Characterization of the Size and Shape of Shot Media for Standards Development

Andrew Babiuk-Murray, Torie Lichti, Nikole McPheron, Michael Thoenen
Faculty Advisors: Paul Mort, Mark Gruninger, Siavash Ghanbari
Industrial Sponsors: Jack Champaigne, Tod Canty, Joe McGreal, Kumar Balan, Shota Watanabe, Larry Catanzarite, Paul Leplay, David Bouttes, Frederic Wiss, Anne-Laure Beaudonnet, Jeff Girman

PURDUE UNIVERSITY
School of Materials Engineering

Sieve analysis the current characterization method for shot media across the shot peening industry. Using sieves limits characterization to size and is unable to place specification limits on shape. The spread of sieve mesh sizes is large, limiting resolution of particle size measurements. There is interest in using image analysis as a supplement or replacement for sieve analysis which allows for accurate size and shape measurements of thousands of particles. The improved resolution of particle data should allow for improved consistency and less variation among shot media. In order to implement this change, the process must be adaptable and feasible across the industry for use with multiple media types.

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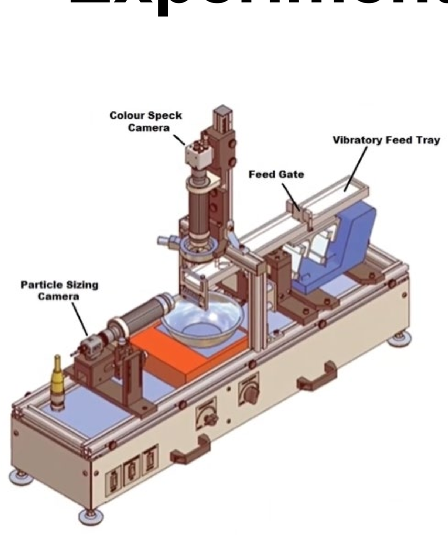
Project Background

- Shot peening is commonly used in the automotive and aerospace industries, and uses small, spherical shot material bombarded at the surface of a metallic part to impart compressive surface stresses to improve fatigue resistance, prevent stress corrosion cracking, and can improve the lifetime of the parts.
- Current standards for shot characterization involve the use of sieves, only providing information on the sample's size distribution.
- Image analysis is a method that can be used to characterize size and shape; using a camera and thousands of particle measurements. The large sample size allows for development of meaningful statistics to describe full distributions.
- To fully characterize media, minimum Feret diameter is chosen to quantify size, while a combination of Elliptical Form Factor, EFF = $\beta\pi A/P^2$, and Aspect Ratio, AR = X_{Fmin}/X_{LF} are chosen to quantify shape.

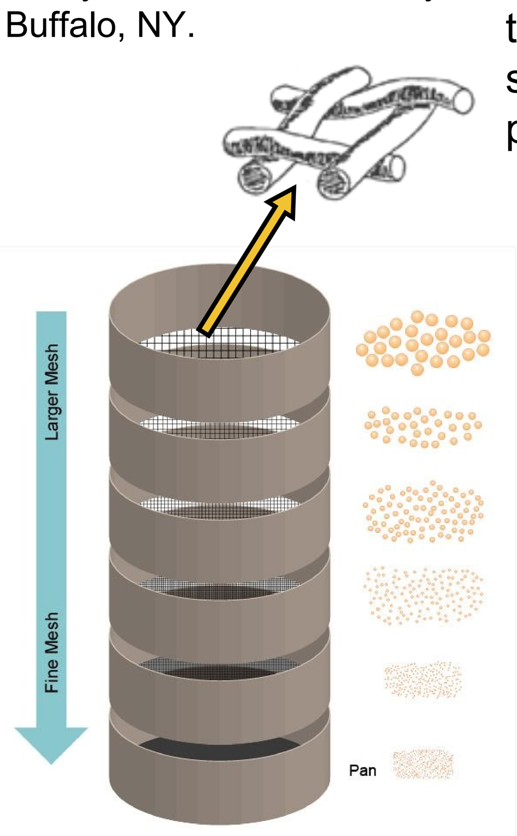
Experimental Procedure



Canty SolidSizer, JM Canty, Buffalo, NY.

