Image Analysis, Characterization, and Methods Development for Shot Peening

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Shot peening is the process of strengthening a material by inducing a compressive stress across the surface. The size and shape of the shot is expected to be uniform; however, there is typically some variance from this ideal. The purpose of this project is to better characterize shot size and shape distributions and perform breakage studies on the change in shape and size distribution. Image analysis provides detailed distributions for size and shape of pristine shot and shot exposed to peening impact. In this poster, the team proposes log-normal and Weibull functions to fit size distributions and roundness as a proposed specification for shape distributions. As well as recommendations for distribution models, the team proposes a breakage prediction model for peened shot using kinetic energy and number of impacts. The intended usage for the project is to affirm colloquial industry knowledge and provide new analysis on the shot peening life cycle.

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CANTY PROCESS TECHNOLOGY

Project Background

Background: Shot peening strengthens a material's surface by inducing a compressive stress. To create a predictable uniform stress, the size and shape of the shot is expected to be uniform; however, there is typically some variance from this ideal. Currently the ASTM and SAE specifications, dating from 1942, require manufacturers to classify the shot size using mesh sieves. This project considers the use of modern image analysis for updated size *and shape* specification. Image analysis provides in-depth analyses of size and shape characteristics and further elucidates the change in these characteristics as a function of peening process variables.

Purpose: This project's goals can be broken down into two sections 1) characterize standard AMASTEEL S-shot peening media based on size and roundness using image analysis and 2) analyze breakage data to create a simple model for predicting likelihood of breakage. The project aims recommend quantifiable specifications for size and shape and provide replicable models for prediction breakage under peening process conditions. This project hopes to affirm colloquial industry knowledge and provide new analysis on the hidden life of a shot.

Samples

Table 1. Table listing size and roundness of S230, S230 H and S550 shot. SAE specification for size has been added for comparison. Currently, there is no SAE specification for roundness; figures in parentheses () are suggested.

Sample		Size (microns)					Roundness (-)		
		D95	D90	D85	D15	D3	R50	R15	R10
S230	D_{eq}	842	814	799	680	635			
	D_{min}	829	805	790	661	614	0.984	0.960	0.926
	SAE spec		<850		>600	>500	(>0.98)	(>0.94)	
S230H	D_{eq}	890	850	831	619	577			
	D_{min}	853	836	809	599	570	0.984	0.966	0.947
	SAE spec		<850		>600	>500	(>0.98)	(>0.94)	
S550	D_{eq}	1889	1824	1799	1597	1538			
	D_{min}	1831	1780	1765	1558	1474	0.989	0.949	0.917
	SAE spec				>1400	>1180	(>0.98)	(>0.94)	

Experimental Procedure

Shot Characterization

Characterization was performed using image analysis tools. The data uses 2D projections of back-lit shot particles falling from a vibratory feeder. A Standard Operating Procedure was created for characterizing shot using the JM Canty SolidSizer. The raw data for induvial particles include the area (A) and perimeter (P). Area and Perimeter were used to calculate Roundness ($R = 4\pi A/P^2$) and Equivalent Circular Diameter ($D_{eq} = 2\sqrt{A/\pi}$).

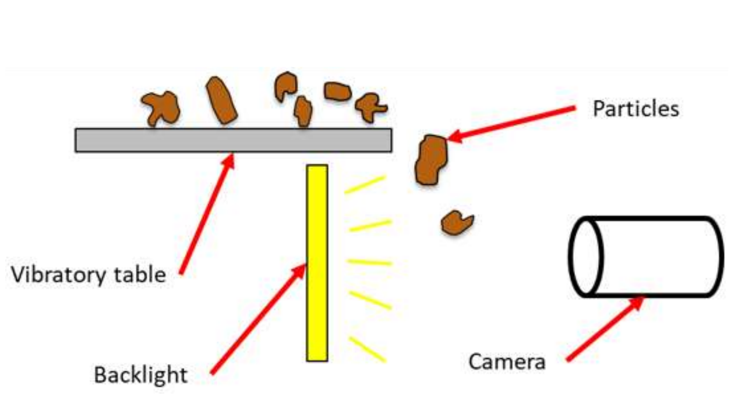

Figure 1: SolidSizer schematic. A curtain of particles falls from a vibratory chute. Back-lit 2D projections are captured by a high-speed camera over a sequence of images. Typical data sets have in excess of 10,000 particle images.

Breakage Characterization

Three shot types i) S550 ii) S230 and iii) S230 Hard were exposed in increments up to 1500 cycles at either 7000 rpm or 8000 rpm using an Ervin tester. The shot was characterized using the shot characterization Standard Operating Procedure. With the data, a model for survival threshold was created by least-squares fitting to a hypothetical equation:
Predicted Survival = $\mathrm{bias} - \ln(KE^k * N^n)$.*

*Bias is the intercept. KE is the kinetic energy of the shot, k is a scaling factor of the importance of the KE. N is the number of impacts and n is the scaling factor of the importance of N.

