Linking Peening Media & Process Impacts

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PURDUE UNIVERSITY

School of Materials Engineering

International Conference on Shot Peening

ICSP15

SEPTEMBER 22-25, 2025

Purdue School of Materials Engineering

CSEE

Center for Surface Engineering and Enhancement

Agenda

1. Peening media size & shape characterization

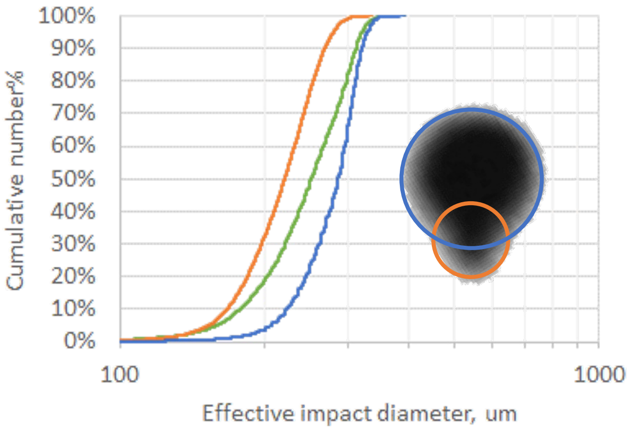
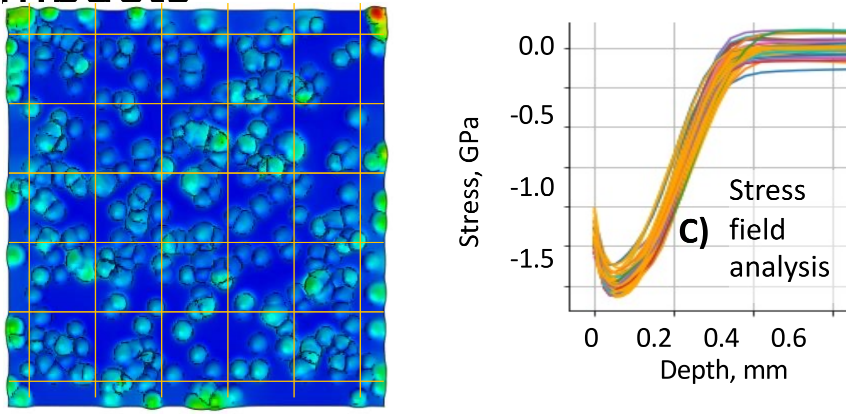


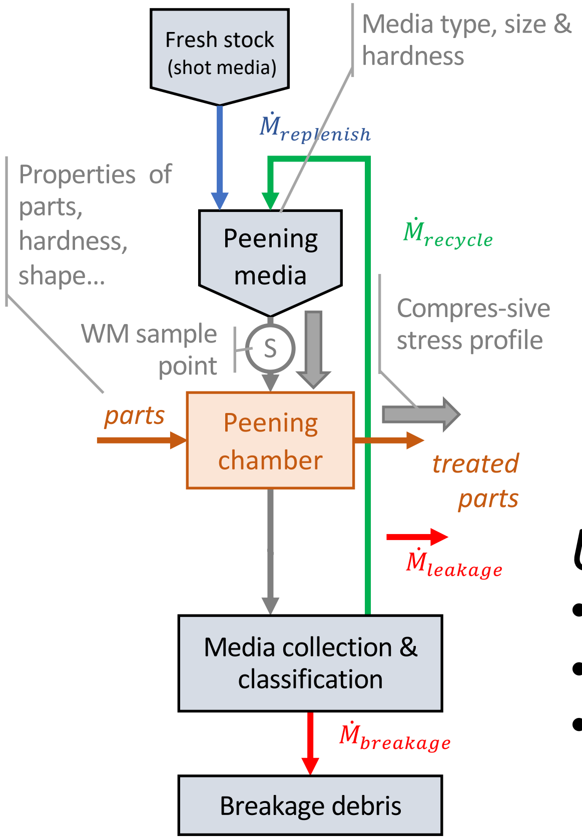
Image Analysis

2. Simulate Peening Process Impacts

ABAQUS based FEM Impingement Model



3. Simulate Conventional Peening Operations



Using:

- *Size/Shape Data*
- *“Real” Conditions*
- *Actual Parts*

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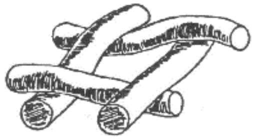
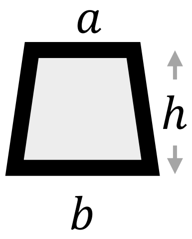
Shot Size & Shape Characterization - Legacy

Size analysis: mass fraction through sieve openings (e.g., SAE J444).


wstyler.com





Particle Diameter (D)

$$D = \sqrt{(a+b)\cdot h/2}$$

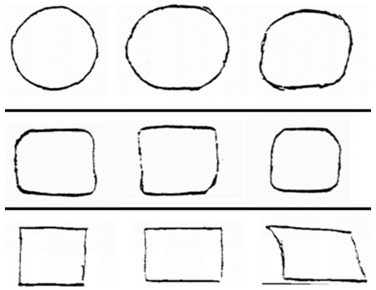
- Long History
- Metals & Ceramics
- Particle Shape

- **Shape inspection**; qualitative comparison (e.g., AMS 2431).

Acceptable

Marginal

Unacceptable



How to deal with particle
- ***Elongation***
- ***Irregularity***
- ***Sample size***

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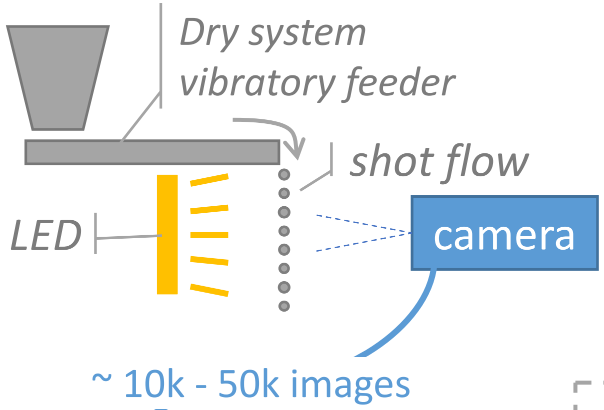
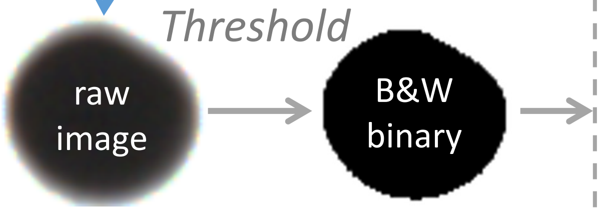
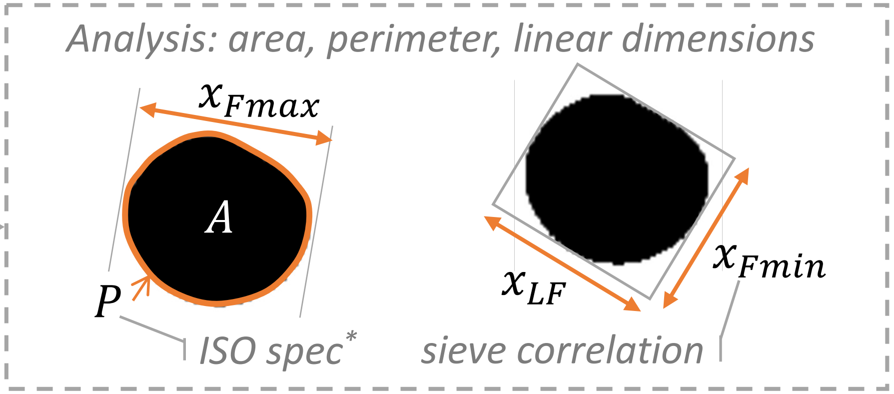
Shot Size & Shape Characterization – Image Analysis

Dynamic image analysis of Shot Particles:

- 2D projections of shot particles, randomly oriented.†







Quantitative analysis for BOTH size and shape

- ❑ Shot size and mass *(peening work):*

$$x_A = Equivalent\ Particle\ Diameter$$

$$x_A = \sqrt{4A/\pi}; \qquad M = \rho \frac{\pi}{6} {x_A}^3$$

A = particle area
M = particle mass
$\rho = particle\ density$

- ❑ Shot Shape (impact stress):

$$Particle\ \mathrm{Form\ Factor}\ (FF) = 4\pi A/P^2$$

†Dry system: Canty SolidSizer (JM Canty, Buffalo, NY): 5-15 um/pixel.
*ISO 9276-6 (2008), Cauchy-Crofton perimeter.