Canty SolidSizer

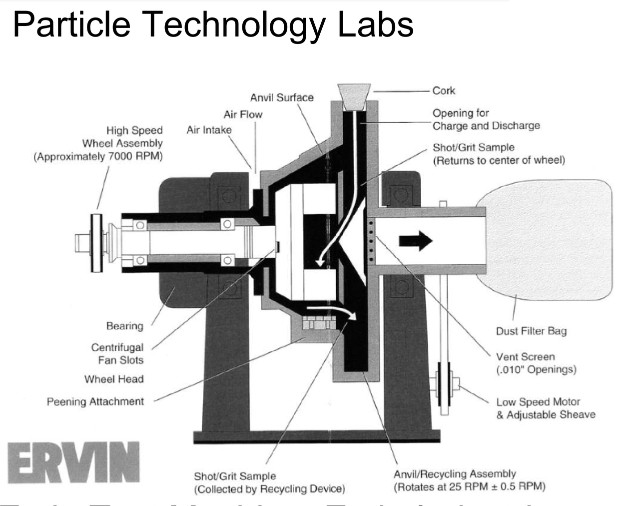
A Canty SolidSizer supplied by JM Canty is used for image analysis characterization of cast, cut-wire, and ceramic shot media. A sample size of 50 mL of shot is placed into a hopper above the vibratory feed tray. Vibrations cause media to fall over the edge in front of the particle sizing camera. The camera and software included with the SolidSizer calculate size and shape parameter values for each particle imaged.



Particle Technology Labs

Sieving

Sieve analysis is performed using sieves ranging from 2.0 mm at the top to 63 µm at the bottom. Approximately 500 grams of media is placed onto the top (coarsest) sieve and the stack is shaken for three minutes until all the media has settled. The remaining mass of media on each sieve is measured.



Ervin Test Machine, Ervin Industries, Ann Arbor, MI.

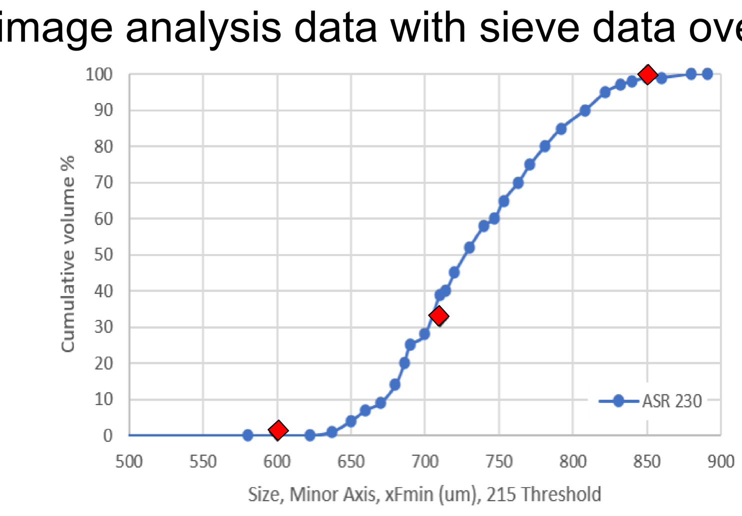
Ervin Test Machine

An in-use proxy test is performed using an Ervin Tester supplied by Ervin Industries to characterize breakdown of media during a peening cycle. To test, 100g of fresh shot is added to the test drum and the Tester is run for 500 cycles at 7100 RPM. After each round, the sample is sieved using a 40-mesh control sieve. The amount retained is weighed and fresh shot is added to maintain a mass of 100g. This procedure is followed until total mass loss equals 50% of initial mass. Samples are characterized between rounds using the SolidSizer.

