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Static and Dynamic Compaction of CL-20 Powders

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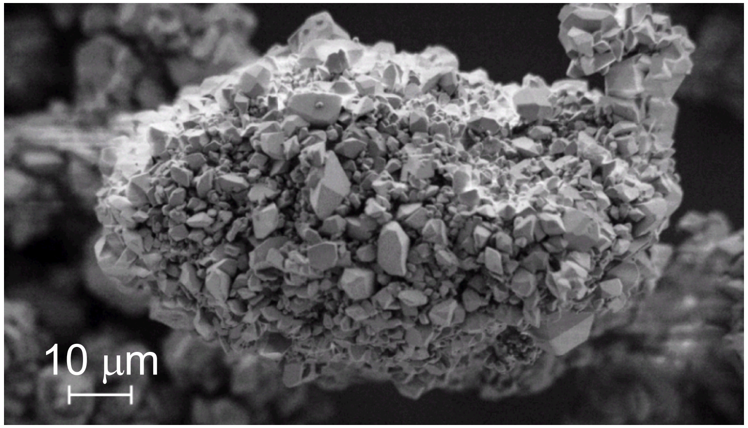
Background

- Motivation
  - Compaction data from beds of CL-20 powders is lacking
  - Understanding bed response to impact/shock a necessary input for predictive capabilities



SEM Image of ε CL-20 particles

- CL-20 explosive
  - High performance
  - High density (2.044 g/cc)
  - Six polymorphs exist (ε used here)
  - Mean particle size of 26 μm

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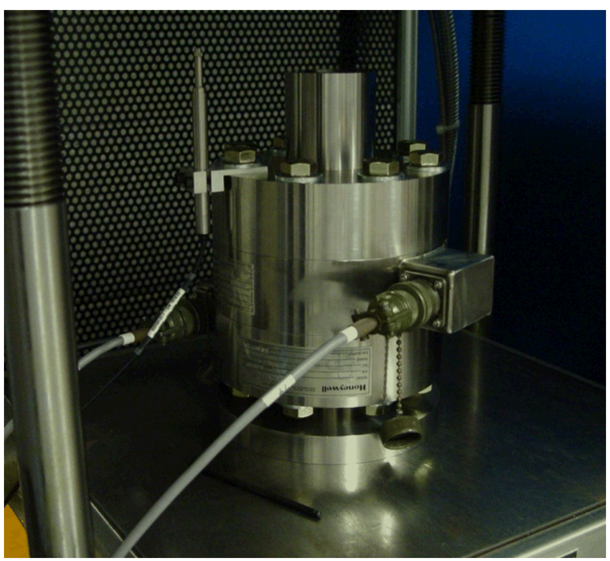
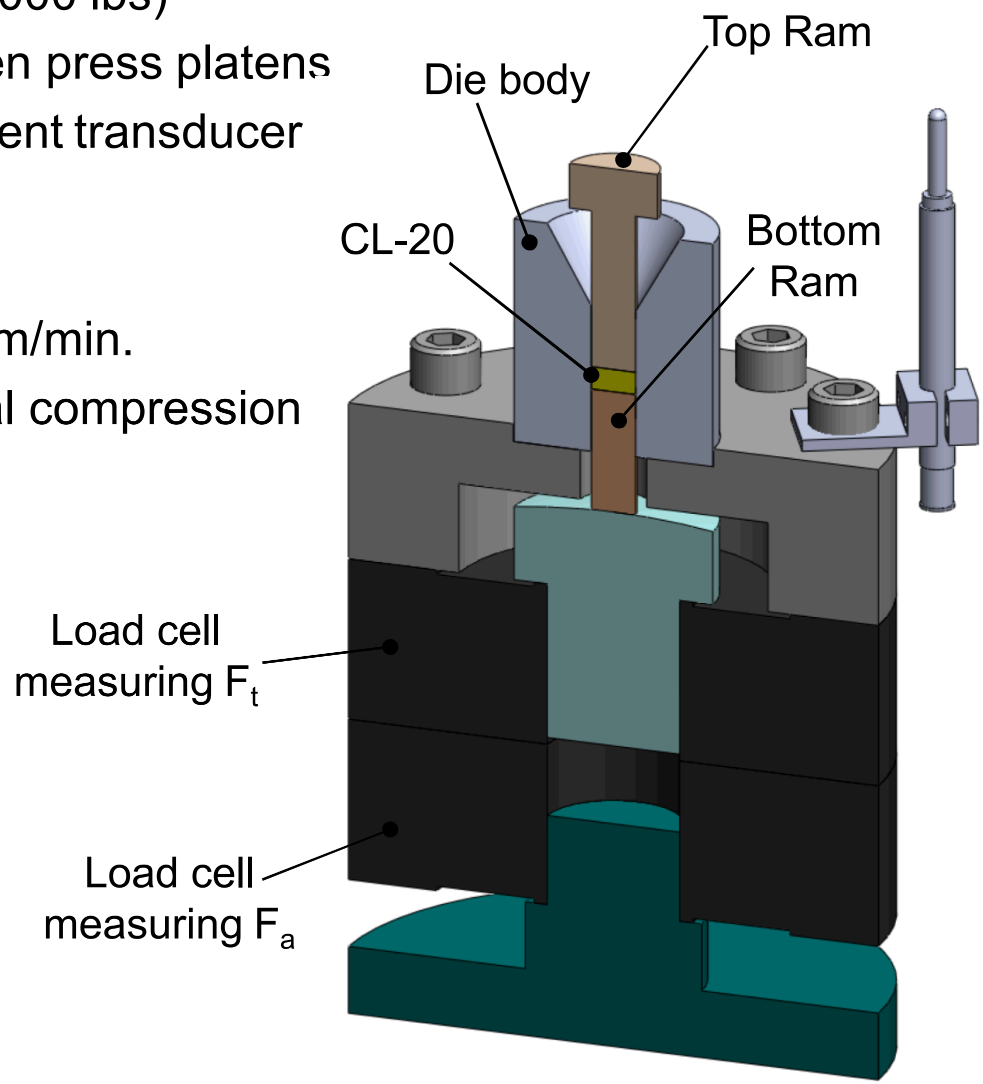
Static Compaction Experiments

