was required in those areas but only required on one side of the part.

I personally haven't seen that requirement before. Just makes sense to me whatever you mask and peen on one side of the part should be done to the other. Process design is checking into it. I will let you know.

Answerer: It sounds like nothing can be done for the part you've already done. Future attempts should be done by peening both sides at the same time with blast streams directly opposing each other. If that is not possible, peen one side with light coverage, then do the same for the other side. Repeat this until you've obtained the desired coverage.

Questioner: Would a warped part be rejectable as an unacceptable part in the shot peen process or in final inspection? If shot peen rejects the part, how do we back it up if it isn't covered in our specification? Thanks in advance.

Answerer: It sounds like you have an opportunity to make improvements in the quality or inspection procedures practices. There should be guidelines for acceptance/rejection of components coming into the shot peen department and again after peening.

There is a special burden on the shot peening operator. If he/she properly peens to the required peening parameters and then if the part warps (often because of thin cross section) who is at fault? The designer or the operator?

Is the operator expected to recognize if the part is warped prior to peening thus rejecting it? Are drawings complete with dimensions and accept/reject levels for both pre- and post-peening?

Perhaps some additional training for designers, inspectors and operators could help address this issue.

Questioner: You make a good point regarding additional training. We do have guidelines for acceptance/rejection criteria but they are straight out of the spec. Our customer is taking responsibility if the part warps as long as it is masked and shot peened according to the model (CATIA) which it is.

Then they will inspect it on their end and make the decision. My concern is us stamping the part as acceptable because there isn't anything in the shot peen spec that addresses accept/reject criteria for a slightly warped part.

Thanks again for your valuable response.

Edge Rollover

Questioner: Hello all. It's been quite some time since developing shot peen applications, but now I've been dragged back in. I've got a nickel-based part that will be peened at 4-8A, with the option of S110 or S170 (with CCW equivalent sizes allowed) ... so we'll go with either CCW 14 or CCW 20 ... but which one?

In our other shops with similar parts, the occasionally nagging problem has been edge rollover. The best solution is to generate the largest break edge (chamfer, radius or whatever the particular requirement is) prior to peening. However, sometimes the max allowed isn't all we'd like it to be.

So the question: Does anyone have any experience as to how much affect shot size has on rollover ... if any ... given that the intensity range must be met regardless?

Answerer #1: This old rollover problem seems to be a never ending one. In my experience the people machining parts to be shot peened rarely know what "Break Edge Condition" is needed to prevent unwanted rollover, and even if they did, they may not want to incur the extra manufacturing costs involved.

Perhaps if an additional guidance Table (linked to the data provided in Tables 1, 2, 3 & 4) was to be included in ARP7488, resolving the problem may actually get a little closer.

At least the people machining parts could be made aware of what "Break Edge Condition" we (the peeners) need to enable us to meet their requirements. Here's hoping !

Answerer #2: A sharp edge is going to roll regardless of shot size, and a rolled edge is not something you want. In fact it's strictly prohibited in most peening specifications and Nadcap requirements dictate you have methods for both detecting sharp edges prior to peening and inspecting for rolled edges post peening.

If possible make your edge breaks at least .010". I've found this to be a safe minimum.

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CASE STUDY

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ACADEMIC STUDY

Dr. David Kirk | Coventry University

ELASTICITY
The Missing Link

INTRODUCTION

In spite of its importance, elasticity is rarely even mentioned in peening articles. This rarity justifies it being considered as a "missing link". This article is divided into two parts. Part A covers the relationship between elasticity and induced indentations. Part B deals with effect of elastic modulus, E, on the deflection of shot-peened Almen strips.

PART A

INTRODUCTION

Elasticity is a very important property for shot peening. It's magnitude is the link that controls the proportion of a flying shot's kinetic energy that is used to produce indentations in components.

When a flying shot particle strikes a component part of its kinetic energy, ½mv^2, is absorbed by the component and part is retained as the kinetic energy of the rebounding particle. This important principle is illustrated in fig.1. Imagine a ball bearing being dropped from a height of 1 m onto a steel plate rebounding to the half-height of 0.5 m. This ratio has been shown, by experiment, to be similar to when steel shot strikes steel components.

