Compaction and Work Hardening Through High Velocity Particle Impact

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Assumptions

- Generalized results sought
- Empirical relationships used
- No temperature dependence
- No strain rate dependence
- Only axial stresses considered
- Strain hardening by particle deformation
- Porosity decrease by particle deformation

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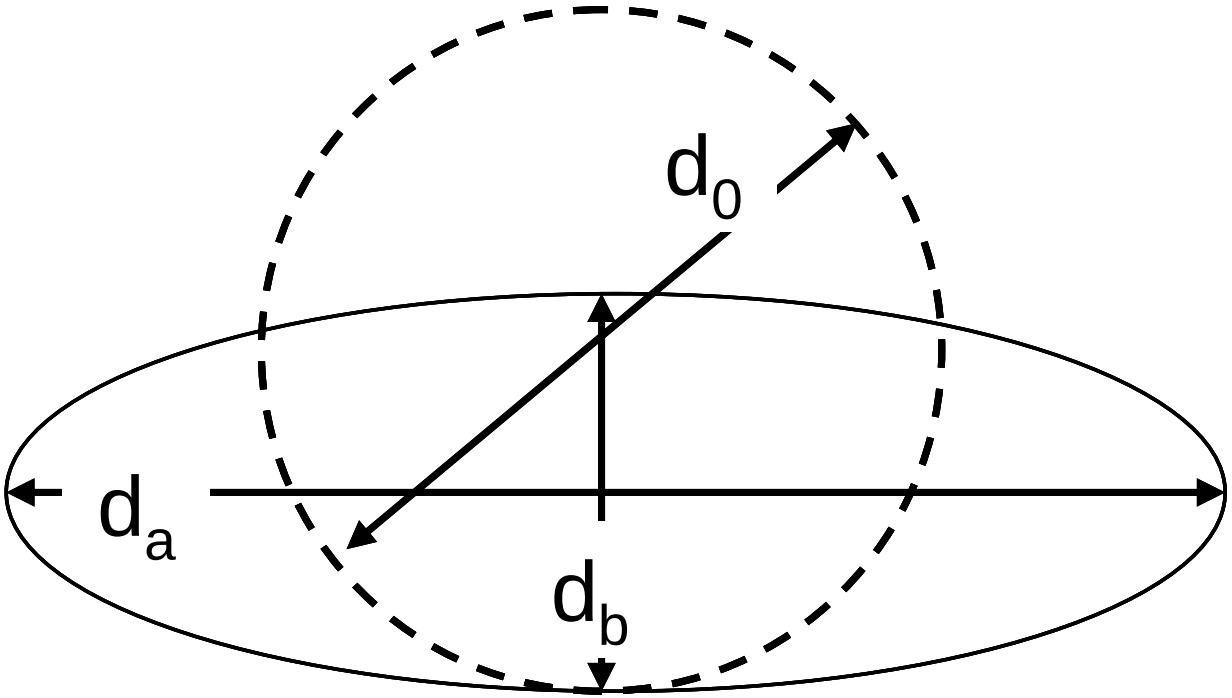
$d_0^{\,3} = d_a^{\,2} d_b$

Particle Deformation



$$d_0^{\,3} = d_a^{\,2} d_b$$

Constant volume

$$f_r = \frac{d_a}{d_0}$$

Flattening ratio

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Some Relationships

$$F = m\frac{dV}{dt} = m\frac{[V-0]}{[d_0 - d_b]/V} = m\frac{V^2}{[d_0 - d_b]}$$

$$\sigma = \frac{F}{A} = \frac{4\rho V^2}{6\left(f_r^{\,2} - 1\right)}$$

Axial stress on impact

$$\varepsilon_{pcs} = \frac{d_0 - d_b}{d_0} = 1 - \left(f_r\right)^{-2}$$

Strain by impact

$$\sigma = K\varepsilon_{pcs}^{\;n} = K\left(1 - f_r^{\,-2}\right)^n$$

Holloman eqn.