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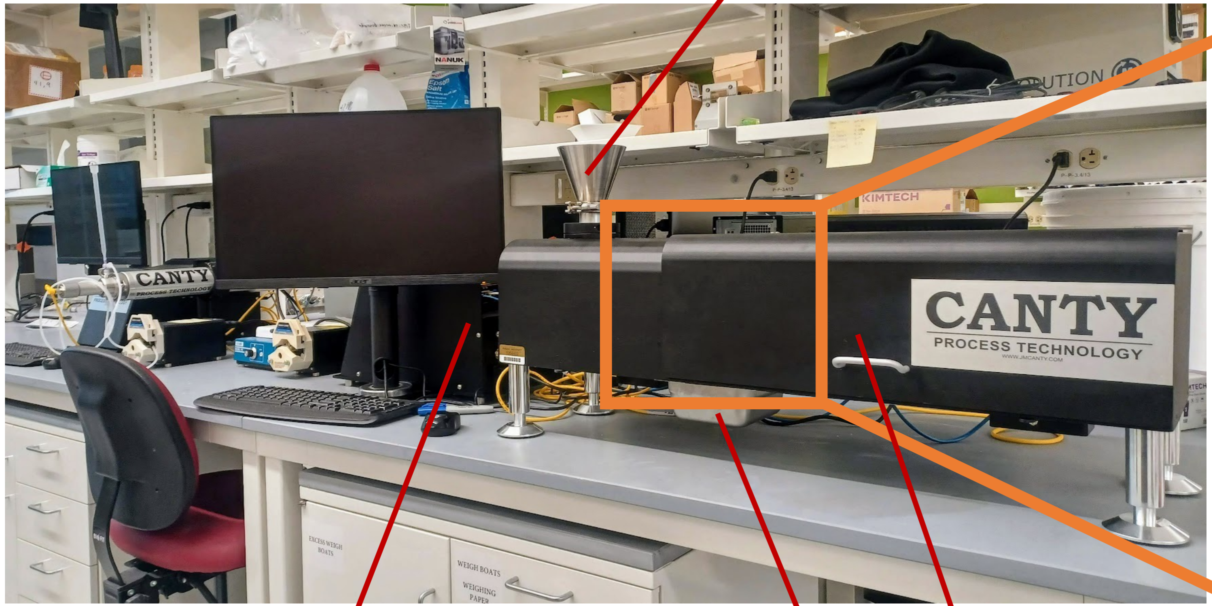
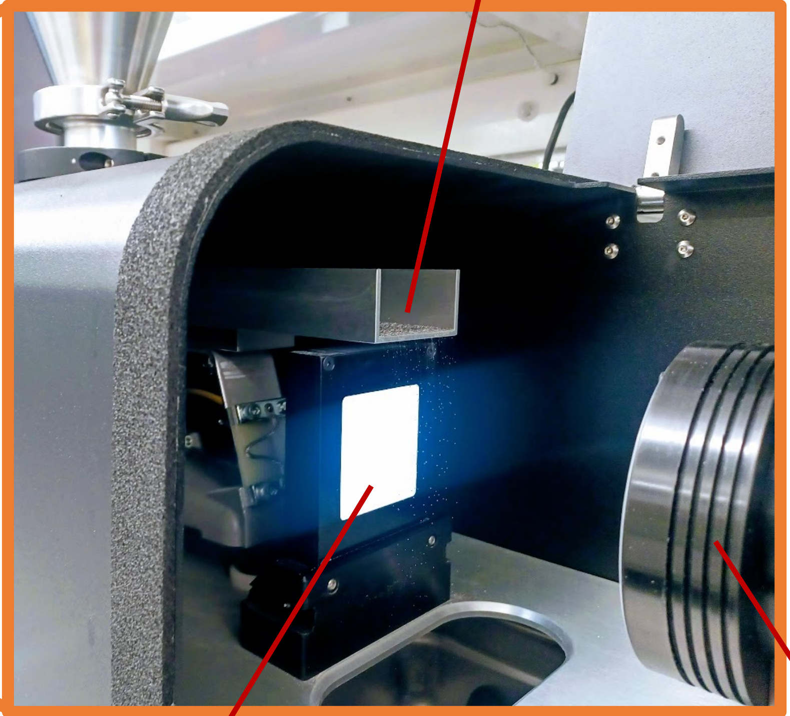
Shot Characterization by Image Analysis at Purdue

Add sample

Vibratory feeder w/ feedback control





Controllers, data acquisition and analysis

Collect sample

Imaging equipment

Backlight, optional w/ strobe

Camera w/ zoom lens, optional front light w/ strobe

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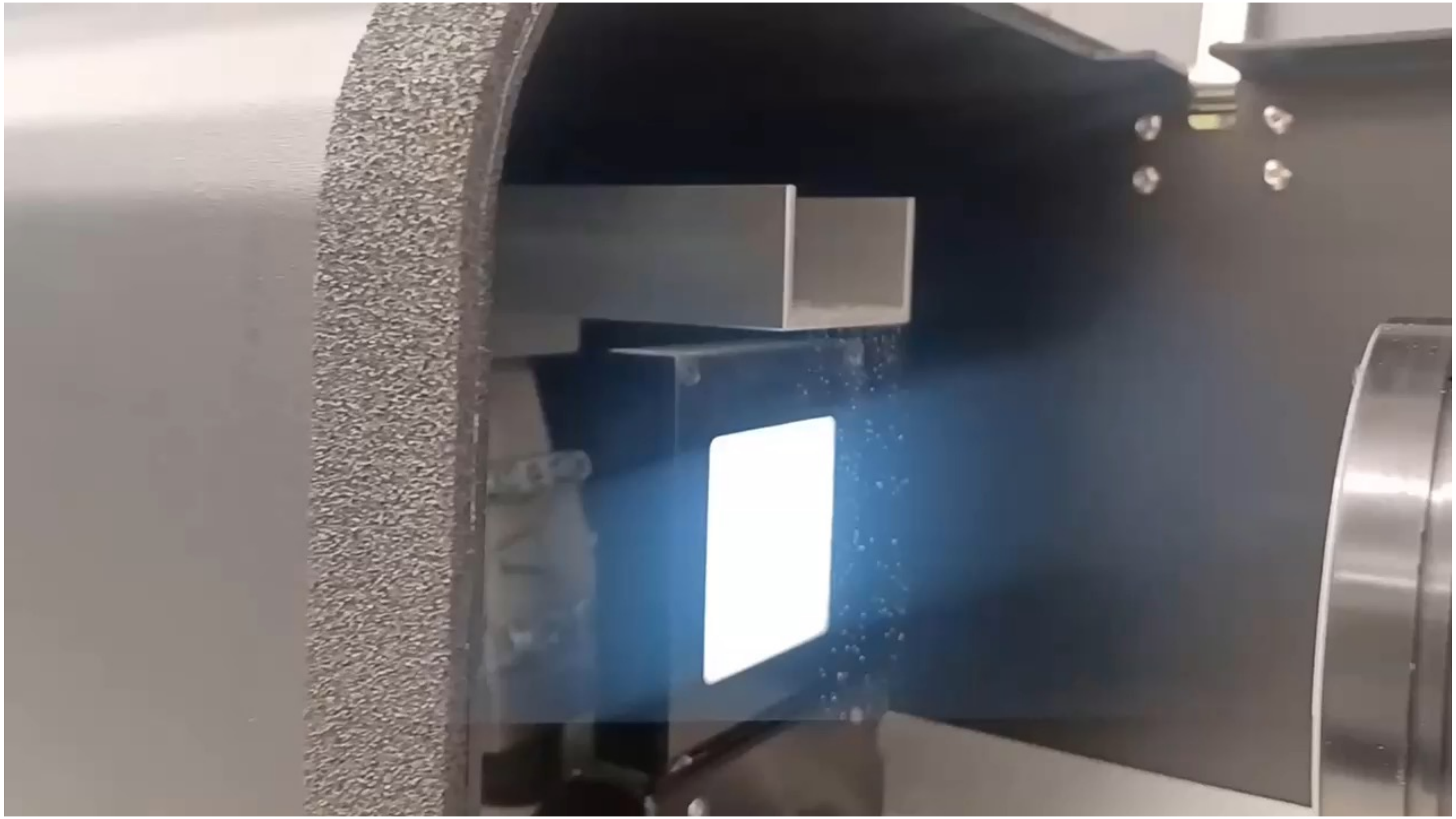
Testing of Shot* via Image Analysis



Note: **S170 Shot**

(Ervin Industries)

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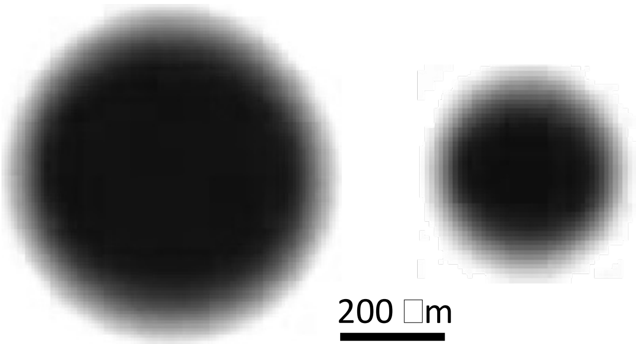
Converting “raw/grayscale” images to “optimized” images

Steel S170 Zirconia Z300

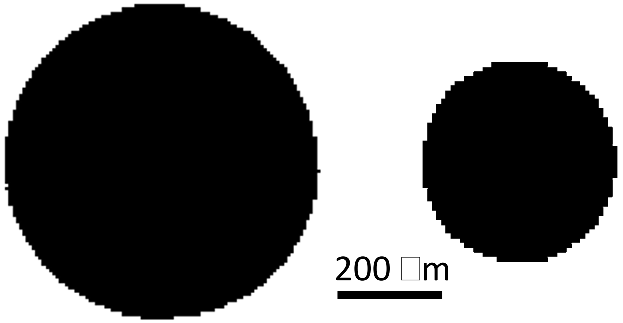
Grayscale



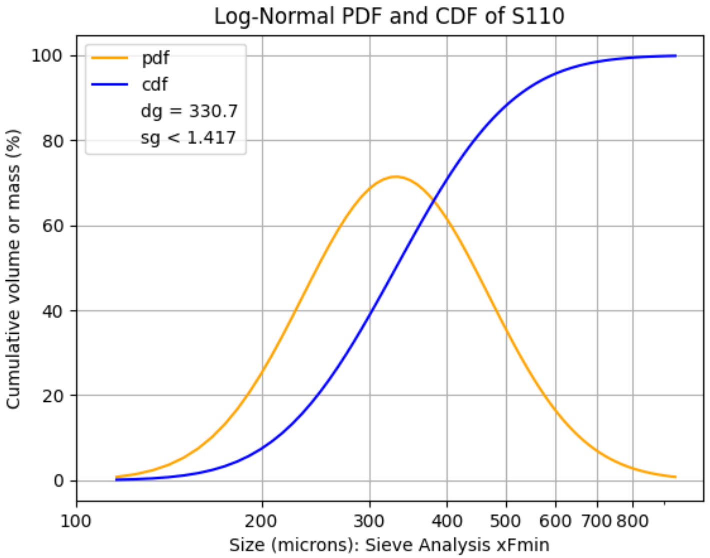
Material	Refractive index	Extinction coefficient
Steel	2.93	3.0
Zirconia	2.16	0

Steel S170 Zirconia Z300

Optimized



	≈ Diameter [mm]	Zoom	Scale [µm/pix]	Focus	Aperture	Exposure Time [µs]
Cast S110	0.400	1.28	7.15	315	15	50
CW 14	0.450	1.28	7.15	315	15	50
Cast S230	0.725	0.97	10.3	530	10	120
CW 20	0.638	0.97	10.3	530	10	120
Cast S330	1.015	0.97	10.3	530	10	120
CW 32	0.945	0.97	10.3	530	10	120



“Optimized Photos” need: 1) shot properties; 2) Tailored Analyzer Settings & 3) “Conversion Math”