- Compression of powder beds 12.7 mm dia. x 6.35 mm tall
- Sensors
  - Honeywell Sensotec load cells (20,000 lbs)
  - MicroEpsilon optical sensor between press platens
  - Sensotec linear variable displacement transducer
- Press Details
  - 30-ton hydraulic press
  - Minimum cross-head speed of 5 mm/min.
- Measured bed height corrected for axial compression



Photograph of apparatus installed in hydraulic press



Static Compaction Analysis

- As-poured initial bed density of 0.79 ± 0.01 g/cc (38.9% TMD)
- Linear F_t vs F_a relationship over applied forces:

  Slope = 0.763   Intercept = -0.398 kN

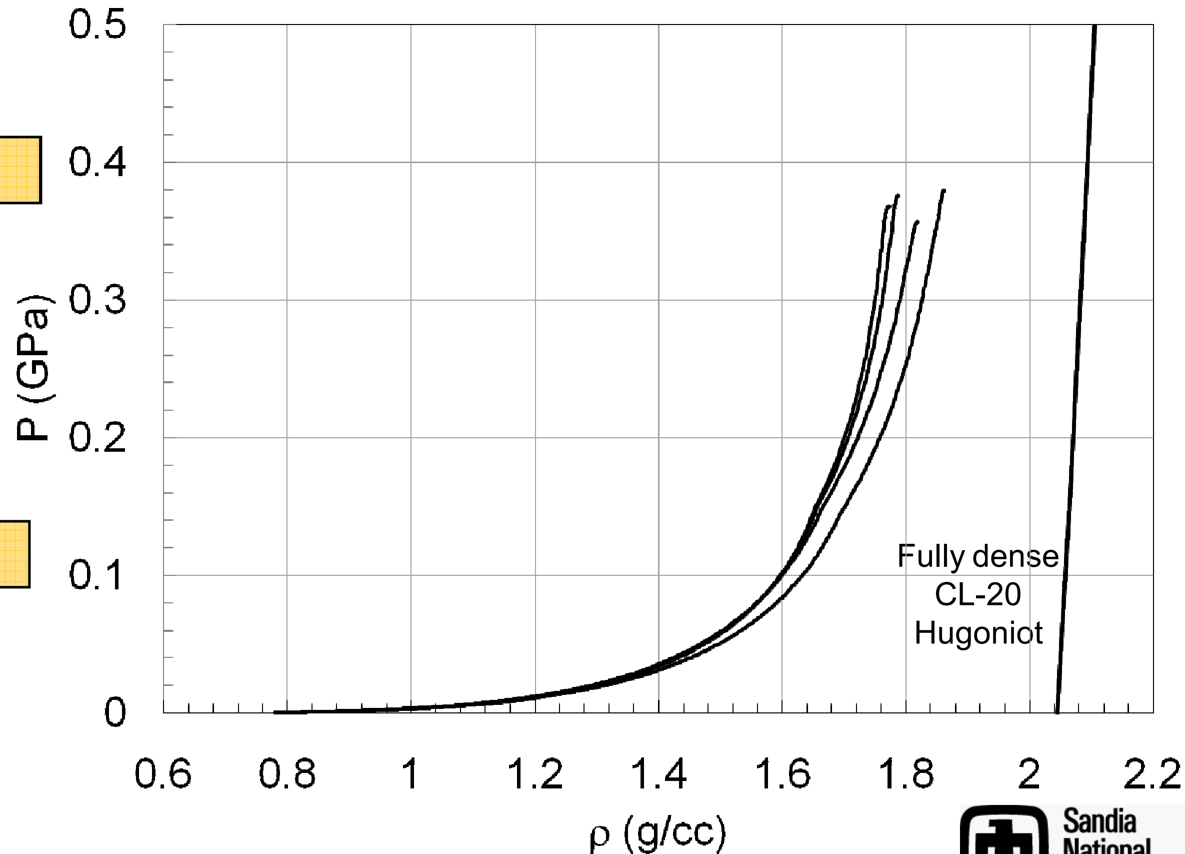