$$\frac{4\rho V^2}{6\left(f_r^{\,2} - 1\right)} = K\left(1 - f_r^{\,-2}\right)^n$$

Equating stresses

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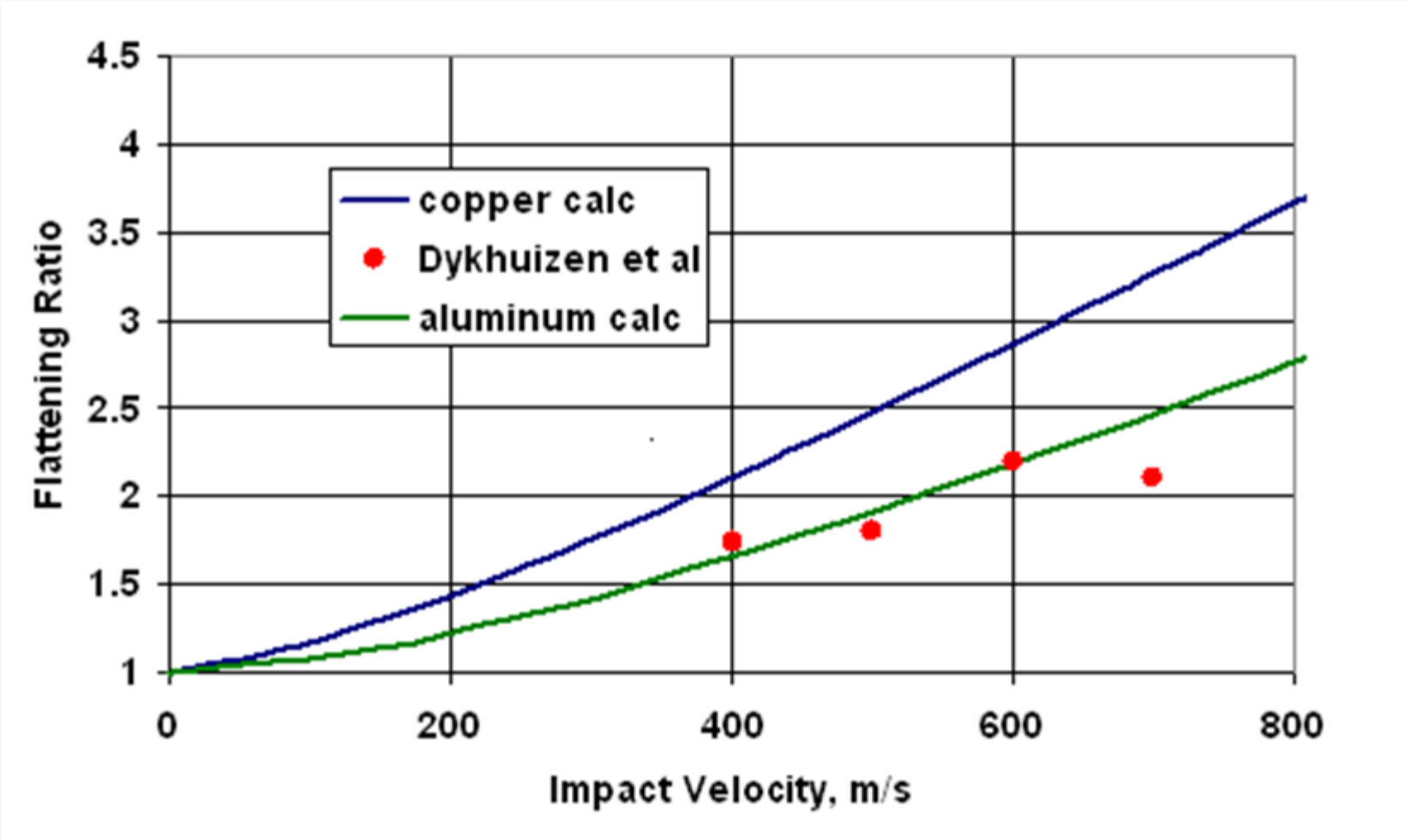
Impact Flattening



