Peening Process Characterization and Optimization

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Abstract

This paper gives an overview of how to predict the intensity of the shot peening process using currently available technology. Methodology, tools, and software are also discussed. Real life examples are presented in the areas of optimization, troubleshooting, and process modeling.

Keywords: Velocity, Intensity, Process Modeling,

Introduction

Since its inception, shot peening has served a wide variety of industries. Aerospace, automotive, power generation, and medical industries use shot peening to enhance the products that we used every day. This has allowed parts to be more durable, smaller, and added to the lifespan of everyday products. Shot peening also has a history of being considered “black magic” or a “headache” in many production facilities. Traditionally, shot peening is a trial and error or even tribal lore when setting up equipment for new, or existing process. Now there is a new technology that is available to characterize the shot peening process.

Why would someone want to characterize the Shot Peening Process? Because it will save resources. The traditional way to setup a machine is very iterative. The process involves an initial setup, which includes setting up nozzles, estimating shot flow and air pressure and running an initial saturation curve. Once the information is compiled from the saturation curve, likely, the settings would have to be adjusted and would require the generation of another saturation curve. This cycle would continue until the process was within specifications and found acceptable.

Another benefit to process characterization and optimization is the ability to understand at what parameters the machine may be unstable or have particularly poor performance. During the normal lifespan of a machine, it will break down, thus requiring troubleshooting and failure analysis. Having the process defined on the equipment will assist troubleshooting and bring equipment online faster.

Process characterization is a procedure where the key inputs and outputs of a process are identified. The inputs are typically screened using a Design Of Experiment (DOE) to simplify modeling of the process. Information is gathered over the entire operating range so that the stable process region can be identified. Finally, models of the process are built over the operating range of the process.

Looking at shot peening there are a really two primary outputs, intensity and coverage. Intensity is measured with almen strips and can only be determined by processing a saturation curve. Coverage can only be evaluated on an actual part or coupon of the same material. Normally coverage is evaluated visually on the surface of the part, sometimes with the aid of magnification, dye or fluorescent tracer. Since coverage is very material dependent, this paper is only addressing the intensity aspect of shot peening.

We will now turn the attention to the key inputs of shot peening: Air pressure, media flow rate, media size, media hardness, impingement angle, nozzle type, nozzle diameter, hose diameter, hose length, and air quality. Of these key inputs, some of them are out of our control such as media size and media hardness which are normally dictated by the OEM. Things like air quality or hose diameter are sometimes beyond our control. This narrows down the list to air pressure, media flow, impingement angle, nozzle type, and nozzle size.

If we wanted to characterize and optimize a process by performing a DOE and using a Response Surface Method, the nozzle style would be selected and we would vary two numeric factors (air pressure and media flow). In order to perform this DOE, it would require the generation of 13 saturation curves. If the DOE was expanded to include three different nozzle styles (three categorical factors), it would require 39 saturation curves and that is only for one impingement angle and one media type. It can be seen that a lot of time and money can be consumed in process characterization. How can the process be simplified?

Approach

We started collecting media velocity data in 2004. The first set of velocity measurements that were collected revealed a strange anomaly in the velocity profile. This was quite a surprise since it was always assumed that more air pressure resulted in more velocity for a given shot flow rate. See Figure 1. To verify that the velocity was actually changing, saturation curves were performed at various points which confirmed the velocity data.