$$\rho = \rho_s \phi$$

Isothermal EOS

$$P = \frac{B_0}{B_0'}\left[\left(\frac{\rho_s}{\rho_{s_0}}\right)^{B_0'} - 1\right]$$

Bed force balance

$$P = \frac{F_a + F_t}{2A}$$



Dynamic Compaction by Planar Impact

- Gas gun impact velocities between 0.17 km/s and 0.95 km/s.
  - 18-m long barrel and 6.35-cm diameter projectile
  - Dual-delay-leg, “push-pull” velocity interferometry (VISAR)
- Beds of CL-20 powders located at impact face of projectile in reverse ballistic arrangement.

Gas gun at SNL’s Explosive Components Facility

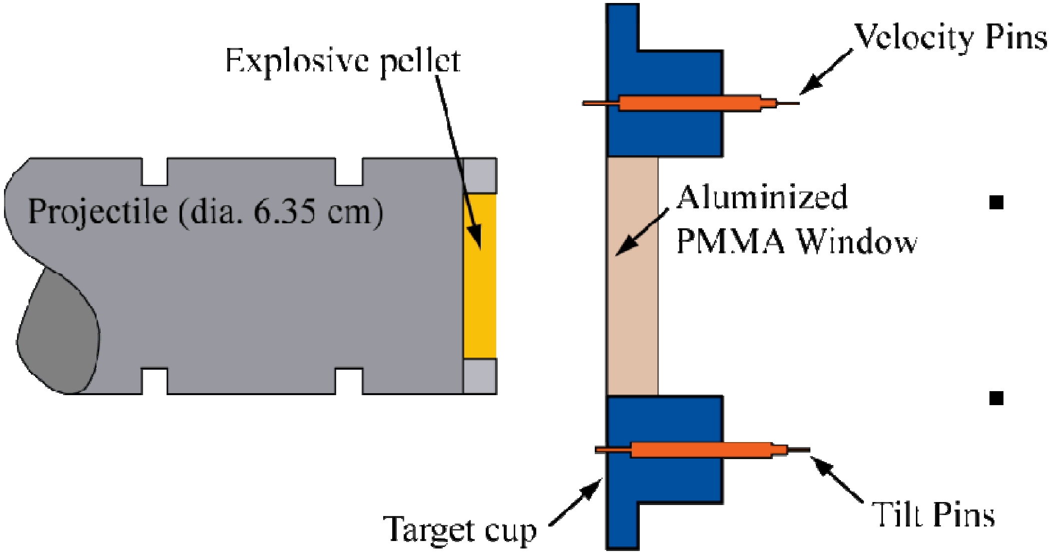
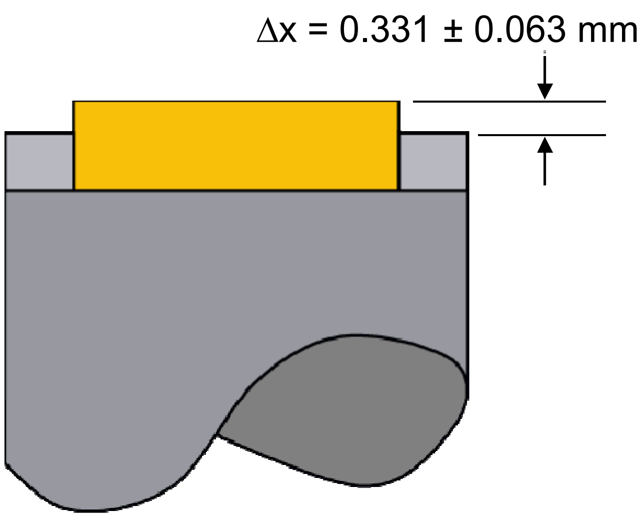