	K, MPa	n
copper	317	0.54
aluminum	180	0.2

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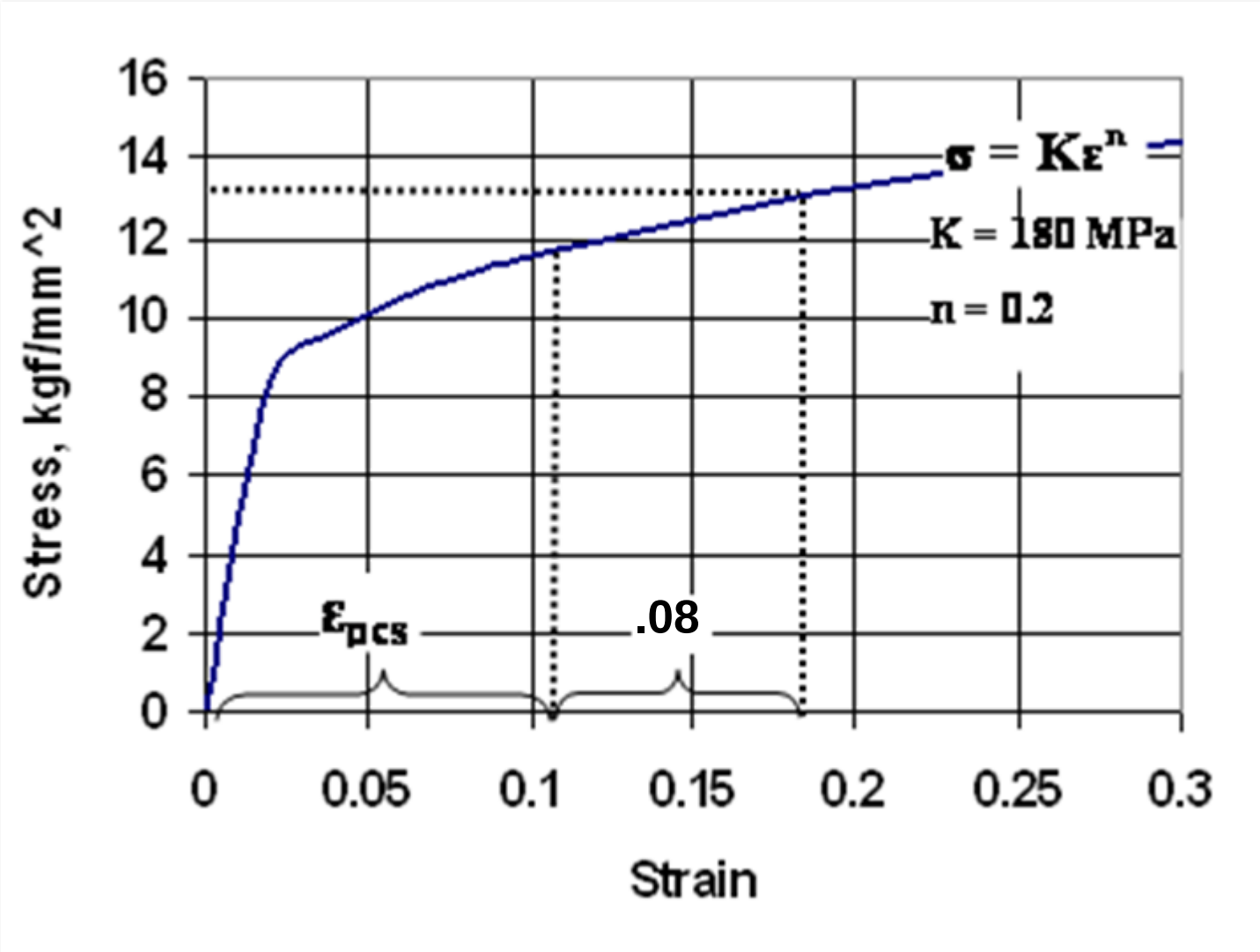
Strain Hardening