Two inter-related parameters indicate the degree of elasticity for materials. These are "Coefficient of Restitution" and "Elastic Modulus". These parameters and their relevance to shot peening form the subject of this article.

COEFFICIENT OF RESTITUTION

The coefficient of restitution, e, is defined by:

$$\mathbf{e = rebound\ velocity/impact\ velocity} \quad (1)$$

For dropped bouncing objects **e** can be estimated from:

$$\mathbf{e = \sqrt{(h/H)}} \quad (2)$$

where **h** is the rebound height and **H** is the drop height.

Consider the situation illustrated in fig.1. **e =** $\sqrt{}$**(0.5m/1m)** = $\sqrt{}$**0.5 = 0.71.**

As stated in the Introduction, the bounce height ratio for steel shot striking steel components is also close to 0.5. We can therefore conclude that:

The coefficient of restitution for shot peening with steel shot is close to 0.71.

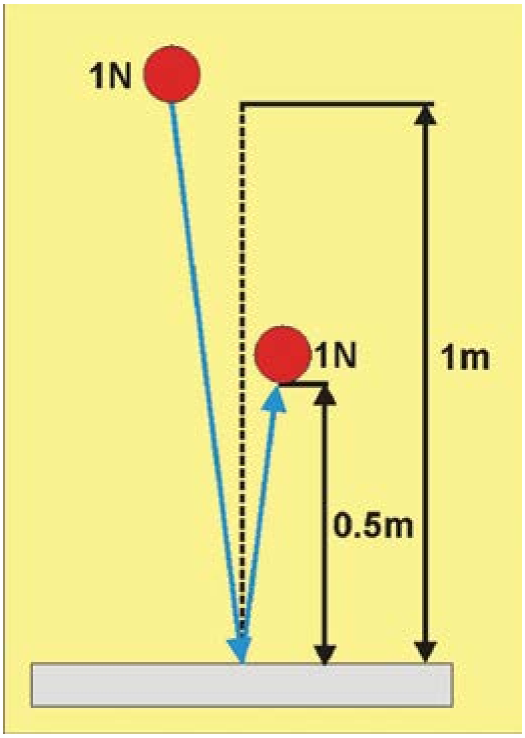

Fig.1. Kinetic energy absorption when impacting a component's surface.

ENERGY TRANSFER

Experimental results indicate that in the shot peening process, the energy transfer from the shot into the target material is mainly in the form of so-called "Elastic-Plastic deformation energy". For energy transfer during shot peening, Plastic deformation energy accounts for the major part (≥72%) and the rest (≤28%) is Elastic deformation energy. The plastic deformation energy is consumed by plastic deformation under the dent. Elastic deformation energy goes into elastic deformation of both the shot particle and the component during impact. Up to 70% of the elastic deformation energy is released during the elastic recovery of the shot particle and the component. The remaining 30% of the elastic deformation energy is stored to provide the driving power for permanent macroscopic deformation of the shot-peened components, e.g., bending.

ELASTICITY LEVELS

Shot particles and components are solids and therefore have a certain level of elasticity. Shot particle elasticity is of primary importance. That importance is the tendency of the particle to return to its original shape after impact with a component. During impact, the force the particle exerts on the component increases rapidly. This force causes the particle to increasingly flatten. As the particle rebounds this flattening is removed. It would be disastrous if the particle stayed flattened!

Useful elasticity levels are indicated by two parameters—elastic modulus and yield strength.

We need impacting shot to behave elastically as illustrated by fig.2 (where flattening has been greatly exaggerated).

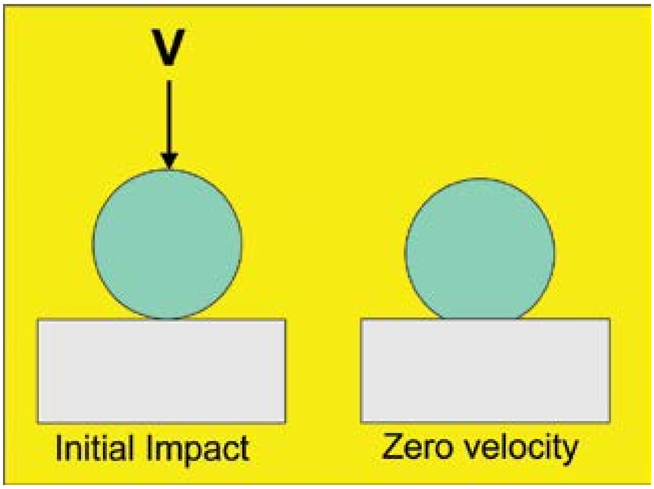

Fig.2. Elastic shot flattening on impact with component.