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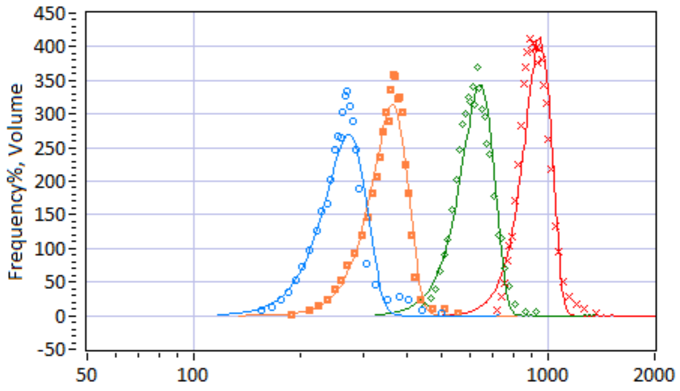
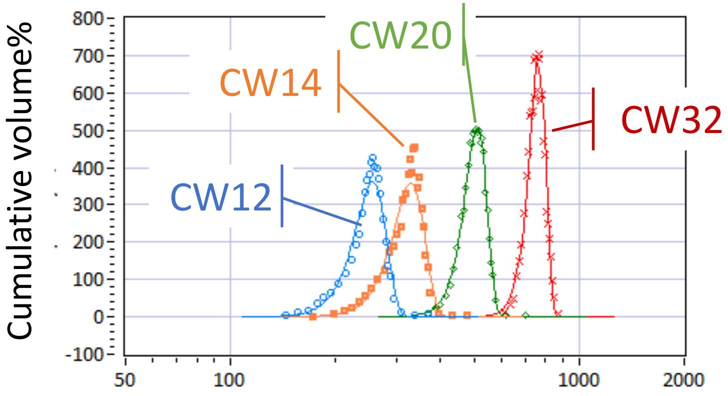
Shot Size Distributions: Image Analysis & Sieve

Cast Shot (Ervin Industries)



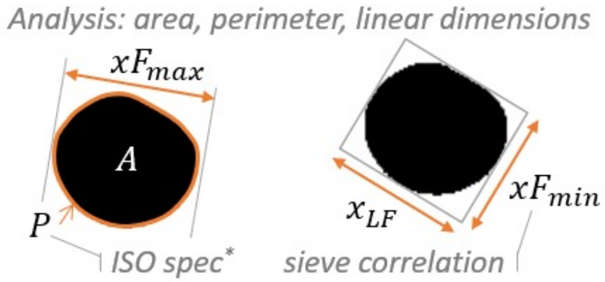
Cut Wire Shot (Toyo Seiko)

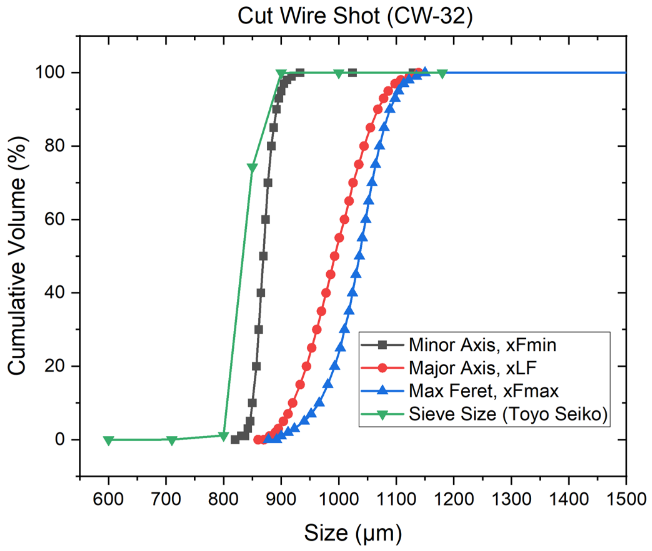


S070: d* = 275 um S110: d* = 365 um
S230: d* = 645 um S330: d* = 951 um

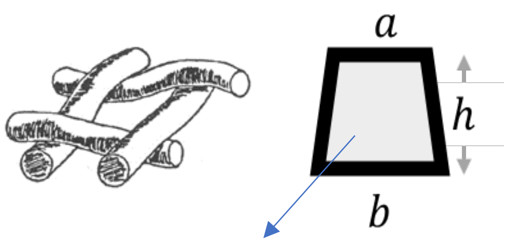
CW12: d* = 256 um CW14: d* = 330 um
CW20: d* = 511 um CW32: d* = 766 um

Image Analysis Data





Sieve Data



$$D = \sqrt{(a+b)\cdot h/2}$$

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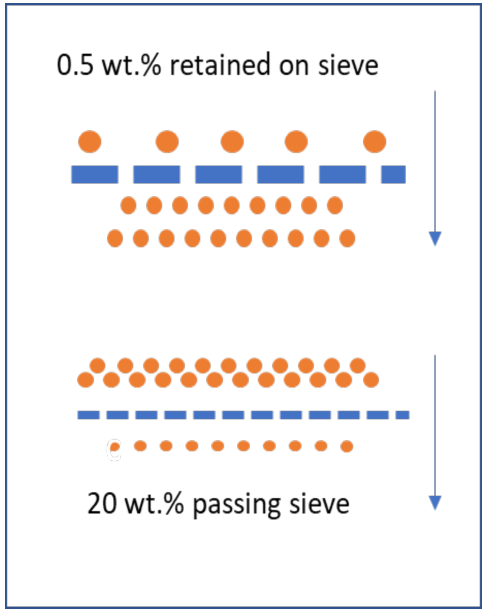
Image Analysis in Shot Size Specifications



J2441 Specifications	CW-14	S110
0.5% (by weight) retained on US Sieve Size mm (in)	0.600 (0.0234)	0.600 (0.0234)
20% (by weight) passing US Sieve Size mm (in)	0.300 (0.0177)	0.300 (0.0177)

J444 Specification

S110

A 90% minimum of S110 retained on 0.180 mm (0.0070 in)

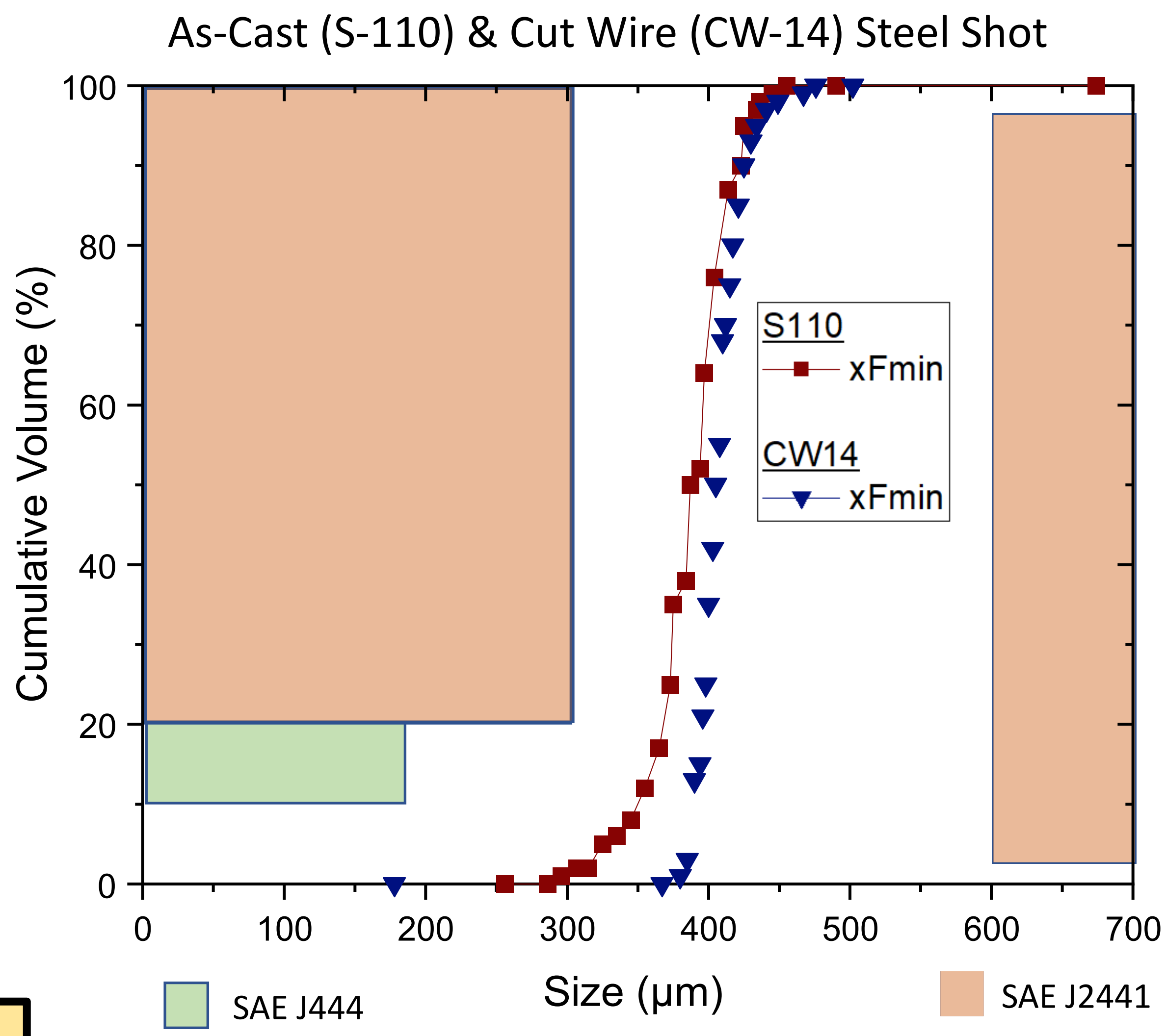


Image Analysis Data Readily Aligns with Existing "Sieve Specifications"