$HV = 3\sigma_{0.08}$ **Tabor eqn.** $\sigma_{0.08} = K\left(\varepsilon_{pcs} + 0.08\right)^n = K\left[\left(1 - f_r^{-2}\right) + 0.08\right]^n$

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Porosity

$$\ln\left(\frac{1-D_0}{1-D}\right)=\frac{P}{\sigma_y}$$

Heckel eqn.

$$P=\sigma=K\varepsilon_{pcs}{}^{n}=K\left(1-f_r{}^{-2}\right)^n$$

$$\%\,porosity=100D=100\left(1-D_0\right)\exp\left[-K\left(1-f_r{}^{-2}\right)^n/\sigma_y\right]$$

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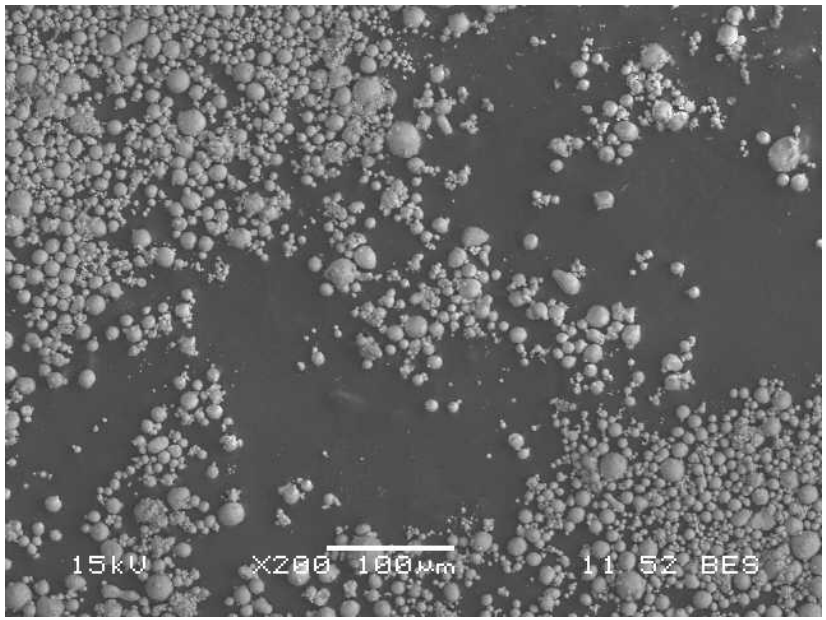
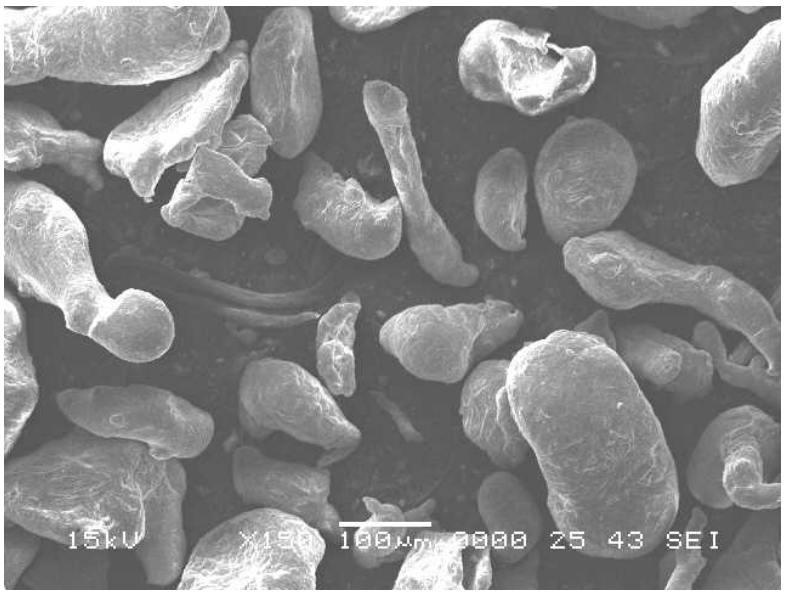
Aluminum Powders