Elastic Modulus

The relationship between applied force and elastic deformation is given by Hooke's Law. This predicts that, for small strains, there is a linear relationship between applied stress and resulting induced strain as illustrated in fig.3. The ratio of applied stress divided by induced strain is known as the elastic modulus, E.

Fig.3 simply indicates that solids can have a wide range of elastic modulus values. Table 1 gives typical numerical values of E and approximate yield strength for some relevant materials.

The great advantages of hard steel as shot material are: low cost, reasonable elastic modulus level, and its ability to be heat treated to very high-yield strength levels. This means that heat-treated steel shot would be incredibly difficult to plastically deform on impact—thank goodness—as illustrated by fig.3. Component properties can, however, require the employment of different shot materials.

Modulus Measurement

Elastic modulus can be measured in tension (pull testing), compression, and bend/flex testing. Measurement for individual shot particles would be very tricky! We resort to measurements on rod samples made and heat-treated from the same steel.

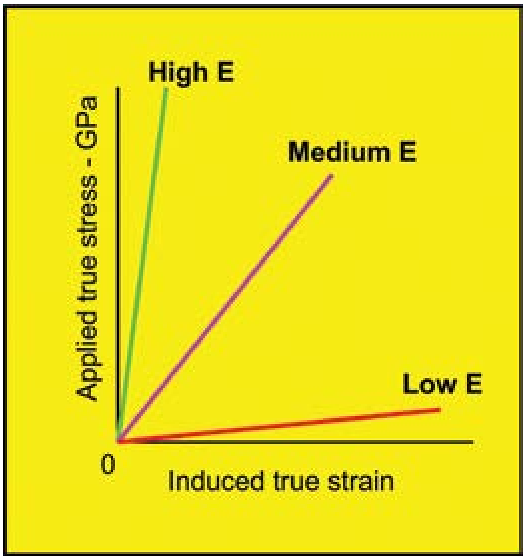

Fig.3. Range of elastic modulus values.

Table 1 Elastic Modulus and Yield Strength Values

Material	E, GPa	Yield Strength, MPa
Hard Steel	210	200-2100
Stainless Steel	180	500
Ceramic	345	≈ 150
Aluminum	71	50
Tungsten Carbide	550	350

PART B

INTRODUCTION

Shot-peened Almen strips, on release from their fixture, adopt a curved shape, see fig.4.

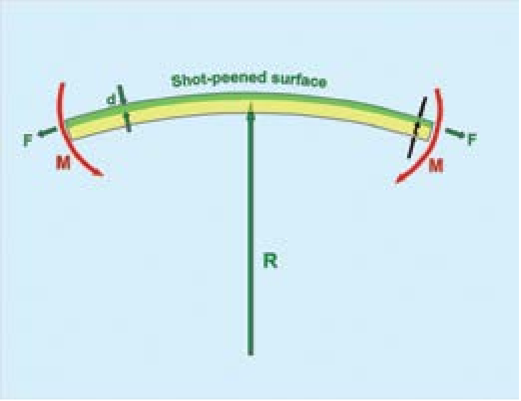

Fig.4. Curved shot-peened Almen Strip.

Curving is due to two factors:

(1) Plastic deformation of the peened surface layer and
(2) Compressive residual stress in the peened surface layer.

The two factors have been shown, experimentally, to be approximately equal in magnitude. This was achieved by measuring the arc height before and after stress-relieving heat treatment. It follows, as an important principle, that:

Half of measured Almen Arc Height is caused by permanent Plastic Deformation and Half is caused by temporary Residual Stress.

Plastic deformation is independent of elastic modulus. Residual stress curving is directly dependent on the compressive residual stress in the deformed surface layer.