Results and Discussion

Characterization of size and shape

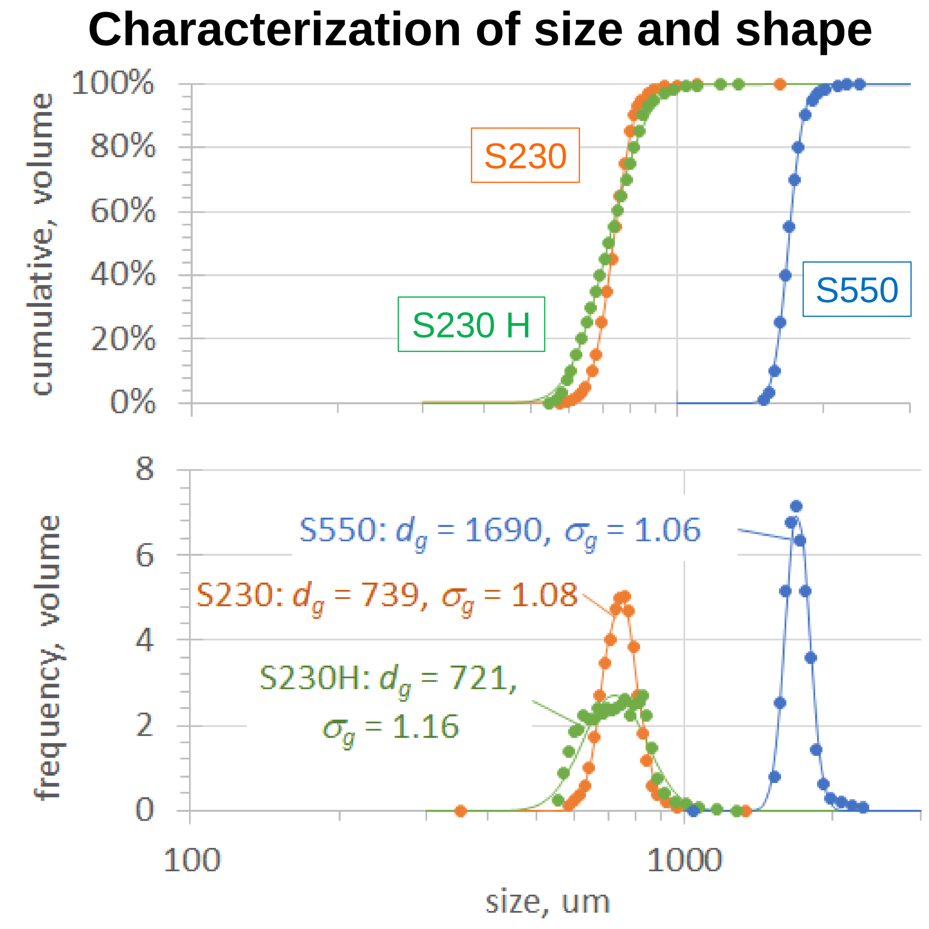

Figure 2. Frequency and cumulative size distributions based on shot volume, AMASTEEL S230, S230 H and S550 (obtained from Ervin Industries, Adrian MI). The plots show the geometric distribution of shot size. S230H has the widest size distribution while S550 has the narrowest.

Per the graphs above and sample table to the left, log-normal (Gaussian) and Weibull (stretched-exponential) functions are used to describe size and shape features respectively. Compared to sieving, image analysis provides more detail on the distribution of size and enables quantified analysis of shape.