H-12



100 mesh

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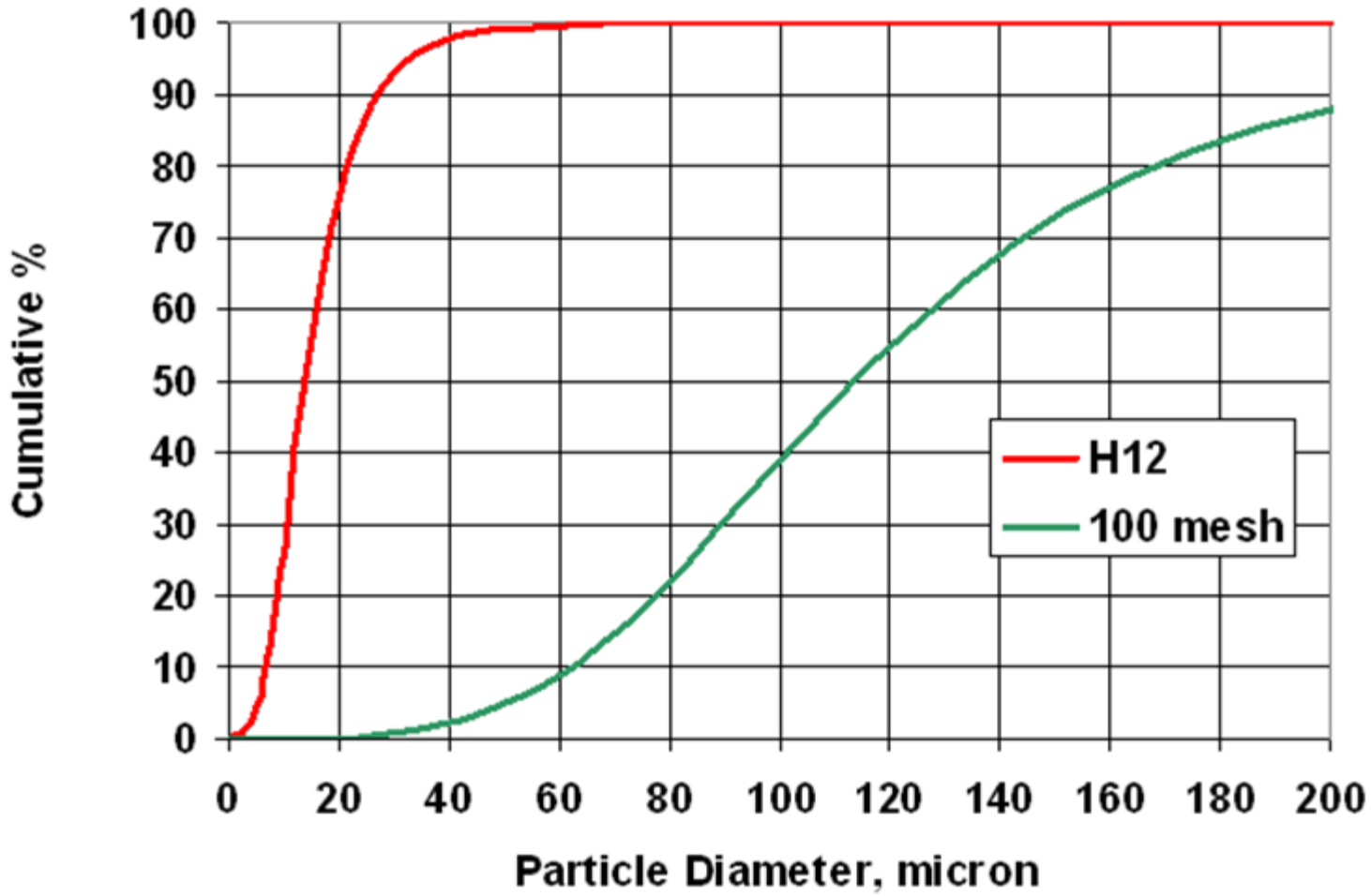
Powder Distributions