CURVATURE VERSUS ALMEN ARC HEIGHT

The magnitude of curving is classically given the term "Curvature", which is defined as 1/R. R being the radius of bending, as shown in fig.4. The smaller the value of R the greater will be the magnitude of 1/R. Arc height can be related to curvature using Euclid's "Intersecting Chord Theorem". This was presented by him some 2,500 years ago! Fig.5 shows how his theorem can be applied to convert Almen arc height, h, into curvature, 1/R.

h is the measured Almen arc height, **x** is half of the strip's length between ball supports and **R** is the effective radius of curvature (actually (R-h) but h is so tiny relative to R that it can be ignored).

Euclid's Intersecting Chord Theorem tells us that $\mathbf{x^2 = h.R}$, hence:

$$\textbf{Curvature } \mathbf{1/R = h/x^2} \qquad (3)$$

Equation (3) shows that curvature increases directly with the magnitude of arc height.

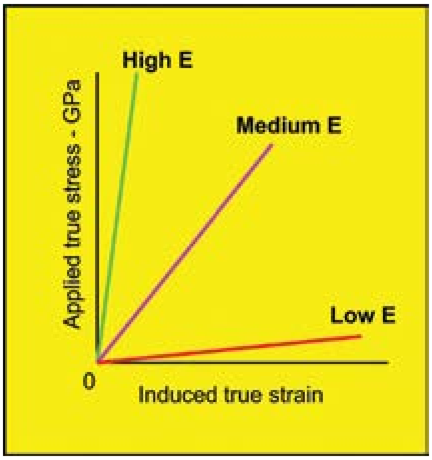

Fig.5. Euclid's Chord Theorem applied to Almen Strip curvature.

EFFECT OF ELASTIC MODULUS ON MEASURED ARC HEIGHT

Compressive residual stress in the peened surface layer causes half of the induced curvature. The amount of curvature depends on the Almen strip's ability to resist bending. This resistance ability is given by:

$$\textbf{Bending resistance} = \mathbf{E^*I} \qquad (4)$$

where **E** is elastic modulus and **I** is the "rigidity factor" (technically known as the "second moment of area" of the strip).

Equation (4) tells us that the resistance to elastic bending depends directly on the magnitude of the strip's elastic modulus. The higher the modulus the greater will be the resistance to bending. It follows that the lower will be the contribution to arc height induced by compressive residual stress in the peened surface layer.

The compressive residual stress in the peened surface layer generates the bending moment, **M**, shown in fig.4. The greater the induced bending moment the greater will be the observed arc height. Basic beam bending theory gives us a simple relationship between the bending moment applied to a beam and its consequent curvature, 1/R :

$$\mathbf{1/R = M/(E^* I)} \qquad (5)$$

where **R** is radius of bending, **E** is elastic modulus, **I** is the "second moment of area" and **M** is applied bending moment.

Equation (5) indicates that curvature (and therefore arc height) increases with increased bending moment but is decreased by increases in either elastic modulus or "second moment of area".

Bending moment and elastic modulus are familiar parameters. "Second moment of area" is less familiar. It is simply a quantitative measure of the rigidity of a beam. Fortunately Almen strips, because of their rectangular shape, have a simple relationship between "second moment of area", I, and their dimensions:

$$\mathbf{I = w^*t^3/12} \qquad (6)$$

where **w** is strip width and **t** is the strip thickness.

The significance of equation (6) can be appreciated by trying to bend a measuring rule. In one direction the rule bends easily. Turn the rule through 90˚ and it is virtually impossible to achieve visible bending.

If we substitute the value of I given by equation (6) into equation (5) we get:

$$\mathbf{1/R = 12M/(E^*w^*t^3)} \qquad (7)$$

Substituting $\mathbf{h/x^2 = 1/R}$ from equation (3) gives:

$$\mathbf{h = 6x2\ ^*M/(E^*w^*t^3)} \qquad (8)$$

where **h** is induced arc height contribution and **x** is half the distance between the support balls of the Almen gage.

Equation (8) is a “definitive equation” that indicates the inter-relationship of all of the significant variation of strip factors.