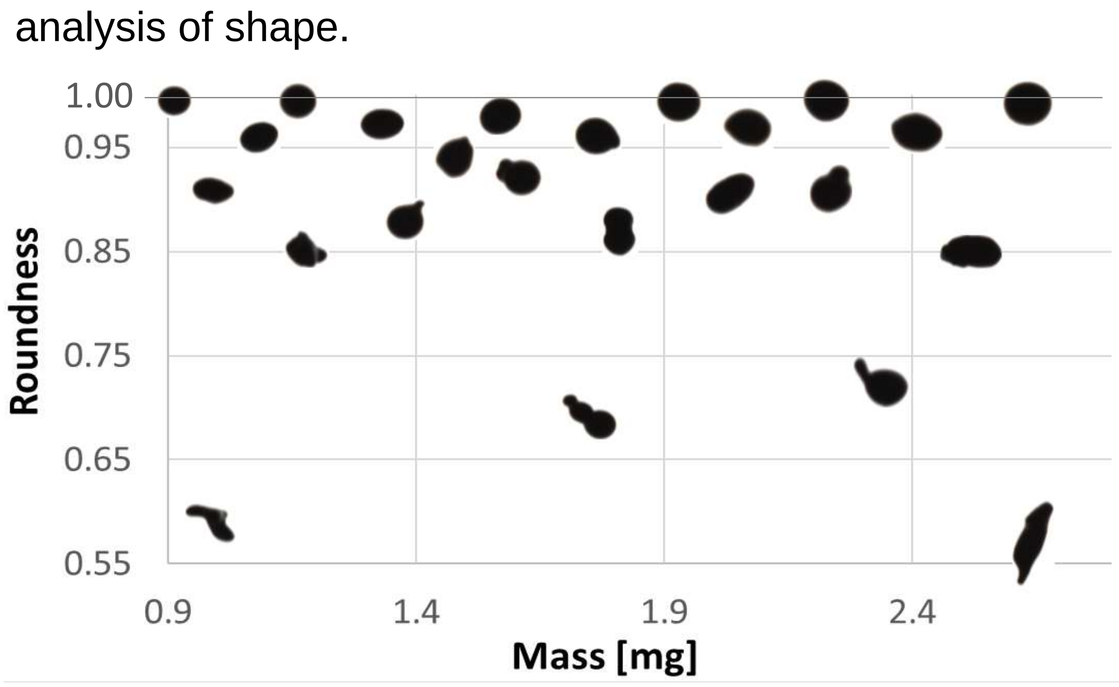

Figure 3. Shape and mass relationship of S230 shot. Images of individual S230 shot particles taken using the JM Canty SolidSizer. Particle mass, $M = \rho(\pi/6)D_{eq}^3$, where the density of steel, ρ = 7.8 g/cm³.

Most shot (~85% by volume) are effectively spherical, with a roundness between 0.95 and 1.0. The lower roundness particles have a variety of irregular shapes. There are shot agglomerates (snowmen) and shot that solidified too fast, retaining their ligament features from the atomization process. Ligaments and "snowmen" shaped particles were able to make it through the sieving process due to their oblong shape. With image analysis, the team can recommend a quantitative method for characterizing shot shape.

Characterization of shape

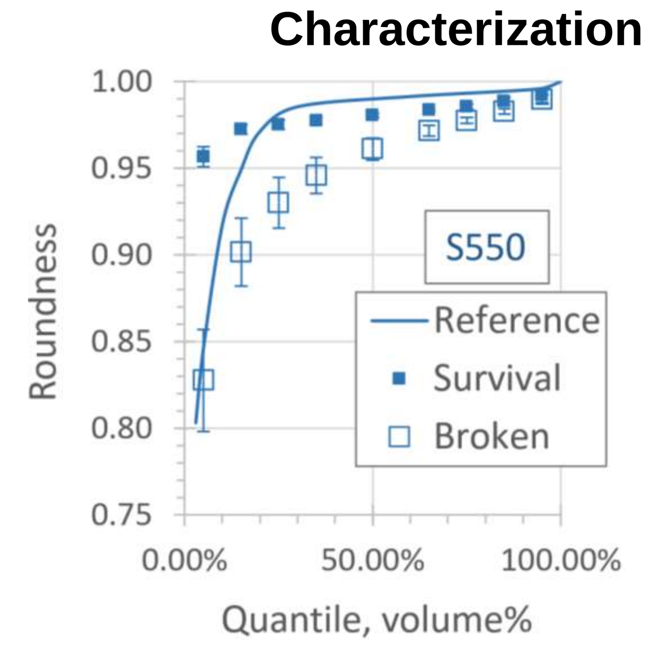

Figure 4: Plot characterizing shot after 1500 cycles in the Ervin Tester. The reference line represents the shape of the as-received shot from Ervin. The solid points represent the shot that remained unbroken and lies to the right of the threshold line on Figure 4. The open points represent the broken shot to the left of the threshold line.

After cumulative impact cycles, the plastic deformation of surviving shot results in marginal reduction of their roundness, while surviving irregular shaped particles may become more round – i.e., "snowmen" break up into their constituent spheres. On the other hand, the debris of broken shot is significantly more irregular (lower roundness) compared to the survivor population.