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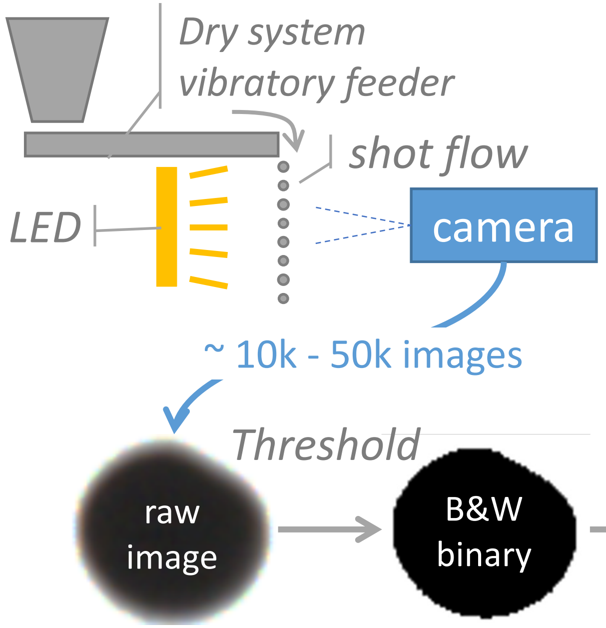
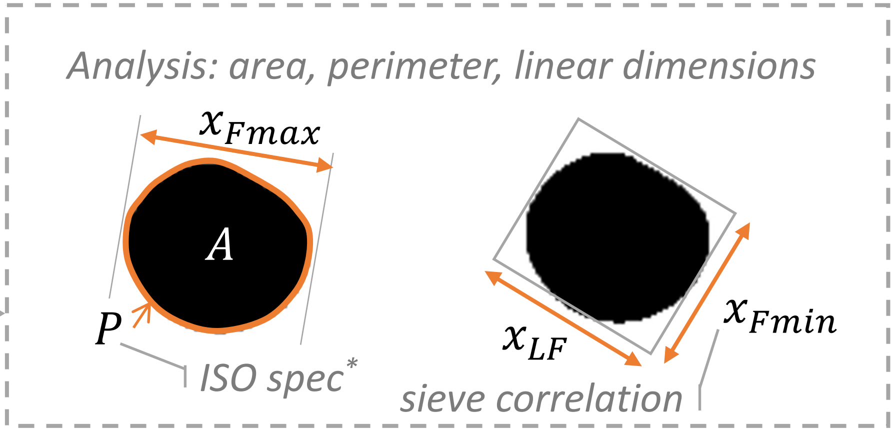
Image Analysis for Characterizing Shape

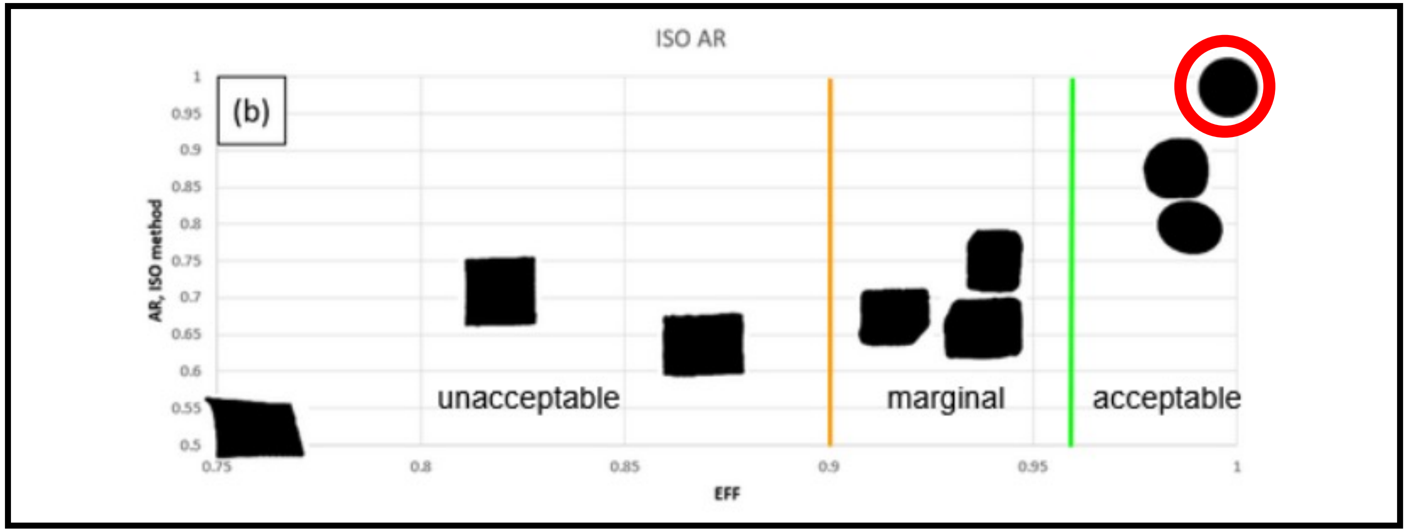


ISO defined "*Form Factor*" compares the measured perimeter to an area-equivalent circle to determine shape *elongation* & *irregularity*



Shape:

- *Form Factor*, $FF = 4\pi A/P^2$
- *Elongation*:
  - AR = Aspect Ratio
  - $AR_{ISO} = xF_{min}/xF_{max}$
- *Irregularity*: $EFF = \beta\pi A/P^2$;
- $\beta = \left(1.5 \cdot (AR+1)/\sqrt{AR} - 1\right)^2$



Apply ISO "Shape Factors" to "shot schematics" to "quantify" shot shapes

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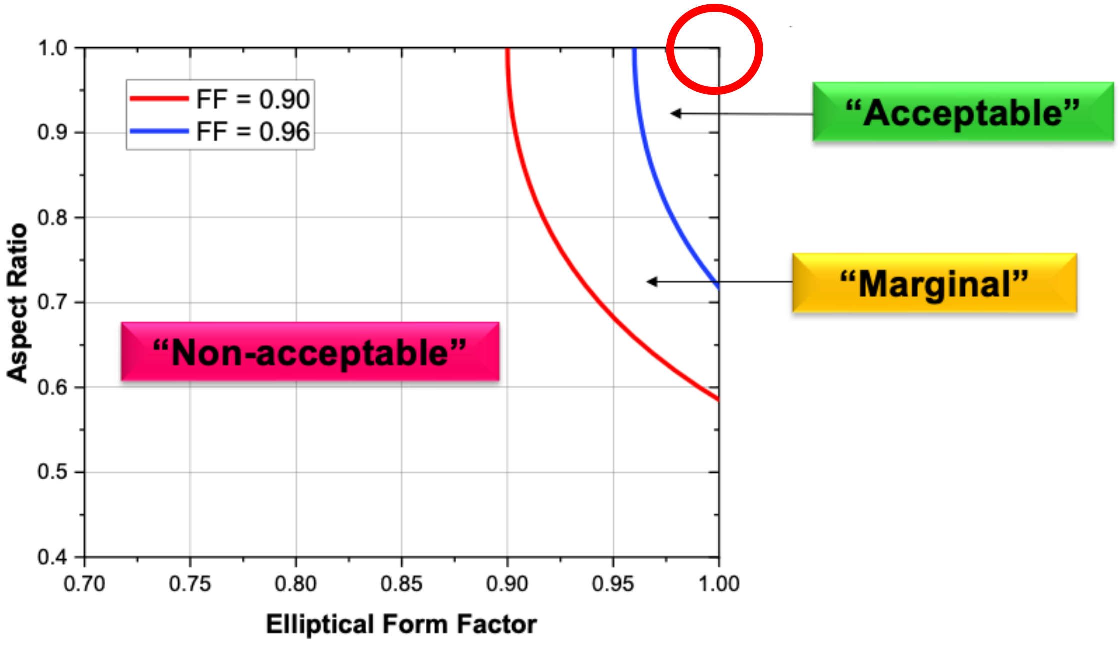
Using quantitatively characterized shot

"Map" Potential Shape Specifications



Shape factor mapping :
- (1,1) is a spherical projection (circle)
- Aspect ratio, AR, → elongation;
- Elliptical Form Factor, EFF, → perimeter irregularity;
- ISO Form Factor, FF, is a lumped-sum measure of both.