Illustration of projectile and target assembly reverse ballistic tests.

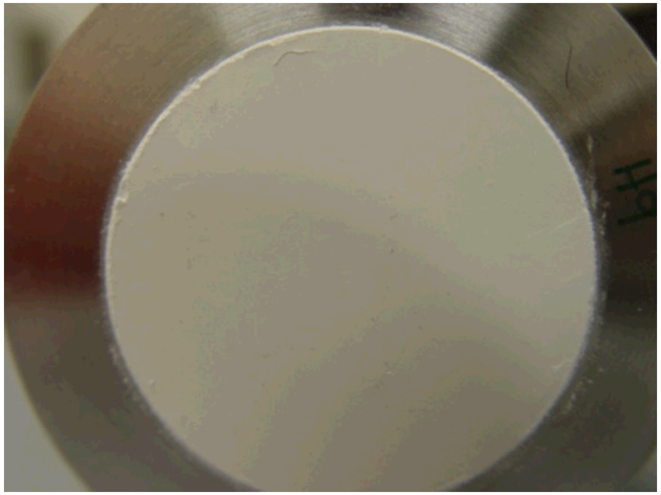
- PMMA window with 12.7 μm aluminum foil
- Three velocity pins and four tilt pins measure projectile arrival at target.

Sample Preparation

- CL-20 powders pressed directly into projectile recess.
  - As-machined recess diameter of 40.6 mm and depth of 4 mm
  - CL-20 powder mass of 7.4641 ± 0.0001 grams
  - As-pressed average bulk density of 1.4233 ± 0.0149 g/cc (69.6%TMD)
- Elastic response and release of powder bed observed
  - Previously observed 0.1-0.2 mm increase in bed height with 250-425 μm sugar beds (Trott, 2007)
  - As-tested average bulk density of 1.3232 ± 0.0194 g/cc (64.7%TMD)



Increase in pressed bed height observed after pressing. Spatial variations of density within the bed are likely.