Results and Discussion

Survival and Breakage after Peening Impact

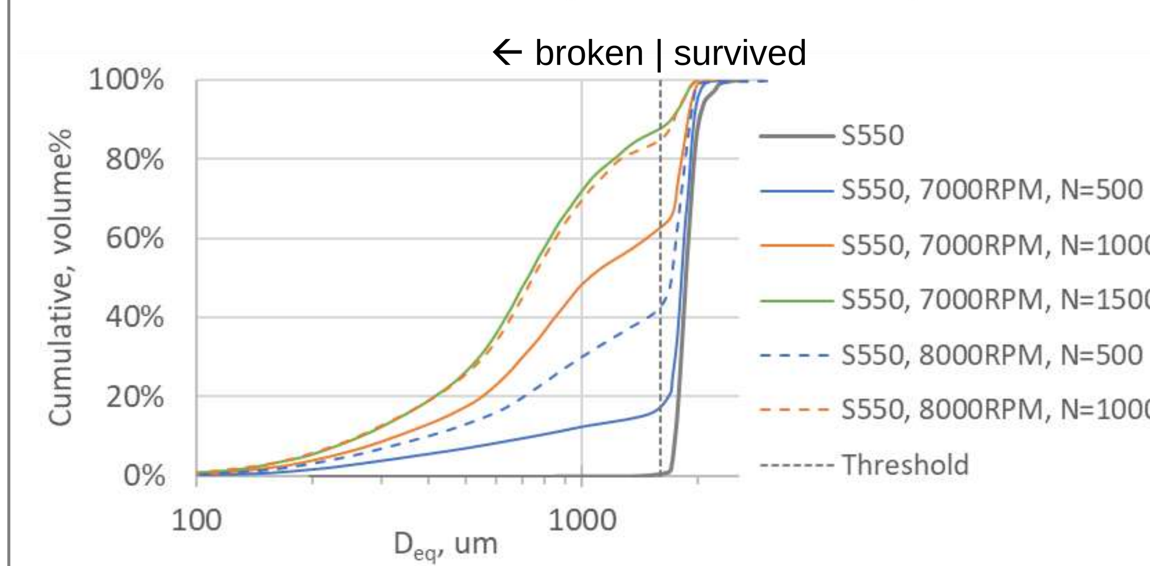

Figure 5: Summary of all trials for S550 breakage study.

The figure above shows a series of 5 trials that were conducted on S550 shot. The vertical dashed line represents the threshold between broken shot (left) and shot that did not break during cycling (right). The survival portion retains its "S-shaped" distribution curve, similar to the as-received S550 shot (graph immediately left). The broken shot has a much broader distribution. With image analysis, we can characterize shot size after breakage into detailed distributions. To the team's knowledge, there is little written information on how shot size distributions change after peening. Our teams work is elucidating the stages of deformation and breakage of shot that is are relevant to useful peening lifespan, i.e., *what happens to shot from its creation until end of its usability*.

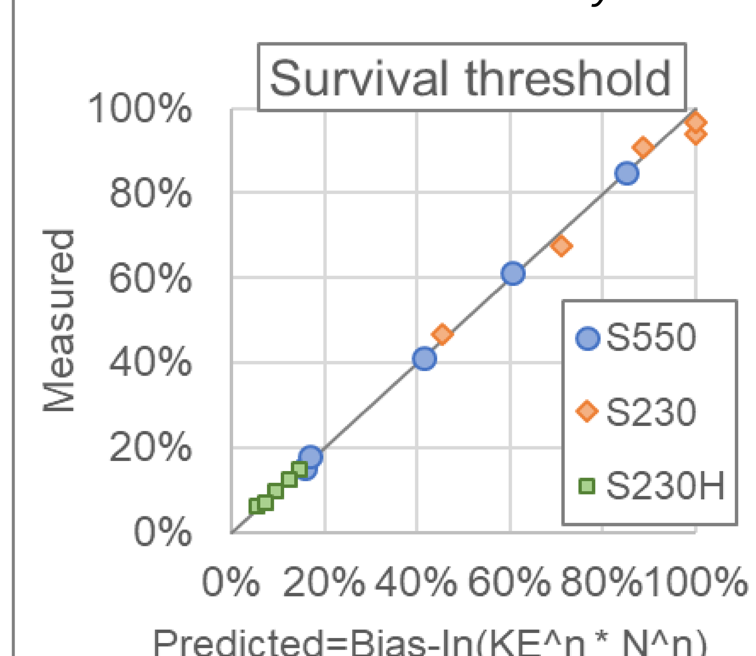

Figure 6. Using the trial size distribution data, a survival threshold was created for S230, S230 H and S550 shot. A model was created to predict percentage of survival. A linear fit model was used to analyze the accuracy of the prediction model.

The plot above shows different survivability depending on the shot type and process conditions. All samples show increased breakage with higher impact speed (higher KE) and number of impacts. Annealing of shot is critical to its survivability. Of the three samples tested, standard S230 had the highest survival probability, and S230H (annealed for higher hardness) had the lowest.

Recommendations

Methodology, JM Canty Image Analysis:
- Analysis software to enable front-lit color analysis for tracer studies of shot-peening interactions;
- Explore in-line analysis for process monitoring and control of high-value-added peening operations.

SAE Specification (work w/ SAE committee):
- Deploy Standard Operating Procedure for Image Analysis.
- Need agreement of updated size specifications.
- Discussion and alignment on shape specifications.

Research:
- Further develop the breakage model using statistical measures (building on this study) combined with microstructural approach (e.g., toughness, crack growth).

Acknowledgements

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