ALMEN STRIP ELASTIC MODULUS VARIABILITY MEASUREMENT

There is no doubt that the Elastic modulus of Almen strips can vary. Variations can occur in both composition and thermos-mechanical processing. Of these, the incidence of preferred orientation is probably the largest factor. Measurement of strip elastic modulus can be carried out by conventional tensile testing or by a Go-No-Go test.

With conventional tensile testing a “dog bone” shaped specimen is pulled using a tensile testing machine. For small strains loading gives a linear stress/strain plot as shown in fig.5. The ratio of stress/strain, E, is derived from the applied stresses and resulting strains as indicated in fig.3.

A simple Go-No-Go test is illustrated in fig.6. A long length of strip, say 1 metre, is supported on fixed rods placed against drawn “too high” and “too low” background curves. For each thickness of Almen strip, N, A and C, a corresponding appropriate load is hung from the center of the strip. Load hanging could be facilitated by using the type of hook shown in the inset. Loading induces bending into a curve shape. If the strip modulus is deemed to be too high then not enough bending will occur. Too much bending would occur if the modulus was deemed to be too low.

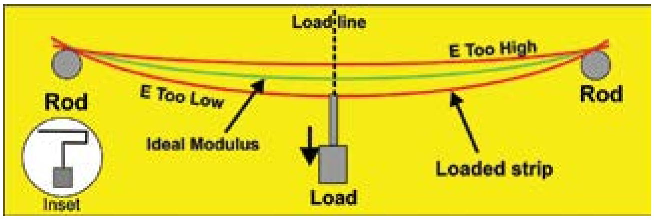

Fig.6. Go-No-Go test facility.

For individual Almen strips a device such as that shown in fig.7 can be used. A force meter is pressed against the center of the peened Almen strip. The Almen gauge then indicates the corresponding strip bending. The Almen gauge readings for different applied forces will yield a straight line graph whose slope is the elastic modulus. This is somewhat tedious but an alternative is to use the device in Go-No-Go mode. For a given thickness of Almen strip, a fixed applied force level will induce a gauge deflection that varies with the magnitude of elastic modulus, E.

DISCUSSION

This article has shown that the elastic properties of shot peening components—especially Almen strips—deserve far more attention than they are generally given. As such, Elasticity can rightly be regarded as a “Missing Link” in the shot peening world.

Fig.7. Device for Almen strip elastic modulus determination.

The elasticity of shot particles determines the proportion of their kinetic energy that is used in dent formation. This also applies to the elasticity of the component. More importantly, elastic modulus value affects the amount of bending of Almen strips when subjected to shot peening.

Elastic modulus variability can be determined easily for long Almen strip samples. Individual strips can be tested quickly using the device just described. For both methods it is necessary to check that strip width—and particularly strip thickness—are not intruding variables.

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Customized Comparison Tools for Peening Coverage

Using Peened Material Samples to Ease Coverage Inspections

EVERY OPERATOR, process developer and quality manager in the shot peening industry knows about the challenges in inspecting and rating the Coverage on peened parts. The achievement of full or 100% Coverage is very essential though to determine the corresponding peening time. Knowing the peening time saves energy and wear, avoids over-peening and is the basis to comply with peening instructions that require specific multiples of 100% Coverage.

Finding a reliable peening time for full Coverage usually requires a Coverage development using several sequential time-based steps producing lower Coverage rates. Estimating Coverage at lower degrees is often difficult and leads to discussions between operators, process developers and quality managers.

In order to address this challenge, SAE J2277 provides patterns for comparing the inspected surface with a graded series of computer-generated pictures. These pictures are an appreciated tool for the inspector but do not claim to reflect reality. The inspection for Coverage on a real part surface after a peening process can be very challenging due to several reasons.

An overview of the difficulties that prevent an easy Coverage assessment can be divided into four categories.

Part condition and accessibility

Since shot peening is usually performed after surface machining, characteristic surface profiles from turning, milling, etc., can make Coverage inspection quite difficult. If a surface is rough, dents will be hard to distinguish from the original surface texture. Even surface colour and brightness will influence the rating results.

There are areas on a part that are hard to access with the standard tools of visual inspection. Areas like the inner side of a boring or undercuts don't give the required access for inspection equipment.