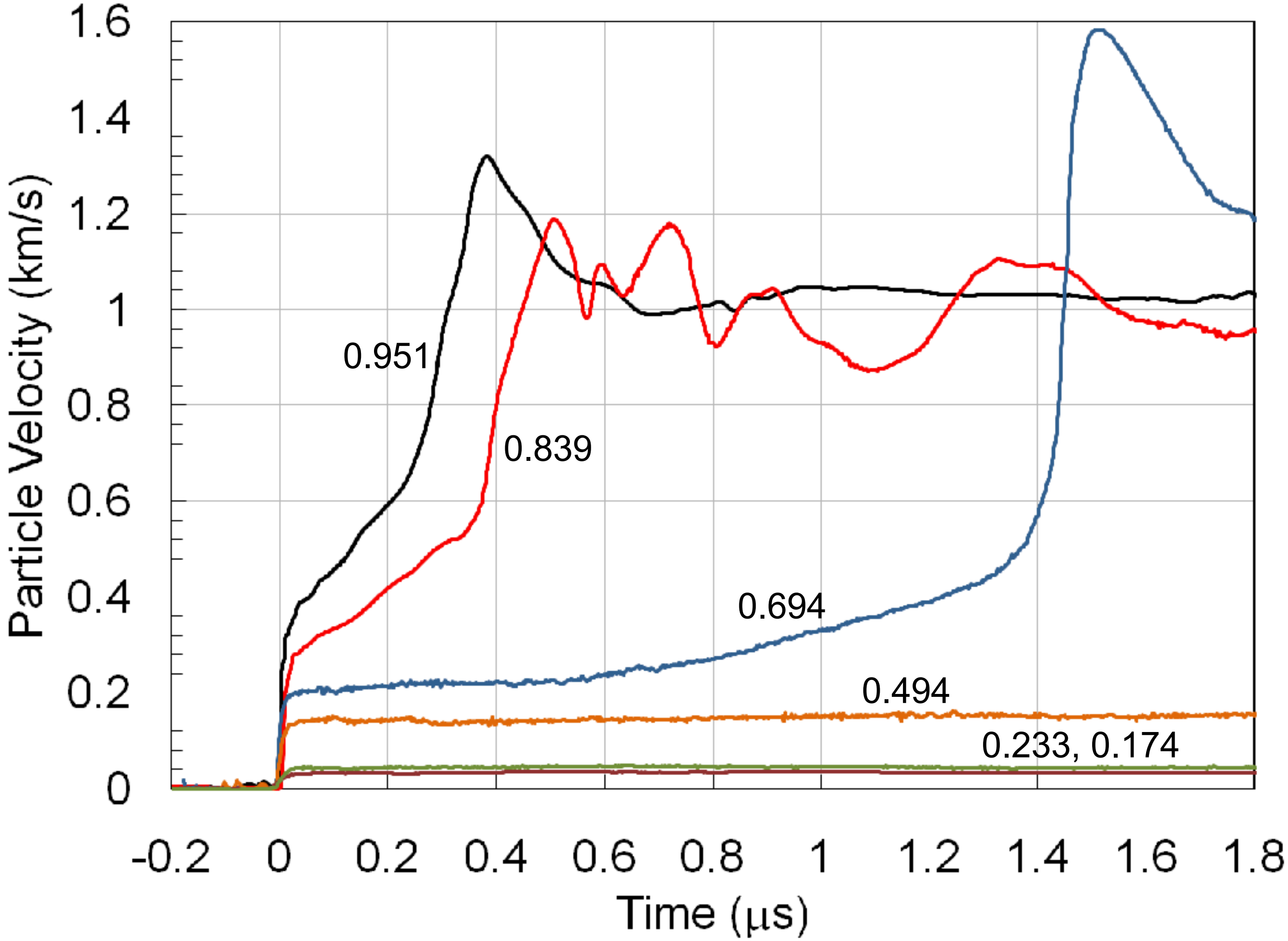


Photograph of pellet surface with increase in bed height visible along perimeter.

Particle Velocity Histories

- Evidence of significant, post-shock reaction observed for $u_0 > 0.5$ km/s
- Post-shock particle velocities used in 1-D analysis of flyer impact
  - Visco-elastic effects of PMMA result is large uncertainties in u_1

Impact Velocity u_0 (km/s)	ϕ_0	Particle Velocity u_1 (km/s)
0.174	0.6391	0.033
0.233	0.6394	0.047
0.494	0.6502	0.140
0.694	0.6492	0.219
0.839	0.6532	0.285
0.951	0.6531	0.350



Planar Impact Analysis

$$\rho = \rho_s \phi$$

Isothermal EOS

$$P = \frac{B_0}{B_0'}\left[\left(\frac{\rho_s}{\rho_{s_0}}\right)^{B_0'} - 1\right]$$