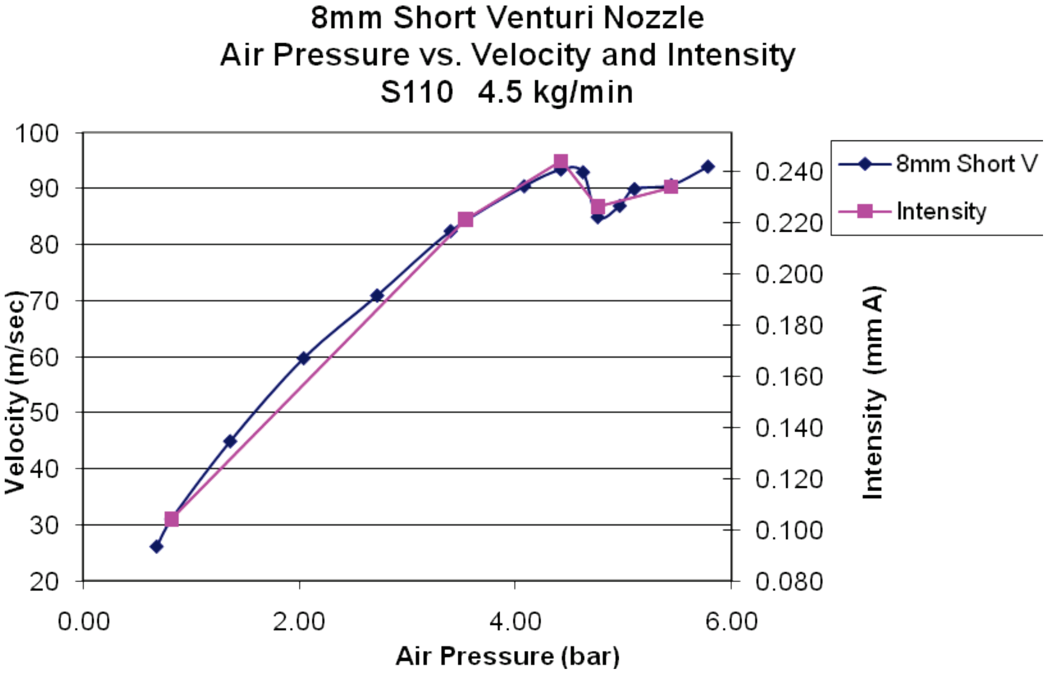

Figure 1: Velocity and Intensity Profile

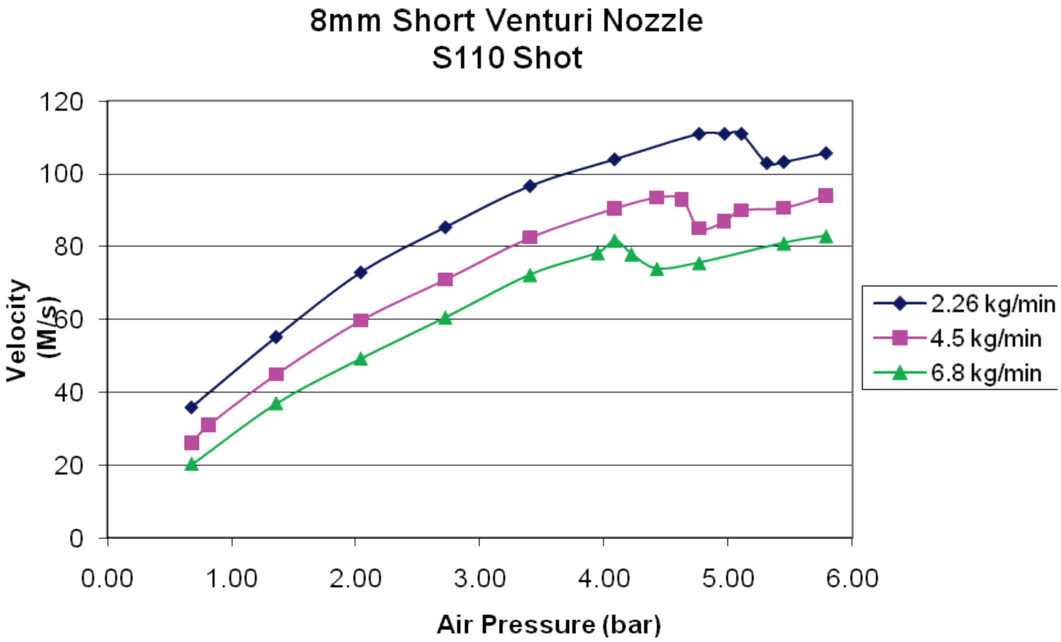

Figure 2: Velocity Profiles at Various Media Flow Rates

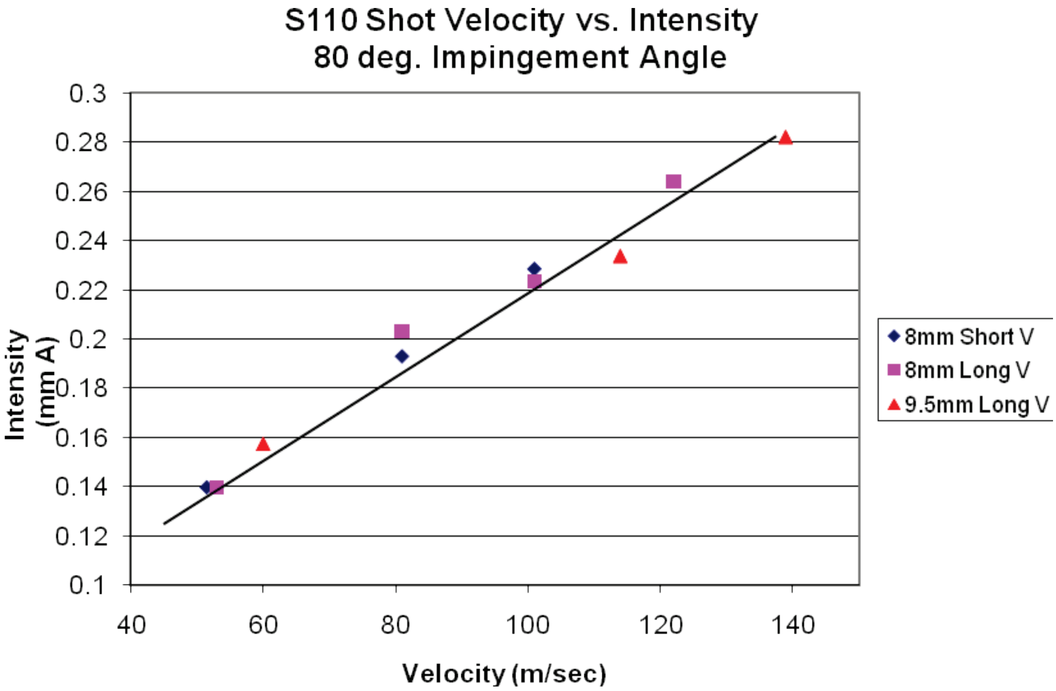

Figure 3: Velocity - Intensity Correlation Graph

Further velocity measurements were gathered to understand the unstable region. As the media flow rate increased the anomaly appeared at lower pressures (Figure 2). With further testing, it was verified that higher velocity equated to higher intensity. This was accomplished by developing saturation curves over a wide variety of velocities with different nozzles (Figure 3). This revealed a fairly linear relationship. With this ability to correlate velocity directly to intensity, it greatly simplifies the data gathering process. Once the relationship of velocity to intensity is established, we only need to measure the velocity of the shot stream of any nozzle, and then we can predict the intensity of that shot stream. Although theoretical equations have been developed to predict intensities, velocity measurements make empirical models much simpler to develop because the key inputs of air pressure, media flow, impingement angle, nozzle type and nozzle size all affect media velocity. This creates a machine specific model for prediction.

One such velocity measurement device is the Tecnar Shotmeter. The camera is aligned with the shot stream, and velocity measurements are quickly and easily gathered. In addition to process modeling, the ability to measure the velocity is a valuable diagnostic tool for tasks such as process optimization, machine health checks and troubleshooting of equipment.

Results

An example of process optimization can be seen in Figure 4. It reveals that the 8 mm short V nozzle has a velocity drop at ~4.7 bar. If the machine was set for 5.7 bar, one could achieve nearly the same results at 4.4 bar. This instability, which could not be easily seen before, can now be identified very quickly and an alternative solution could be implemented. For example, another nozzle could be chosen for this application, which may perform better which would allow the air pressure to be reduced even further to 3.74 bar. Furthermore, all the process optimization information can be gathered and evaluated without running a single almen strip until the very end for verification.