Populate shot images on map for modeling

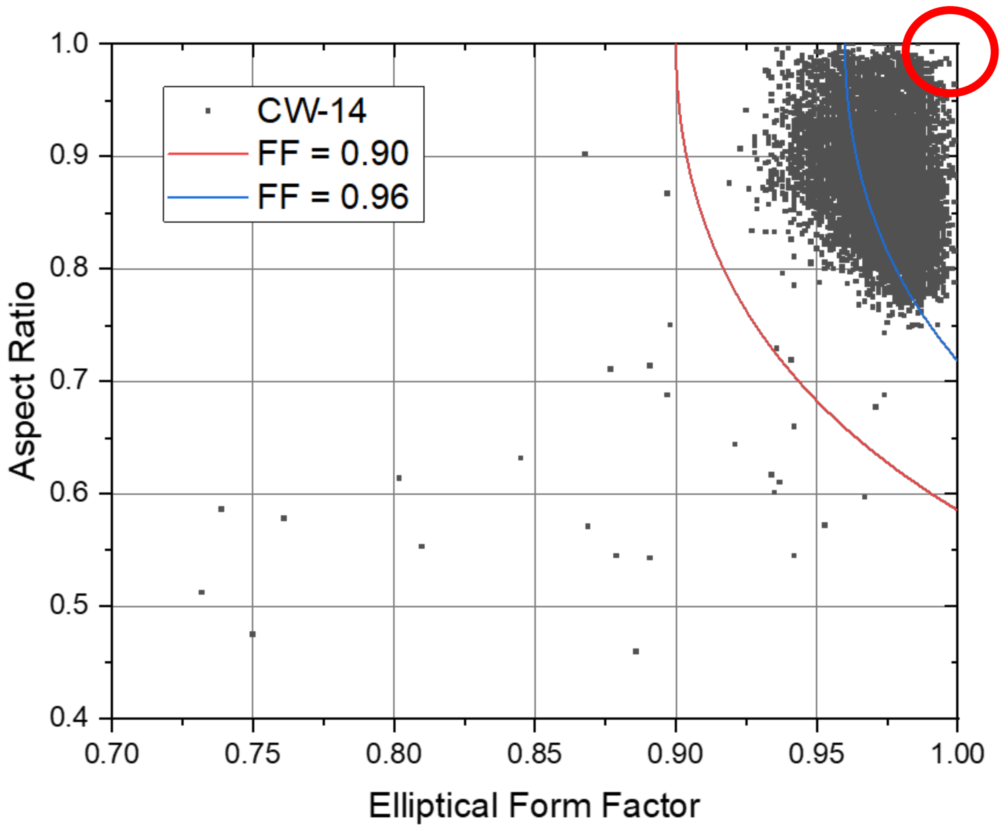


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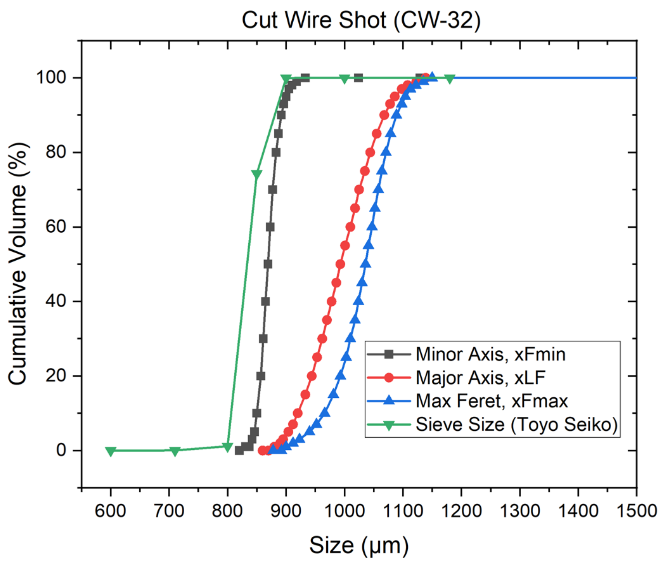
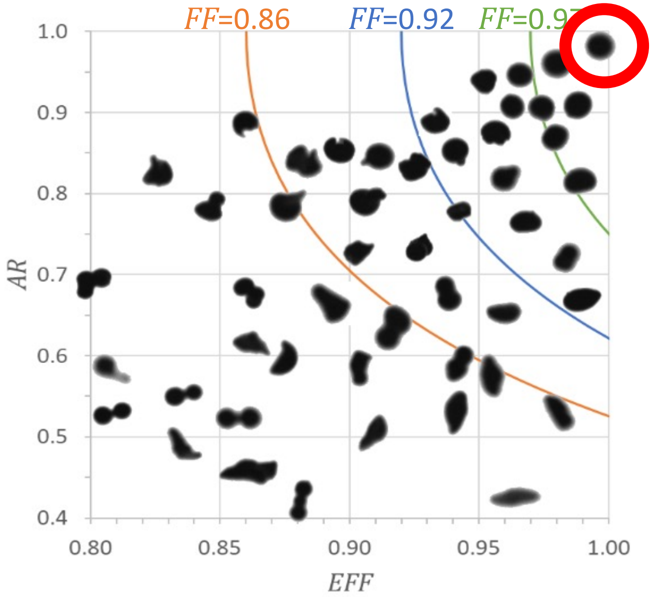
Image Analysis Summary

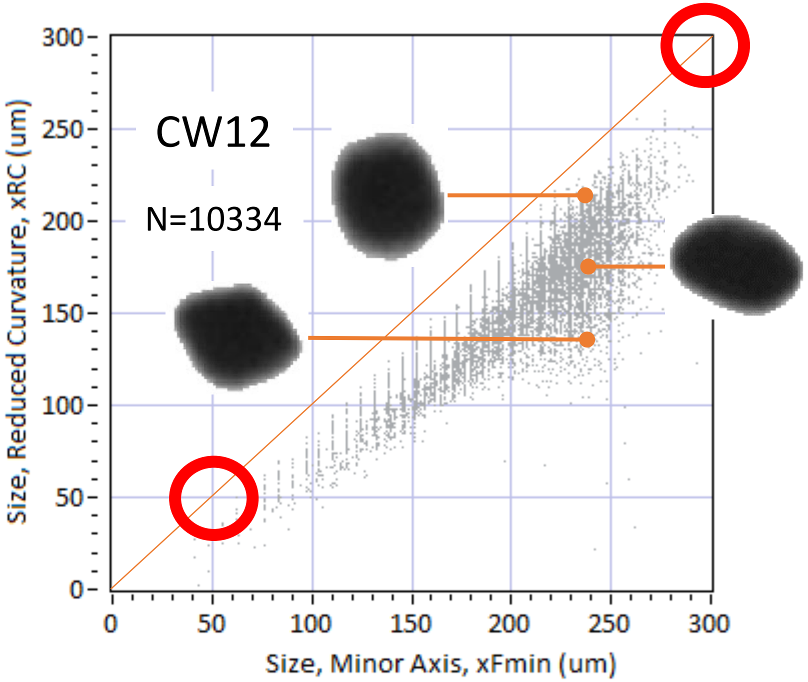
- Provides a statistically significant way to quantitatively characterize shot



Size
(Peening Work)



Shape
(Impact Stress)

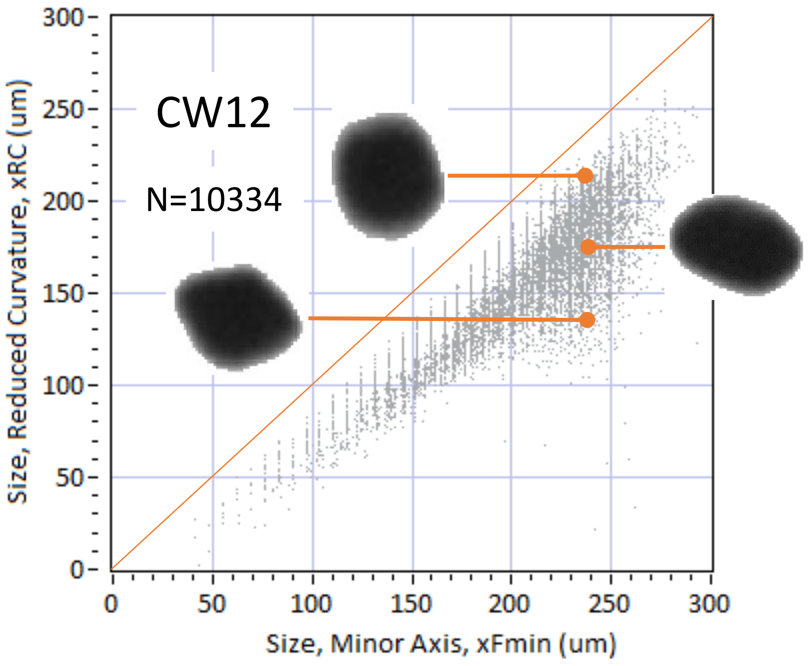


Size & Shape

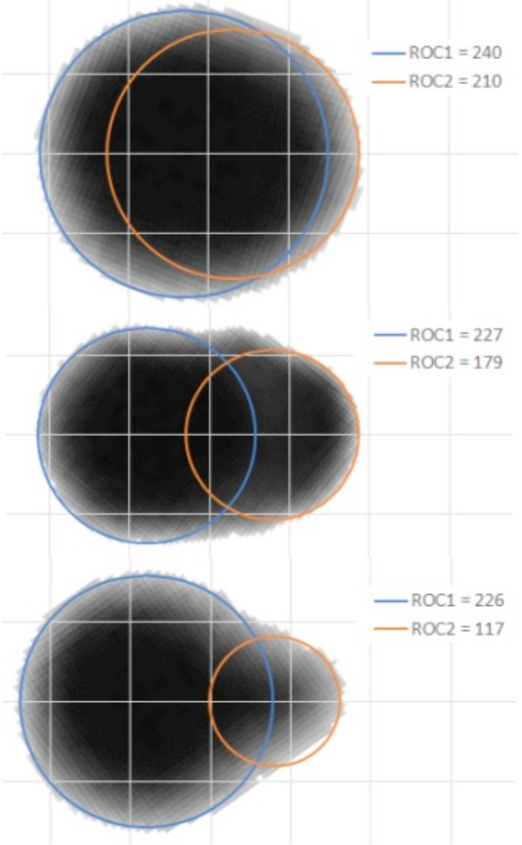
- Provides robust information to simulate accurate peening impacts

2. Simulating Peening Process Impacts (literally)

How can image analysis data be used to model residual stresses that arise from peening?

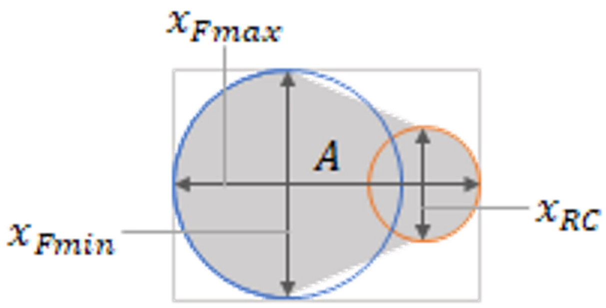


Size & Shape



"Glued spheres"

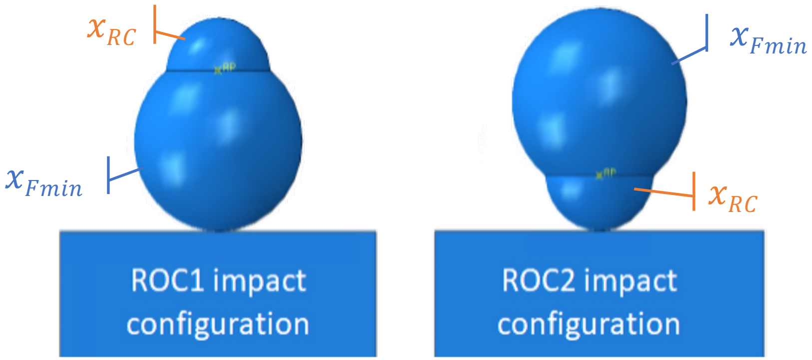
Glued sphere "approach"

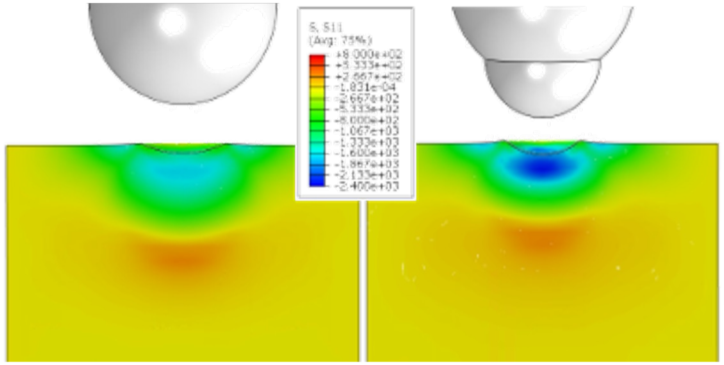


"Captures shape effect" by using an "effective" radius of curvature (χ_{RC})