Illumination and magnification

The lighting and magnification tools used for Coverage inspection do have an impact since they can change the visual impression of the surface. Light source direction, movement and brightness, surface reflections and size of the inspected area can change the visual impression the dents have on the inspector's view. Therefore, it is important to keep illumination and magnification consistent throughout a Coverage development.

Depth and size of individual dents

Inspecting Coverage that has been created at low Intensities or on hard surfaces is difficult since the individual dents cannot be detected easily. It is particularly hard determining the Coverage of parts that have been treated by ultrasonic peening since dents are extremely flat.

Dent size is also dependent on shot size, leading to very small dents with small peening media. The varying dent sizes of cast steel shot also cause different-sized dents that make it harder to rate the Coverage on a part.

Inspectors

Two different, equally experienced inspectors assessing the same surface will usually end up with different results in Coverage rates, sometimes of more than 20%. This shows that, even though theoretically the Coverage is well-defined, Coverage determination comes with a subjectivity that is unwanted in the process. Even the same inspector may determine a different Coverage for the same surface on two different days.

To address the problems, there are several well-established methods. Instead of only one inspector, multiple persons can help improve the determined values. This is however cost and time intensive and not always possible. The same goes for time-consuming Coverage developments.

THE BENEFITS OF COVERAGE SAMPLES

Instead of spending a lot of time on every individual Coverage determination, the use of customized Coverage comparison samples helps to reduce the time and personnel effort that has to be put in every part.

The specimens for the Coverage Samples are manufactured from the same material and in the same pre-processed state as the components to be peened. A reproducible peening process is then applied, the media and Intensity of which


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correspond to the real process. Using a specialized shot peening machine that can easily change the peening time by changing the number of passes or velocity, it can create several steps of Coverage in the range of 10 and 100%.

When later on the inspector compares the samples with the peened part, he or she will find a similar visual impression on both surfaces. The recognition of the Coverage state will then be a lot closer to its correct value.

The key to create reliable Coverage samples is that the rate of each sample needs to be determined as precisely as possible. As automized systems are still under development and themselves need to be trained by humans, there is the need for a procedure that ensures a high quality in Coverage determination, addressing most of the aforementioned problems. The idea is to use the experience of a number of inspectors in the Coverage development of samples and to combine this with the means of statistical mathematics.

Statistical Coverage development

Though the individual dents cannot be foreseen in a chaotic media impact like in shot peening, the increase rate is predictable by a statistic formula from SAE J2277, connecting the degree of Coverage with the time needed to achieve it.

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

C_n percent Coverage (decimal) after n cycles,

C_1 percent Coverage (decimal) after 1 cycle,

n number of cycles (number of passes, number of rotations, or uniformly chosen increments of time)

By converting the formula defined in SAE J2277 to

$$C_1 = 1-\sqrt[n]{(1-C_n)}$$

and inserting the values determined by an inspector, each inspection results in a C_1-value. Collecting C_1-values for every Coverage step and operator and building the average value over all of them leaves you with an averaged C_1-value.

This principle allows the use of all ratings of all inspectors for each step in the Coverage development of a sample which overcomes the main problem presented above—that low Coverages are hard to determine correctly.

Coverage development with multiple inspectors

Instead of relying on an automized system, the use of pictures, or on one inspector alone, we can apply the principle of "swarm intelligence" by the use of the averaged C_1-value.

These can be experienced operators, process developers or quality inspectors within the company. They should give their personal ratings for several steps with a growing number of passes or peening time on the samples. Even if the "swarm" may be small the average rating of Coverage should be closer to reality and more reliable than single ratings from each individual. Even inspections by the same person on several different days are possible to increase statistical data and improve accuracy. Values that are too far from the averaged value can be cut from the calculated result to further improve the Coverage values.