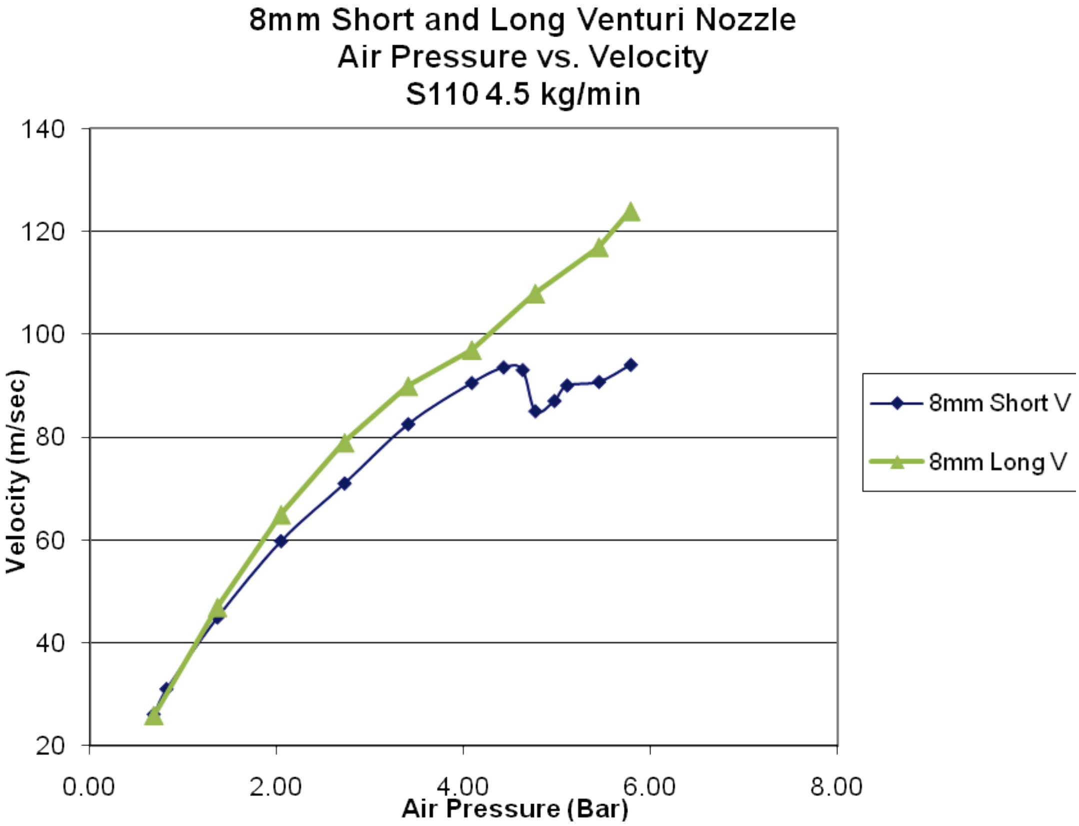

Figure 4: Nozzle Velocity Profiles for Process Optimization

The same information can also be used for troubleshooting. If process problems occur, the velocity measurements can be compared to previous ones to identify potential problems, or eliminate suspected issues. One such instance occurred when a customer was having problems with machine consistency. The machine was not peening within specifications, nor did the machine exhibit repeatability. After monitoring velocity for an extended period of time, it was confirmed that the machine was running very stable. They then traced it back to a lot of almen strips that were improperly heat-treated. Another area where velocity measurements are very helpful is on a multi-nozzle machine. Each nozzle can be checked and compared to the other nozzles to ensure they are all peening with the correct intensity. This greatly reduces setup and troubleshooting time.

The last significant way that media velocity measurement simplifies things is in process modeling. As mentioned above, without the ability to measure media velocity, process modeling is a very tedious project which includes large designs of experiments, hundreds of almen strips, and a lot of machine and personnel time.