Peening simulation with glued sphere approach

Discrete impact effects are shape dependent

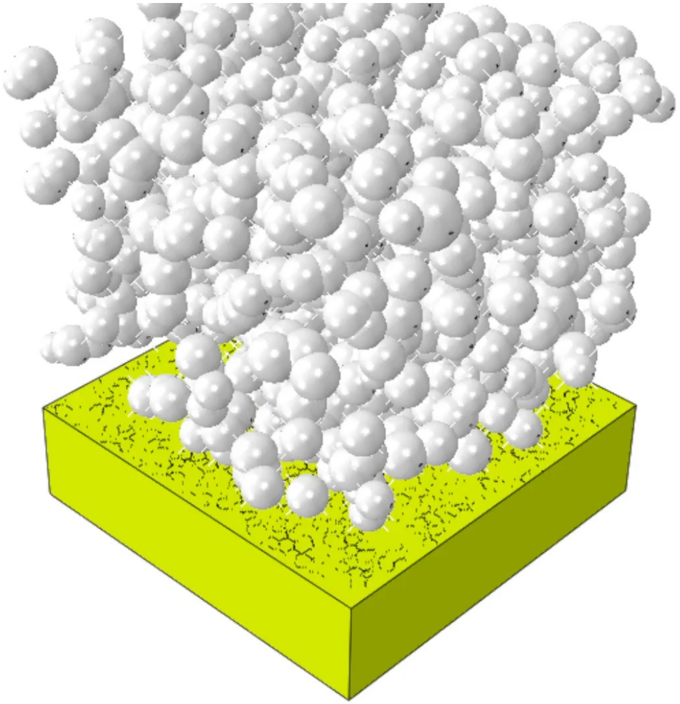




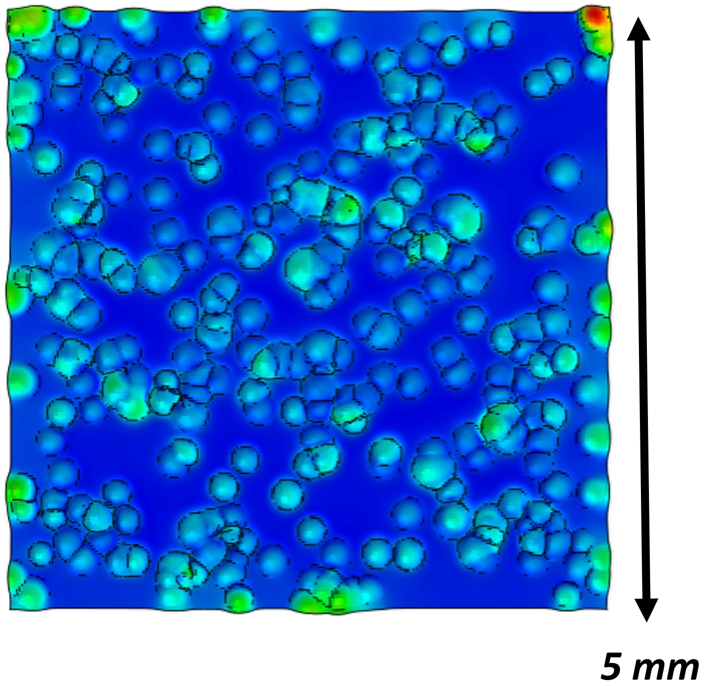
FEM using simple Hertzian contact model – sphere on plate

(ABAQUS Inc.)

Peening Simulation



312 Impacts; 100% Coverage



Glued sphere approach incorporates key shape & peening effects:

- ***Discrete impact modeling***
- ***Effective media dimple size***
- ***Compressive depth profile***
- ***Media mass flux***

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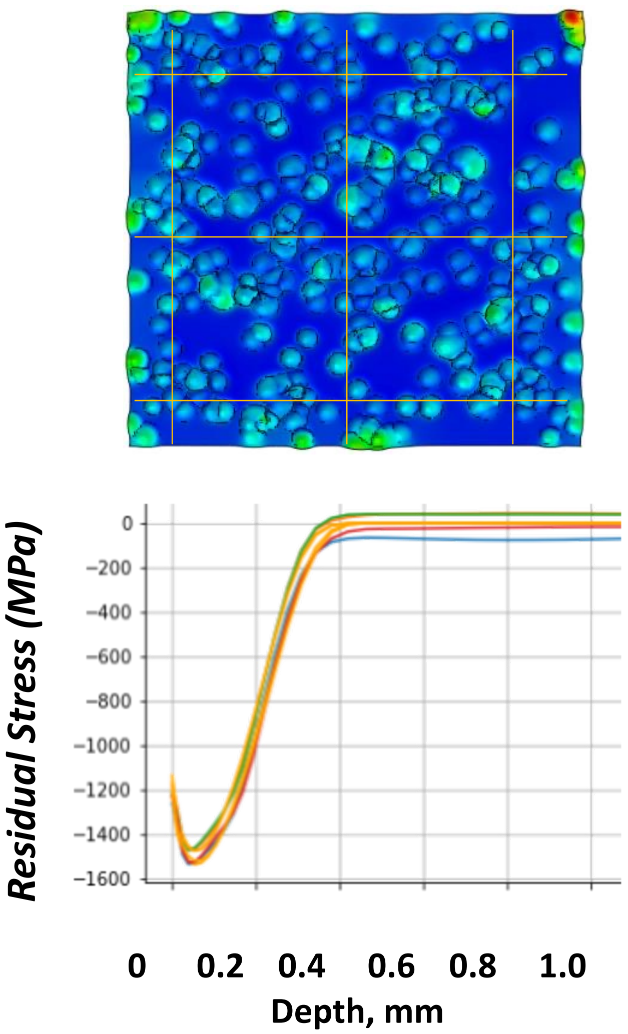
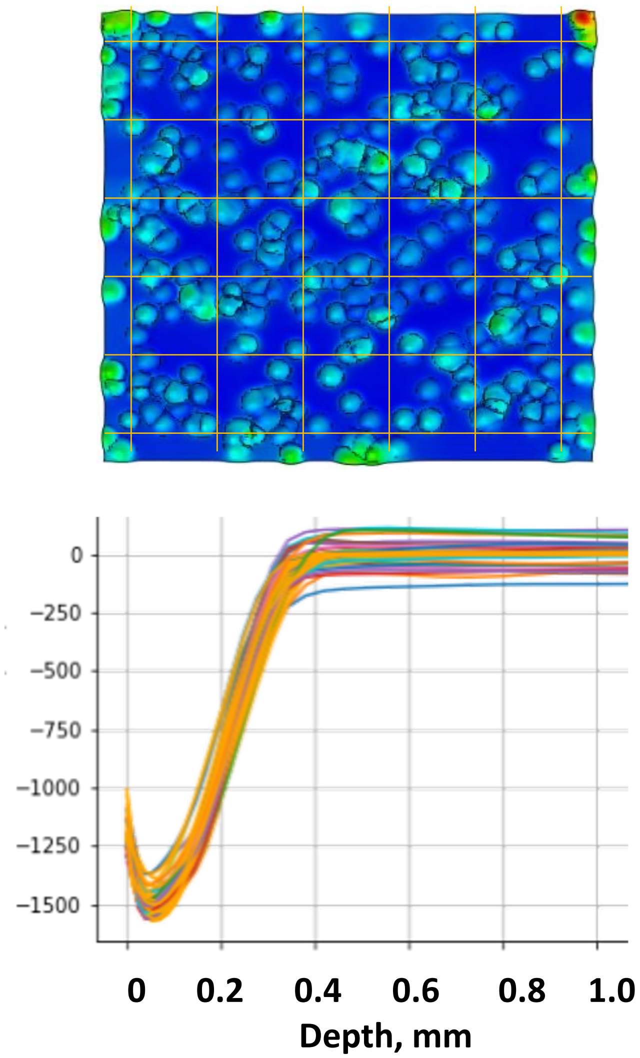
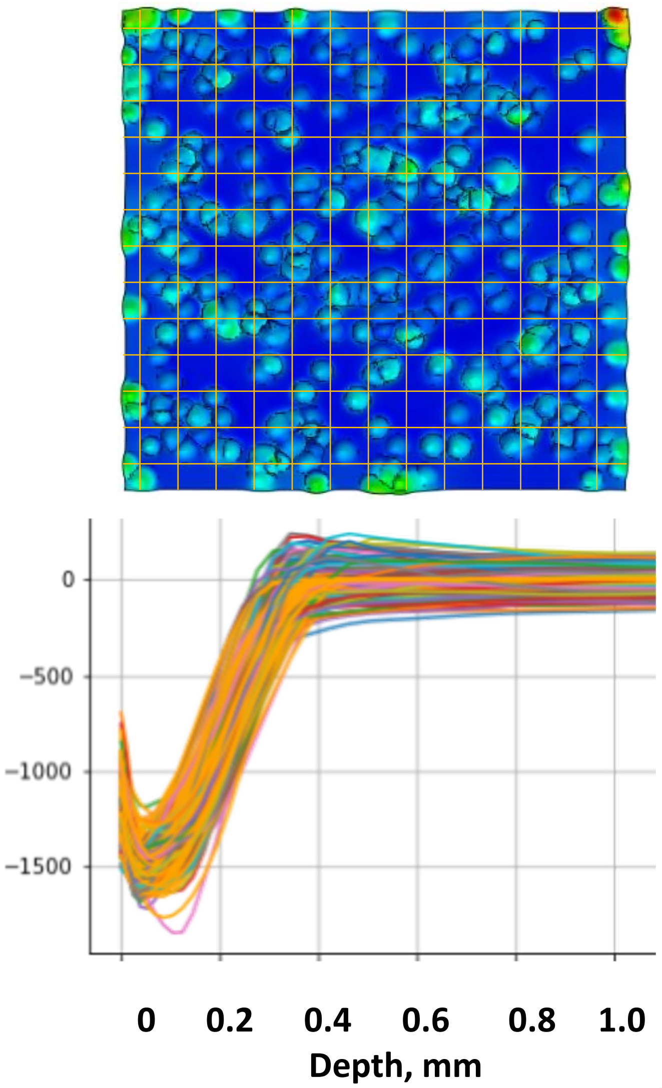
Peening Process Simulations Repeatability