Results

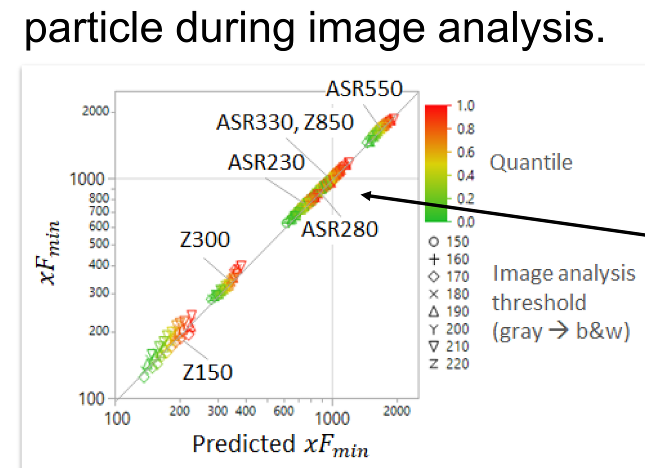
Size Parameter

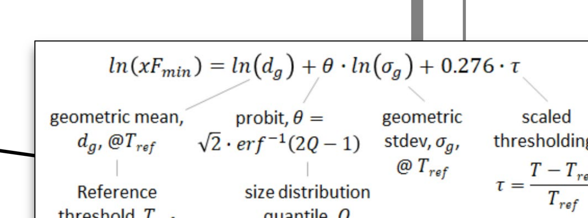
Minimum Feret diameter (xFmin) is the shortest distance between two parallel tangents of a 2D projection. Sieving is compared to minimum Feret. Graphs below show the image analysis data with sieve data overlain (red dots).



Graph showing the image analysis data of xFmin with sieve data (dots) overlain for cast shot (ASR 230).

A composite model was created to predict the xFmin at various thresholds. Based on the graph below it is seen that the model provides a good correlation. Using the model, the ideal threshold can be found for each material type. Information from the sieve analysis and the image analysis are used to calculate the threshold. The threshold affects what is included as a part of the particle during image analysis.

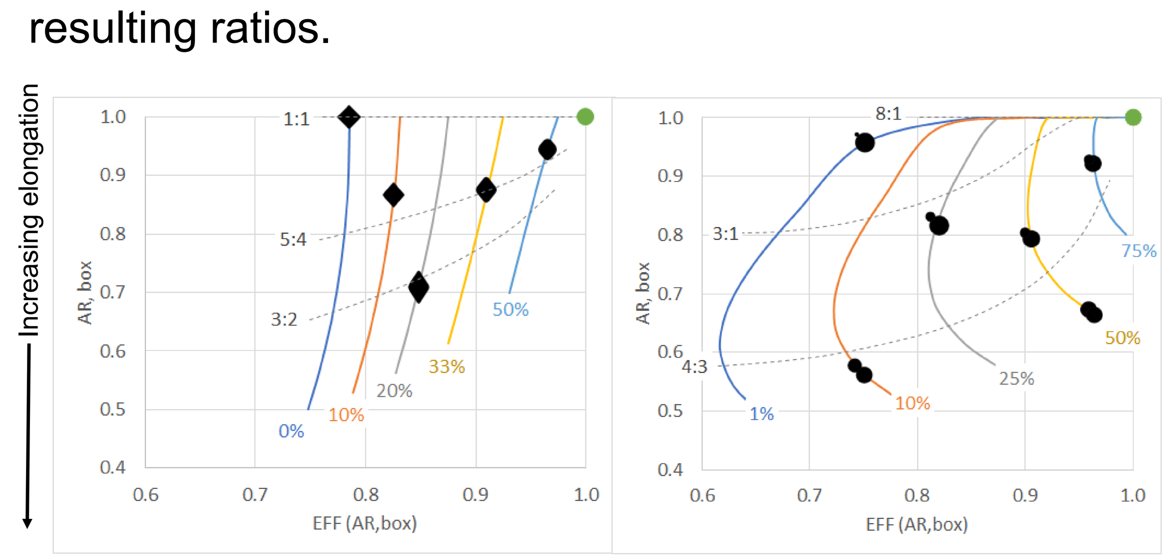




Graph showing the predicted xFmin versus the measured xFmin. Note the grouping along the 45-degree line indicates a good fit model.