The first step is to gather the velocity information for each nozzle size and type over the operating range of the machine. This has to be done for each media type that is desired to be modeled. Typically it requires under an hour to collect the data for each nozzle. Once the data is collected, then the information should be analyzed to reveal any unstable velocity regions in the operating range of the nozzle. This information can then be imported into a data analysis tool to analyze the information and to output an equation describing the collected information. The author uses Design-Expert by Stat-ease for this function. A typical equation looks like Eq. 1. A media velocity equation is specific to the machine, as there is a wide variety of configurations for equipment. Now that there is mathematical model for velocity, intensity needs to be combined into the equation.

$$v=c_1+c_2*p+c_3*f+c_4*p^2+c_5*f^2+c_6*p*f+c_7*p^3+c_8*f^3+c_9*p^2*f+c_{10}*p*f^2 \qquad (1)$$

where v is velocity, f is media flow, p is air pressure, and c_x are constants.

To determine the intensity to velocity correlation, saturation curves must be performed. Typically this is collected at the extremes of the velocity, and one or two mid points. Saturation curves should be performed with the media stream at approx 90 degree angle to the almen strip. This will show the maximum intensity that can be achieved. The author chooses to run these curves at approximately 80–85 degrees to minimize the effects of rebounding shot interfering with the media stream. This data is then plotted and a simple regression analysis can be performed to determine the equation. A typical equation would look like Eq. 2. The media intensity to velocity equation is specific to the size and hardness of the media, but can be applied to any equipment; therefore, it is only required to be developed once.

$$i_{90} = c_a*v^2 + c_b*v + c_c \qquad (2)$$

Where i_{90} is intensity at 90 degree impingement angle, and c_y are constants.

The velocity formula (Eq. 1) can be substituted into the velocity term in Eq. 2 for the predictive model for intensity. This model is valid for impingement angles close to 90 degrees. Since the velocity vector normal to the surface of the almen strip dictates the intensity. At 90 degrees the entire velocity vector is the vector normal to the surface. As the impingement angle changes, so does the normal component to the velocity vector. Equation 3 shows the relationship. To expand the model to cover a wider variety of impingement angles, Equation 2 must be substituted into Eq. 3.

$$i_\theta = i_{90}*\sin(\theta) \qquad (3)$$

where i_θ is intensity at impingement angle θ

This new equation yields a predictive equation of the shot peening process across the operating range of the equipment and a variety of impingement angles. The process models that have been developed have been tested down to a 35 degree impingement angle and have greatly reduced development time. Typically, intensities can be predicted within .015mm A. Table 1 lists actual results from process modeling. Predicted intensities are listed above actual (italicized-bold font) intensities.

Table 1: Predicted vs. Actual Intensity Values from Process Modeling

	45 Degree			60 Degree			90 degree		
	Air Pres (Bar)	Media Flow (kg/min)	Intensity (mm) Pred/ Actual	Air Pres (Bar)	Media Flow (kg/min)	Intensity (mm) Pred/ Actual	Air Pres (Bar)	Media Flow (kg/min)	Intensity (mm) Pred/ Actual
.15-.23N	1.02	9.1	0.188	0.75	9.1	0.188	0.68	9.1	0.206
			0.196			***0.185***			***0.211***
.25-.38N	1.50	2.7	0.320	0.95	2.7	0.320	0.68	2.7	0.320
			0.297			***0.315***			***0.315***
.10-.18A	2.31	2.7	0.140	1.43	2.7	0.140	1.02	2.7	0.140
			0.124			***0.137***			***0.142***
.15-.23A	6.12	1.4	0.183	3.06	2.7	0.188	2.11	2.7	0.191
			0.160			***0.183***			***0.193***

Conclusion

In conclusion, process characterization with regards to shot peening has been very difficult in the past. Although theoretical equations were developed to predict intensity, machinery specific velocity can reveal a greater level of detail including potentially unstable regions which should be avoided in shot peening process development. This information can be compiled to build an empirical model of specific equipment to reduce process development time. New technology which can measure the velocity of peening media greatly simplifies the process. This information can also aid in process optimization and assist in machine troubleshooting.