"Glued spheres" provides repeatable, accurate stress field simulations

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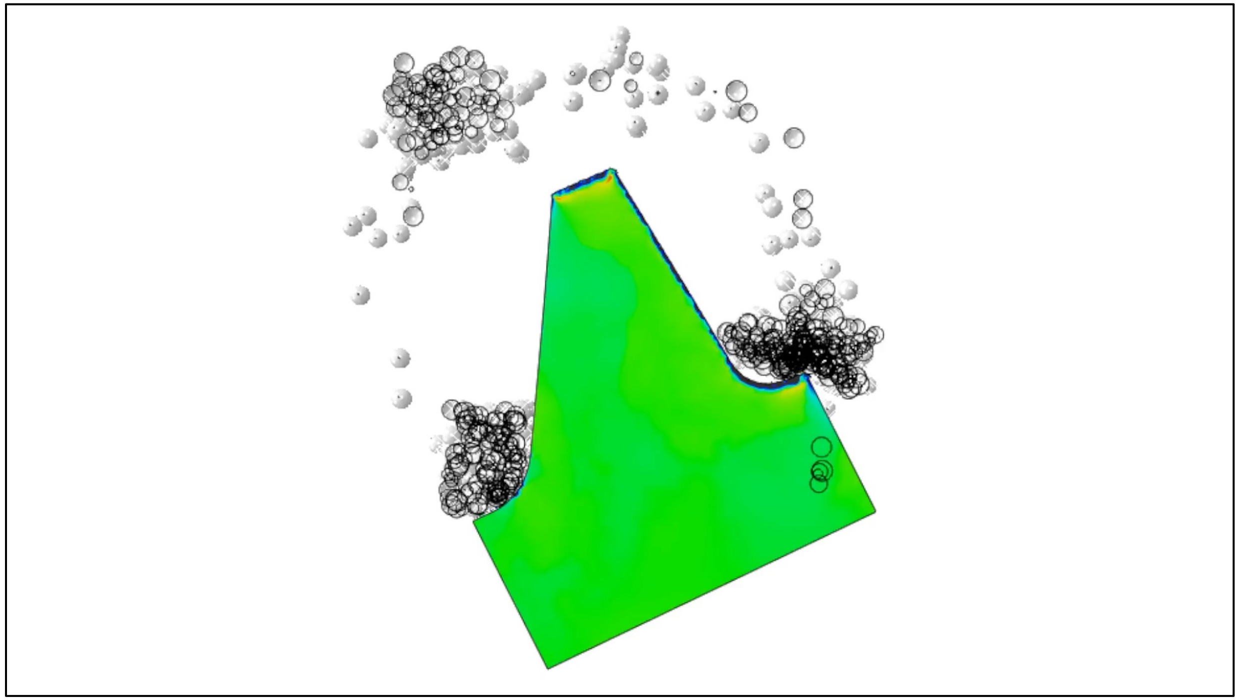
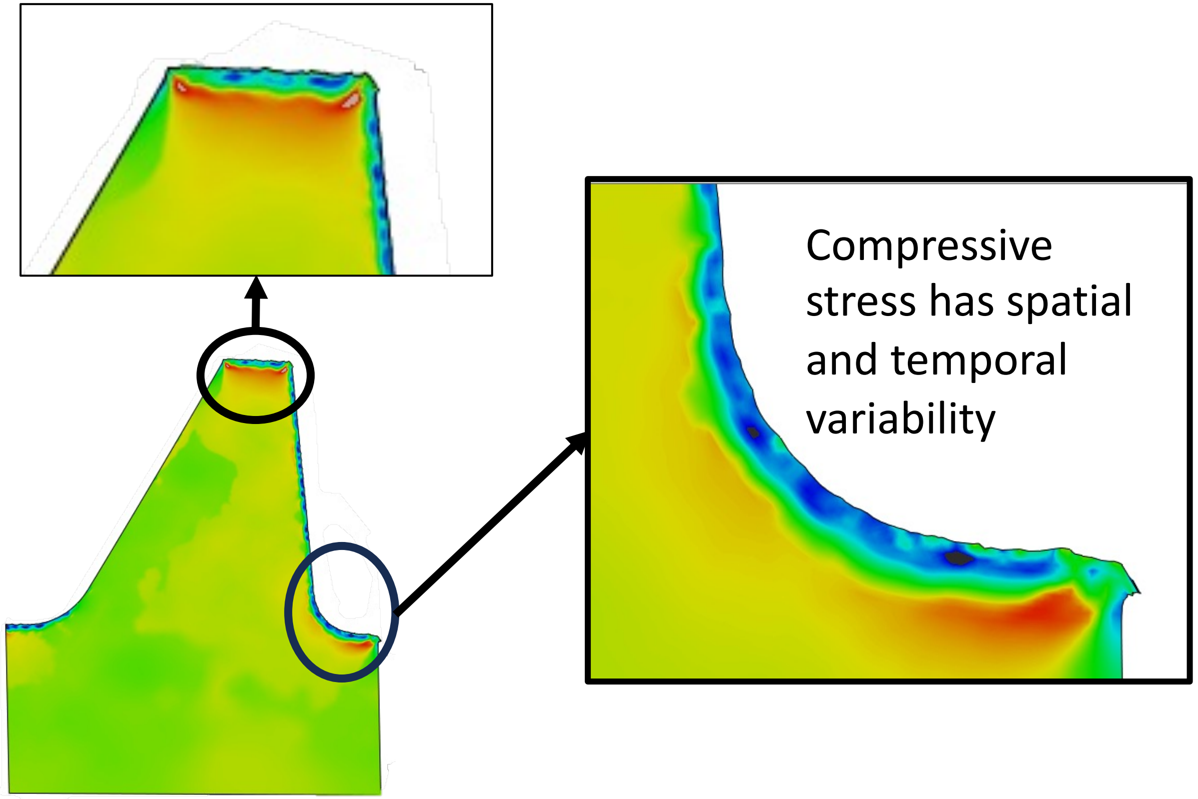
Peening Simulations of “Real Parts” (Using Representative Volume Elements





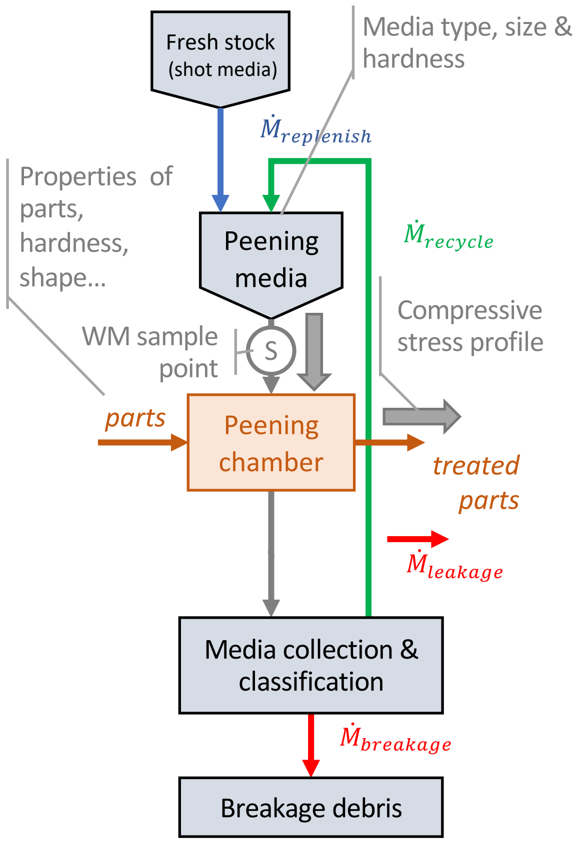
Representative volume elements (RVE’s) are used to capture the effect of part geometry in “real parts” by using

- **Impact angle**
- ***Effective peening flux***

3. Simulate Conventional Peening Operations

How do you combine image analysis & "glued sphere" modeling into a "conventional peening simulation"?

Flow Sheet Model



Identify "Boundary Conditions"

- Part Attributes (Collision factor)
  - Material
  - Geometry
- "Steady State" Mass Flow:
  - $M_{replenish} = M_{leakage} + M_{breakage}$
  - Total Steady State Mass Flow = $M_{replenish} + M_{recy}$
- Utilize known peening conditions to model media evolution and part residual stress
  - Size & Shape of initial media charge
  - Deployed peening power

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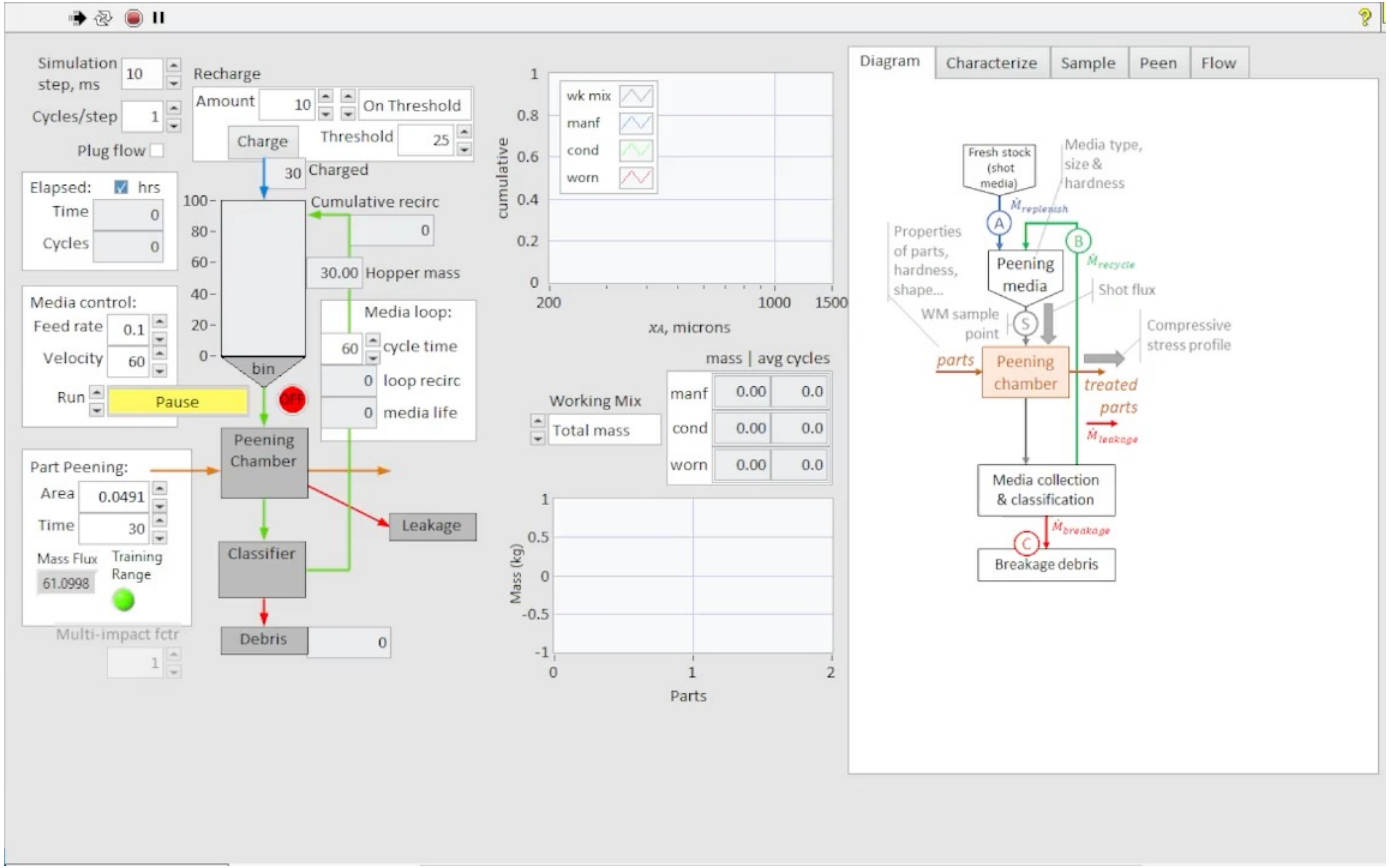
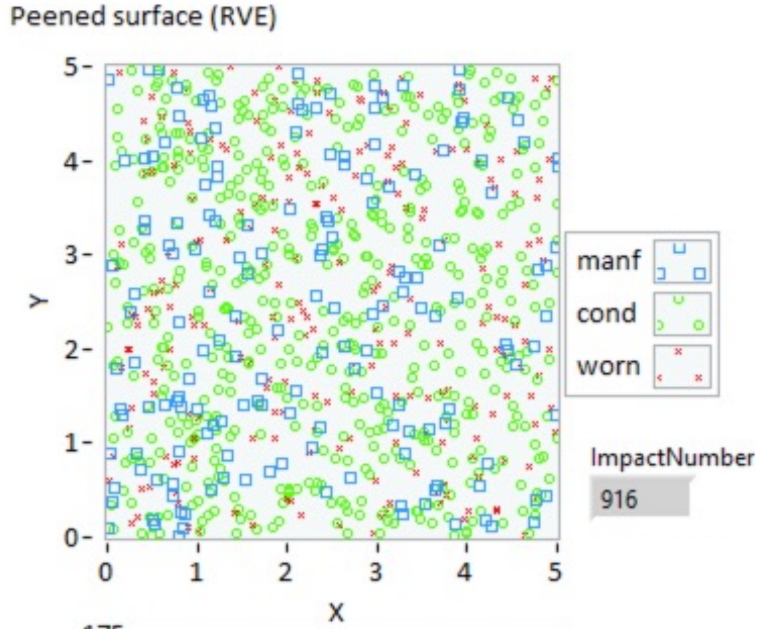
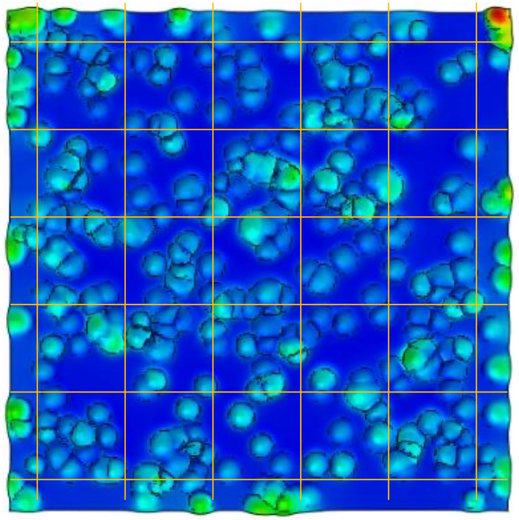
Peening Simulation