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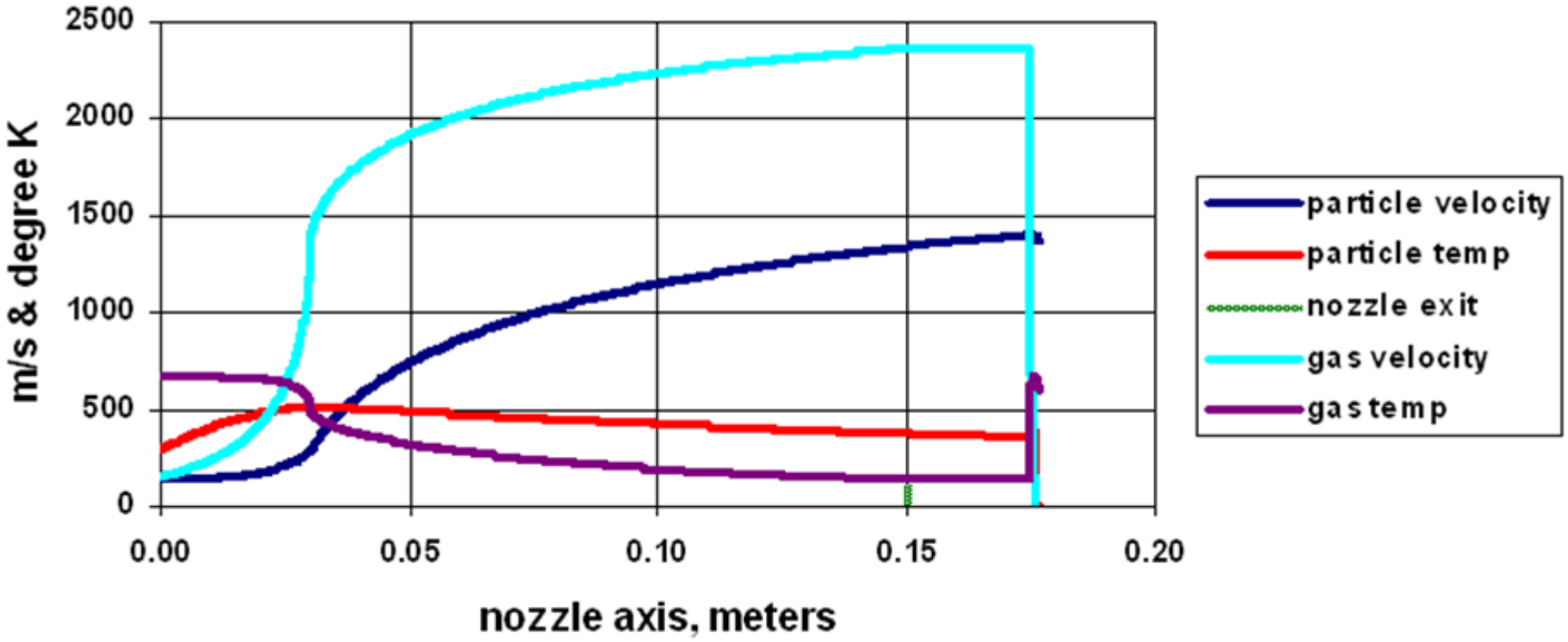
Hardness and Porosity Related to Impact Velocity



Velocity and temperature of a 20 micron aluminum particle, accelerated by 400 C, 2.76 MPa helium