Shape Parameter

Aspect Ratio (AR) and Elliptical Form Factor (EFF) are parameters that account for both the angularity and elongation of a particle. For cut-wire shot it can be seen that as conditioning increases both parameters approach a value of 1. For cast shot, some particles contain "satellites" or agglomerates attached to the particle due to the processing techniques. Plots show the basic archetypal shapes, potential satellite size and resulting ratios.



Graph depicting the AR and EFF for as cut cut-wire shot. Note that plot contours are for archetypal shapes.

Graph depicting the AR and EFF for cast shot. Note the tiny extra particles called "satellites".

Breakage

Hardened steel shot, regular steel shot and as cut cut-wire shot are tested in the Ervin Tester. The critical impact number, I*, for each sample was different. Hardened steel shot had the lowest I* value, indicating fast breakdown due to its hardened state. As-cut CW shot had the largest I* value indicating slow breakdown and higher durability.

Sample	I* (50% replacement)
ASH 230	1000
ASR 230	2000
AWCR28-AC	3000

Table displaying the different critical impact numbers, I*, for each sample tested. The critical impact number represents the number of impacts to replace 50% of the original mass.

Discussion

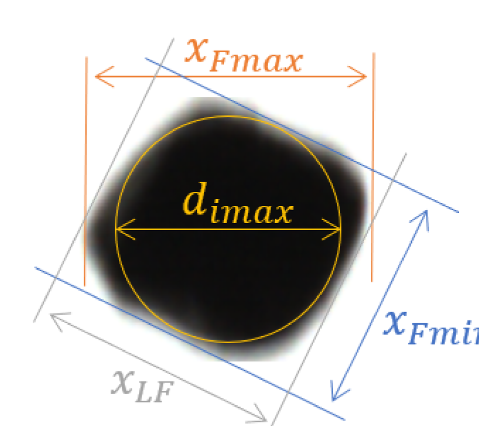
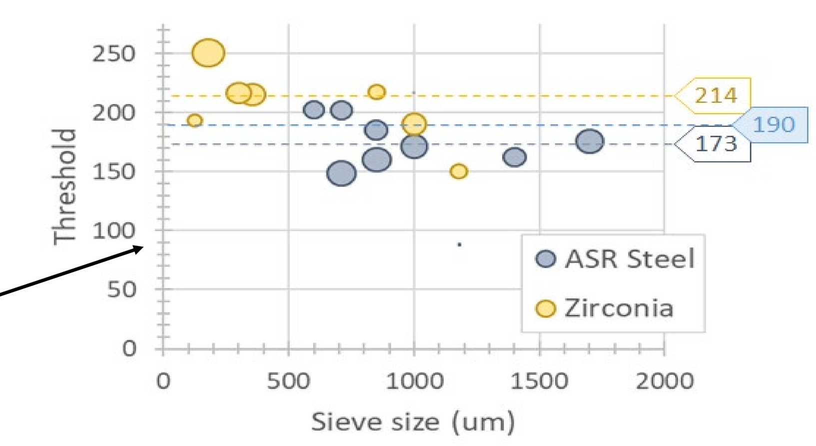


Image of particle taken using image analysis showing various measurement methods.