Mass conservation

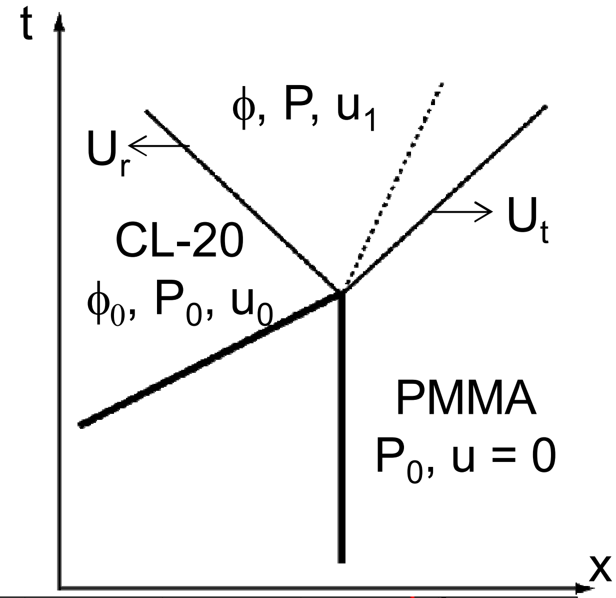
$$[\rho w] = 0 \qquad \frac{\rho_s \phi}{\rho_{s_0}\phi_0} = \frac{U_r - u_0}{U_r - u_1}$$