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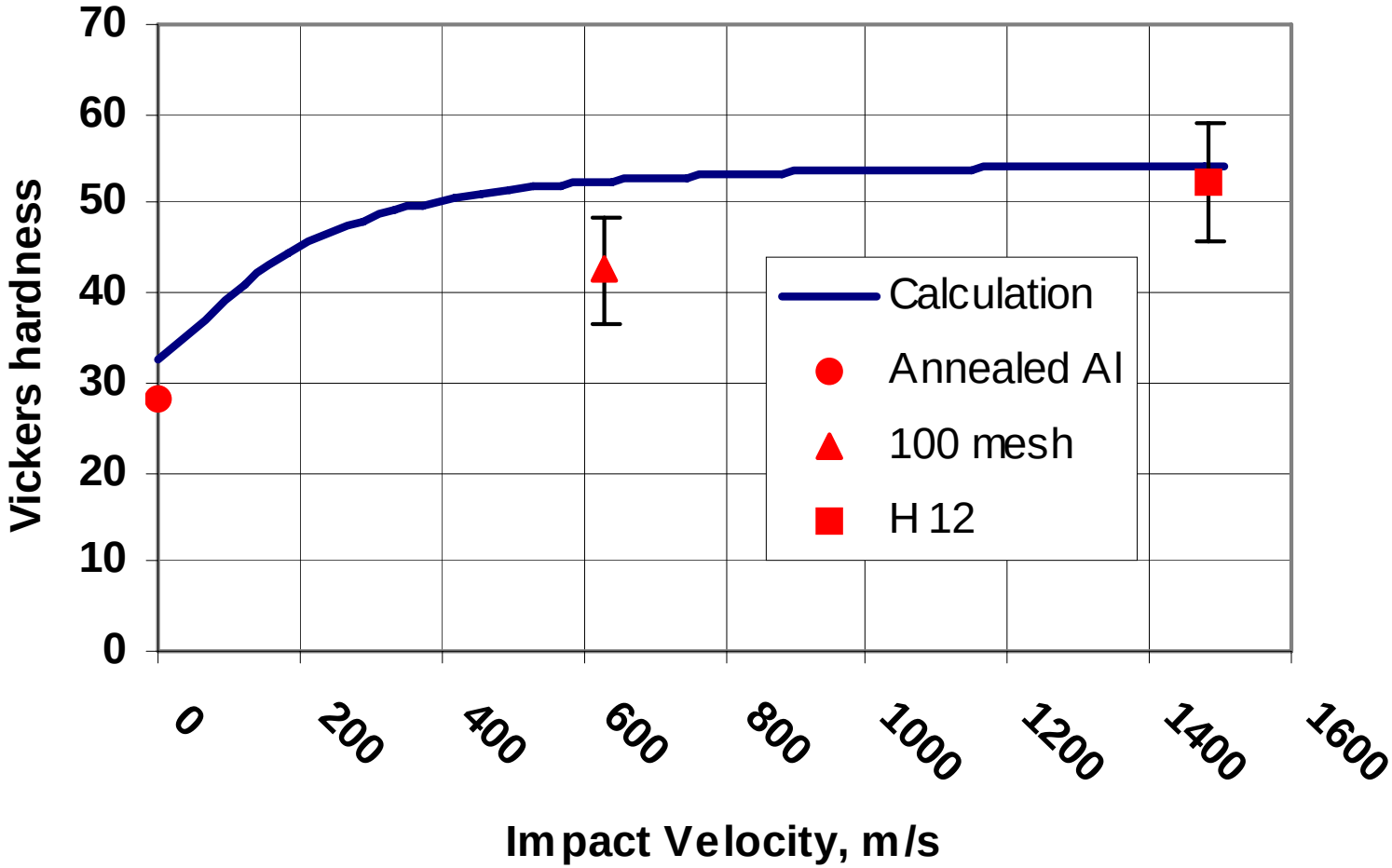
Hardness Prediction - Experiment Comparison