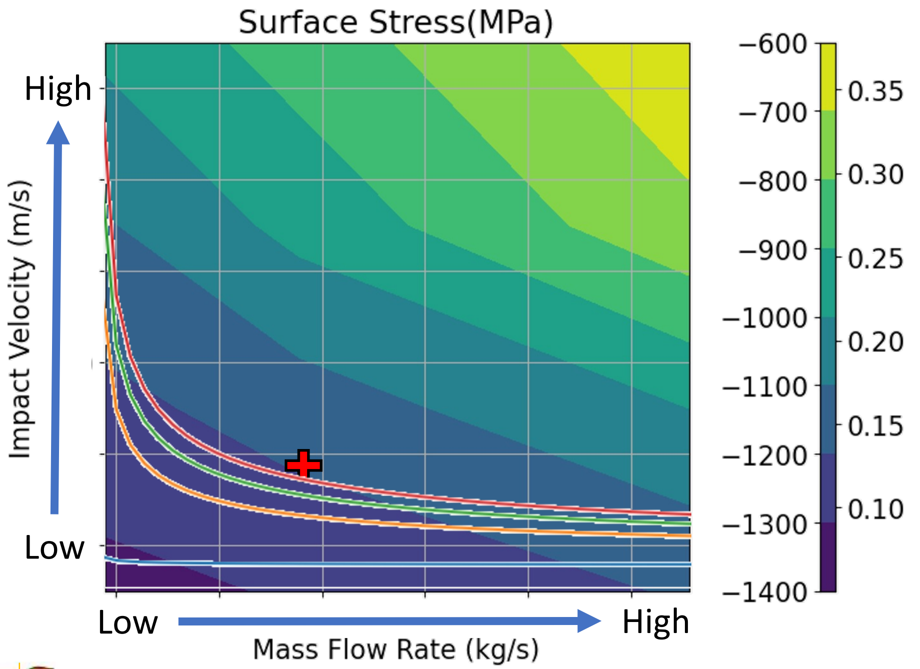


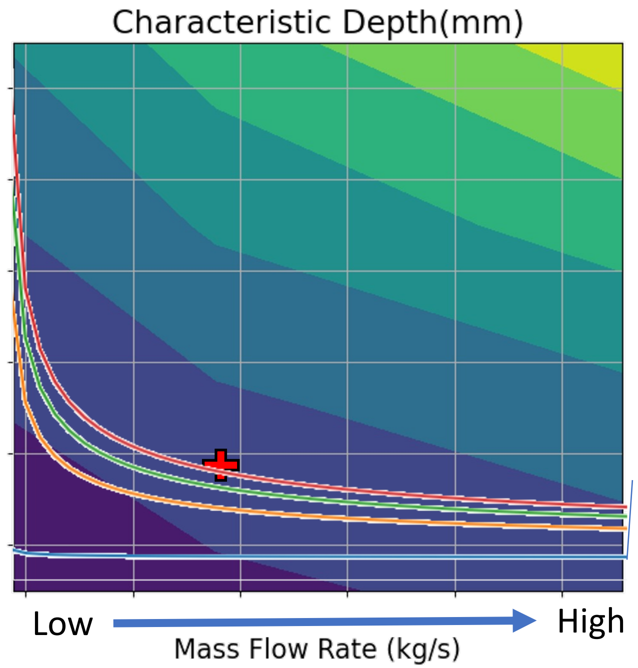
Peening Simulation Outcome



Random Impact Simulation







Lines of equal work, according to power balance equation

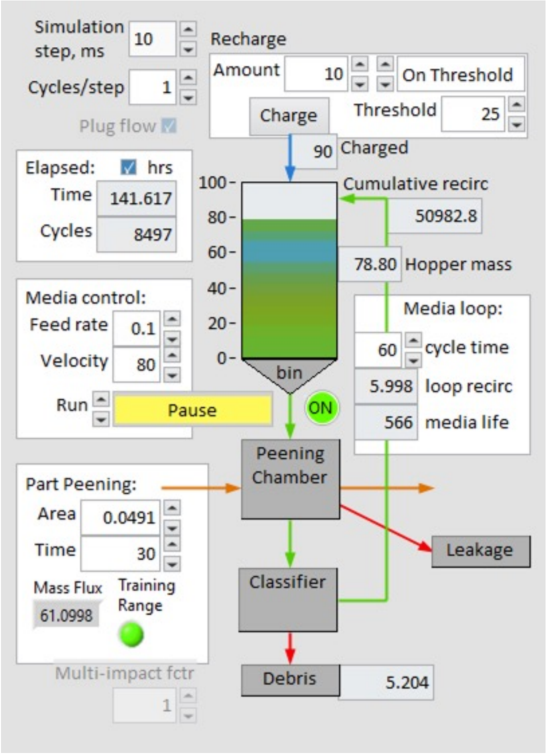
-Industrial Reference Setting

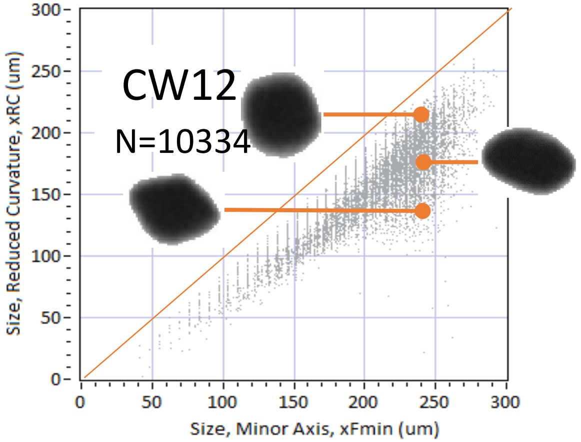
Summary

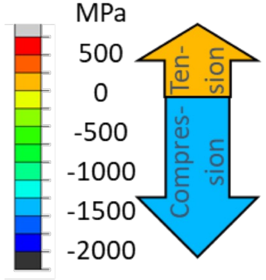
1. **Image Analysis is an effective tool to characterize media size and shape with some uses being:**
   - Specification enhancement
   - Residual stress modeling
   - Peening simulation

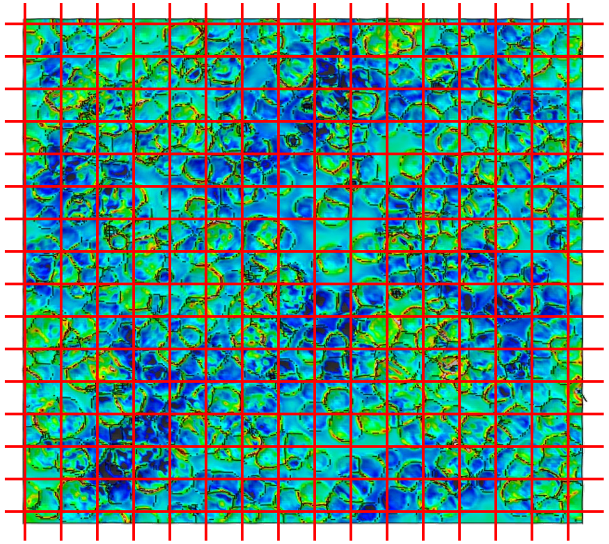
2. **Residual stress modeling can be accurately accomplished in a variety of environments using data from image analysis**

3. **Peening simulations can be made to reproduce industrial peening operations with "typical" conditions and "real" parts**









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Author's Acknowledgements

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CANTY
PROCESS TECHNOLOGY

Electronics Inc.
Shot Peening Control

TOYO SEIKO North America, Inc.
World Leading Company for Shot Peening Media

ERVIN

Purdue University MSE 2022 Graduates: Bradley Nance, Erin McCarthy, Sui Tay & Andrew Thoman