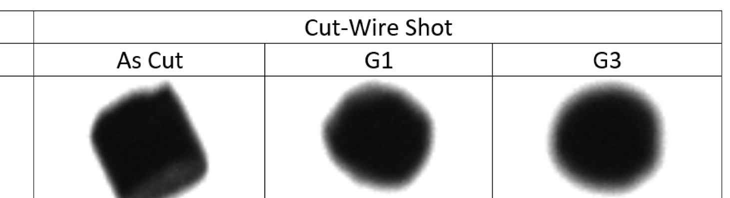
Size Parameter

Minimum Feret diameter provides reasonable correlation to sieving. It is also well defined in current ISO specifications and when compared to other possibilities, i.e. max inscribed diameter (Dimax), it requires less computational overhead. Video analysis is utilized to compare various thresholds on identical particles. The composite model predicts the xFmin at various thresholds using a probit function, allowing for linear regression. The equation for the model can be rearranged to solve for the threshold, thus allowing for the "ideal threshold" to be found for each material type: 214 for zirconia, 173 for steel. Based on this information a reference threshold of 190 is suggested. This is due to 190 being a good middle ground between the two without having to account for optical/material properties.



Graph depicting the ideal thresholds for shot and zirconia shot material. Note the 190 is a reference threshold found in between the two.

Shape Parameter

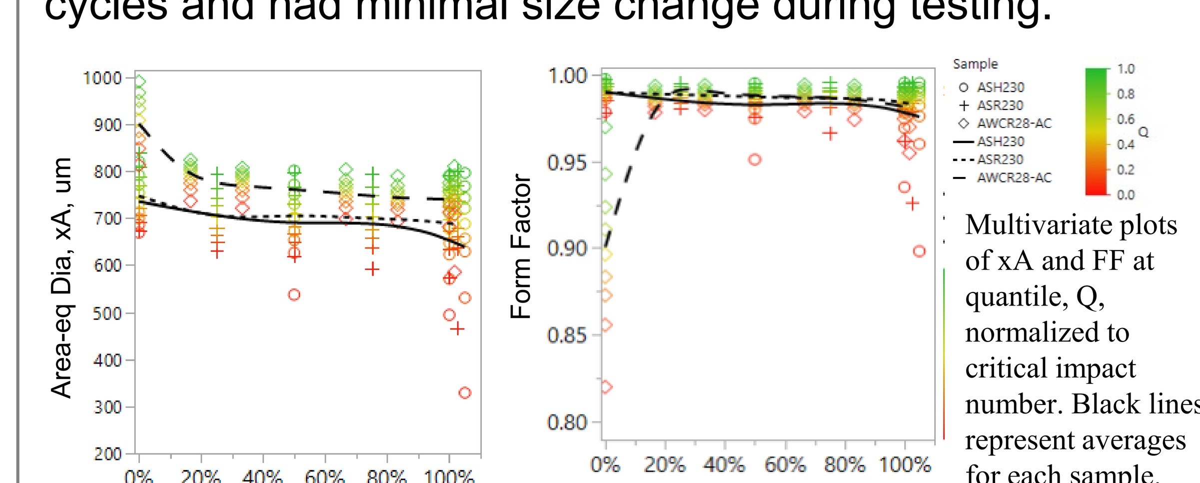
Condition:	Cut-Wire Shot: As Cut	Cut-Wire Shot: G1	Cut-Wire Shot: G3
Image:			
AR:	0.75	0.93	0.95
EFF:	0.92	0.98	0.99

Condition:	Cast Shot: ASR		
Image:			
AR:	0.68	0.79	0.97
EFF:	0.84	0.96	0.99

Images of various particles exemplifying values for the shape parameters.

Breakage

Hardened and regular steel shot had similar trends for size (xA) and shape (FF). The hardened media exhibits more breakdown of the low quantile tails seen with the spread of red circles on both plots. The as-cut cut wire shot experienced significant rounding in the first 500 cycles and had minimal size change during testing.



Multivariate plots of xA and FF at quantile, Q, normalized to critical impact number. Black lines represent averages for each sample.

Recommendations

Minimum Feret is the best size parameter for correlation with sieving. Two factors are needed to adequately describe the shape of particles. A reference threshold of 190 is recommended for image analysis. It could be of interest to further investigate the breakage using shot from an actual peening operation as well as investigate the effectiveness of industry used tools like the spiralator that are not in current specifications.