Velocities calculated, K = 180 MPa, n = 0.2

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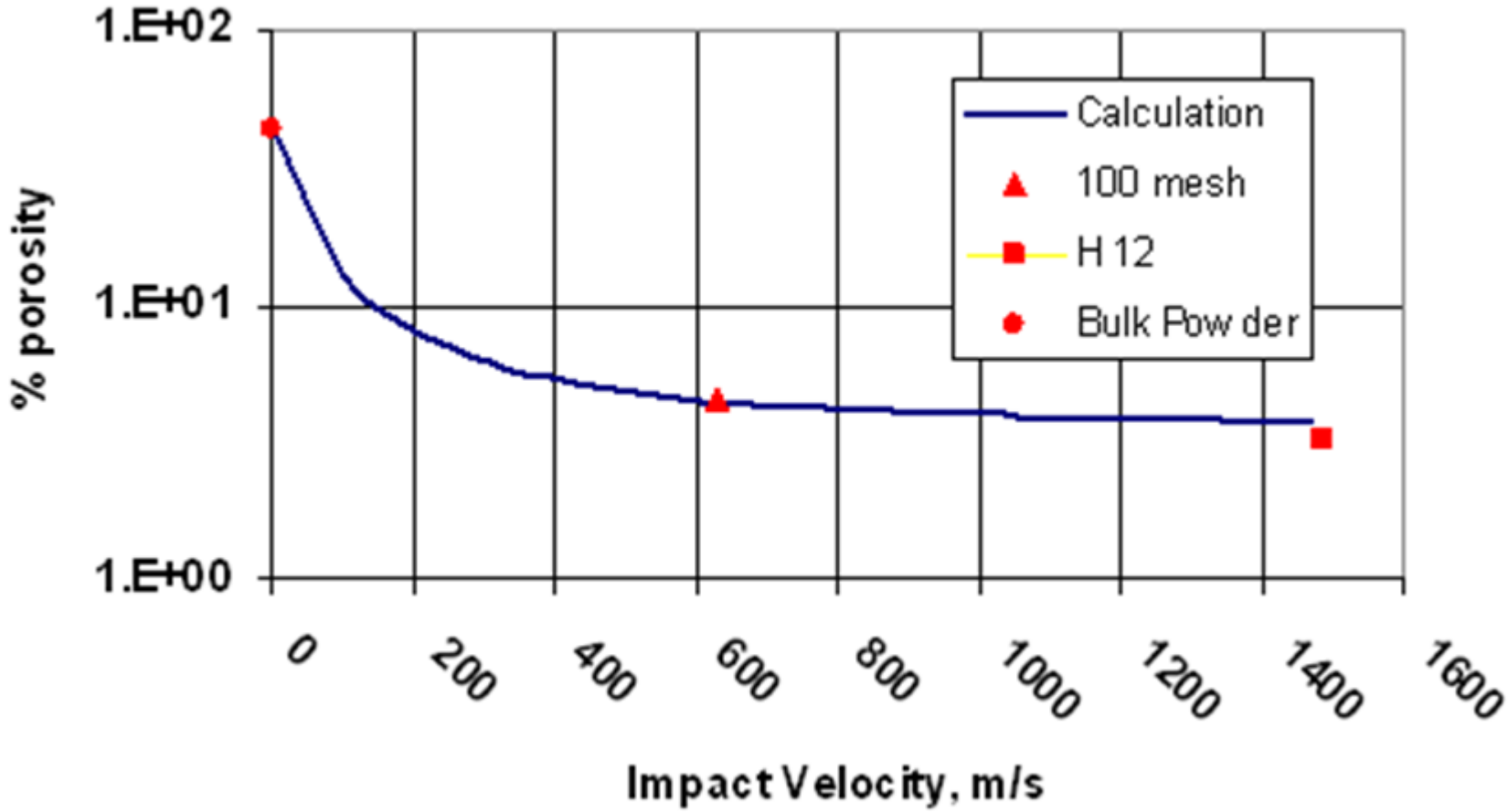
Porosity Prediction - Experiment Comparison



Yield strength = 69 MPa

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Conclusions

- Simple, intuitive relationships can give realistic predictions
- More rigorous relationships of questionable need due to material constants variability
- Most materials are fully hardened above their critical deposition velocity
- The effect of size distribution on velocity is considered in future work
- The effect of strain rate on deformation will be considered in future work.

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questions?

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