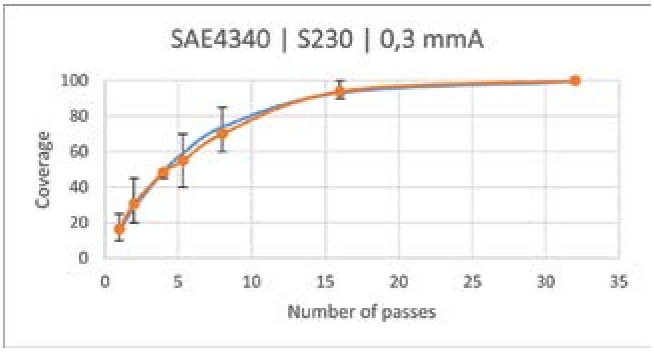

Figure 1: Coverage over number of passes

Using the formula from SAE J2247, a curve can be created from the averaged C_1-value as shown in Figure 1. The blue curve is the averaged data from five inspectors, each of these providing three Coverage inspections on seven different Coverage levels. As expected, the accuracy of the determinations around 50% has the highest deviation and differs the most from the idealized Coverage curve showing the usefulness of this method.

CUSTOMIZED COVERAGE SAMPLES

While the procedure above can be used to improve Coverage determination in every shot peening facility, the creation of Coverage samples comes with problems on its own. Peening standardized Coverage samples requires a different nozzle movement compared to the production process and a machine that is versatile enough to make the changes necessary. Additionally, the creation of Coverage samples requires machine and operator time that is often not available.

sentenso is offering custom-peened Coverage samples that are peened in our specialized peening machine featuring a range of sensors to ensure process stability over every Coverage step created. Our team of experienced Level 2 and Level 3 shot peening operators determines the Coverage on preproduction samples. These values are then used to create the actual Coverage samples that are created with the calculated number of passes from the curve created.

The Coverage samples should have a handy format similar to Almen Strips so the Coverage is basically uniform over the width and length. The samples are stored in a foam-lined case in which they are sorted according to material, peening media, shot peening Intensity and degree of Coverage in order to determine the respective degree of Coverage on the component in direct comparison side by side. The case can easily be carried to the inspection site. In order to provide the same condition of the peened samples and to avoid changes by corrosion, the sample surface can either be protected by a layer of PTFE or with a special protective coating depending on the sample material.


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Coverage samples are supplied in a convenient foam-lined case

Coverage 17-4PH 0,31 mmA ASH 230 35%

In addition to everyday Coverage determination, the Coverage samples can be used for internal training of new process engineers and operators. This significantly reduces the time required to familiarize the staff with the Coverage determination and enhances its quality. Experienced inspectors can also use the samples for regular self-training and -monitoring.

For more information on sentenso's custom-peened Coverage samples, please contact info@sentenso.de, visit *www.sentenso.com*, or scan the QR code.

Airless Machines for Peening of Coil Springs

MECSHOT, a well-known name for more than 32 years in the field of surface preparation machines, has set new trends by manufacturing custom-built shot blasting and shot peening machines—both air-operated and airless machines. MecShot machines are not only cost competitive but also have low operative cost.

Springs, which are used in rail or automotive industry, are constantly exposed to torsion and compressive loading which causes material fatigue and consequently breakage. To prevent this failure, shot peening is a well-established process that ensures higher strength of the material and prolongs its service life. Research shows that springs subjected to shot peening increases the life of springs up to 10 times.

MecShot has designed and developed a wheel blast machine for shot peening of coil springs used in railway coaches and wagons. Coil springs loaded on revolving rollers are fed into the blasting chamber from one end through a roller conveyor system. After peening, they are unloaded from the other end. The blasting chamber is provided with protective replaceable wear-resistant Mn liners. A set of wheels propel the shot in controlled quantity by the MagnaValve and the surface of revolving springs are peened evenly. Shots are collected and transferred to a shot classifier which supplies even-sized shots for peening. The generated dust is sucked into a dust collector, leaving clean air in the atmosphere and making the environment pollution free.

MecShot has also designed and developed an airless wheel blast machine for stress peening of coil springs to increase fatigue life. Coil springs are mounted between conical fixtures and are hydraulically compressed through a certain level to induce stress. The job is mounted on an indexing table which rotates and revolves through an electro-mechanical drive. Two turbines fire the shots on the compressed spring with a high velocity. An AC drive is provided to control speed of the turbine and satellite. The coil springs are placed manually on the indexing table and potential meters indicate the quantum of spring compression. The machine is fitted with a dust collector for effective suction and a rotary screen separator for the supply of uniformly sized abrasive.

Airless wheel blast machine for the shot peening of coil springs

Stress peening machine

Please contact for more information:

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