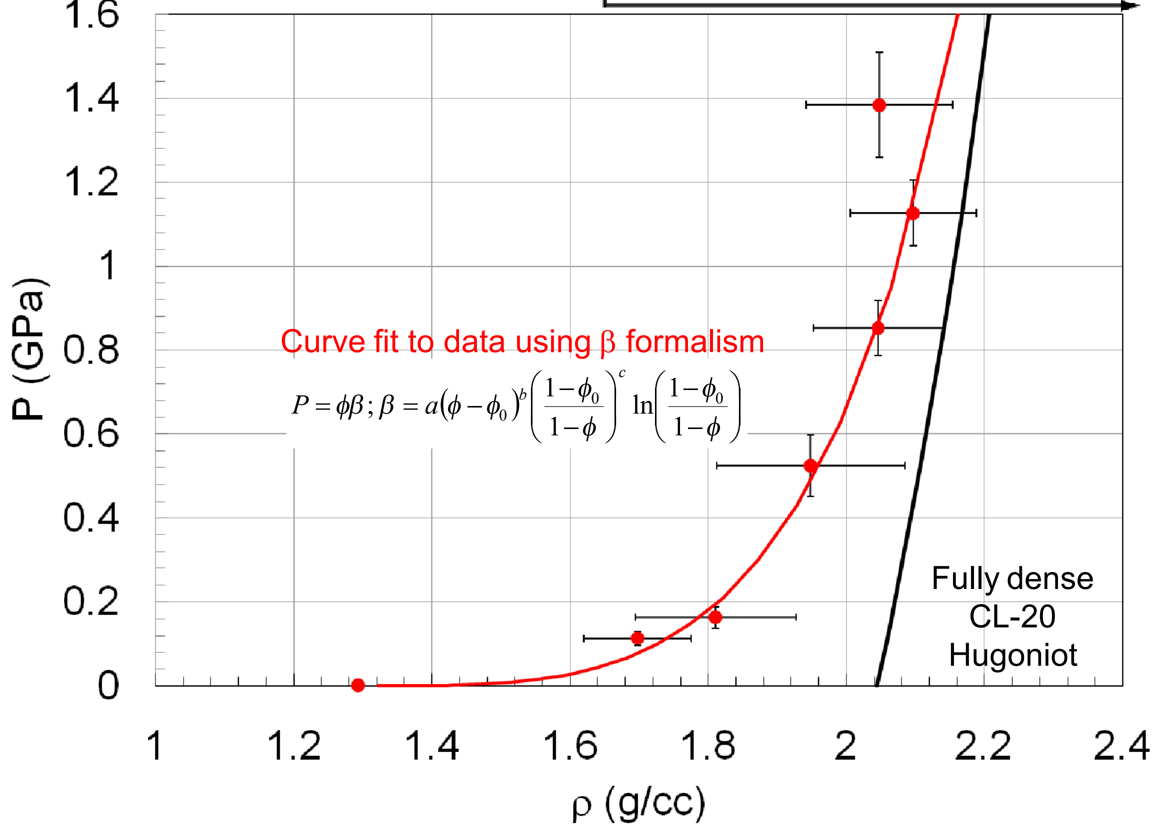
Conservation of momentum

$$[P + \rho w^2] = 0$$

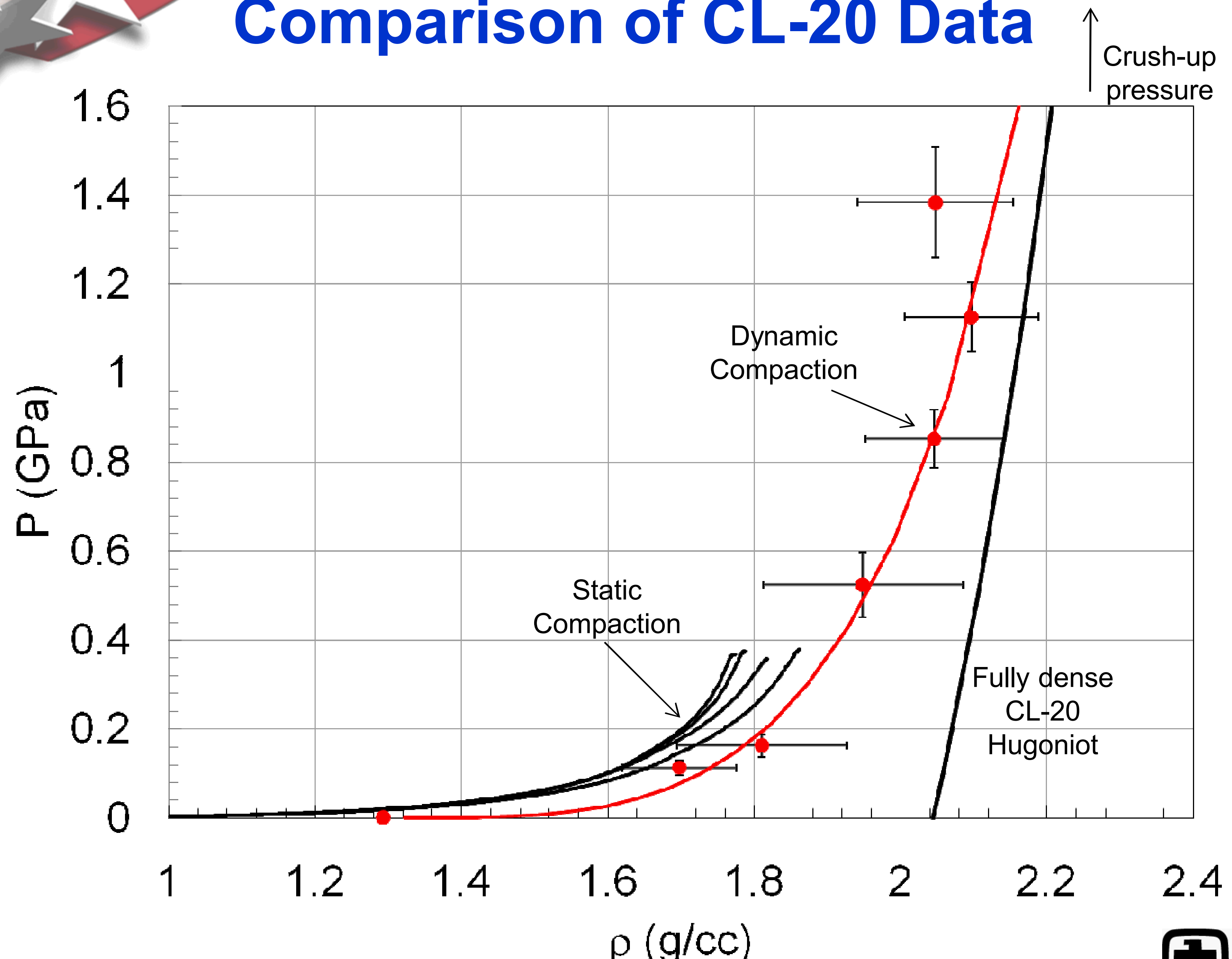
$$P = P_0 + \rho_{s_0}\phi_0 (u_1 - u_0)(U_r - u_o)$$

$$P = P_0 + \rho_{PMMA_0} u_1 \left(c_0 + s_1 u_1 + s_2 {u_1}^2\right)$$





Comparison of CL-20 Data



Conclusions

- Static and dynamic compaction behavior of pressed beds of ε CL-20 has been investigated.
  - Static compaction data obtained for CL-20 using a recently built apparatus in a 30-ton hydraulic press.
  - Dynamic compaction data obtained with gas gun in a reverse ballistic arrangement.

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Backup Slides

Material EOS

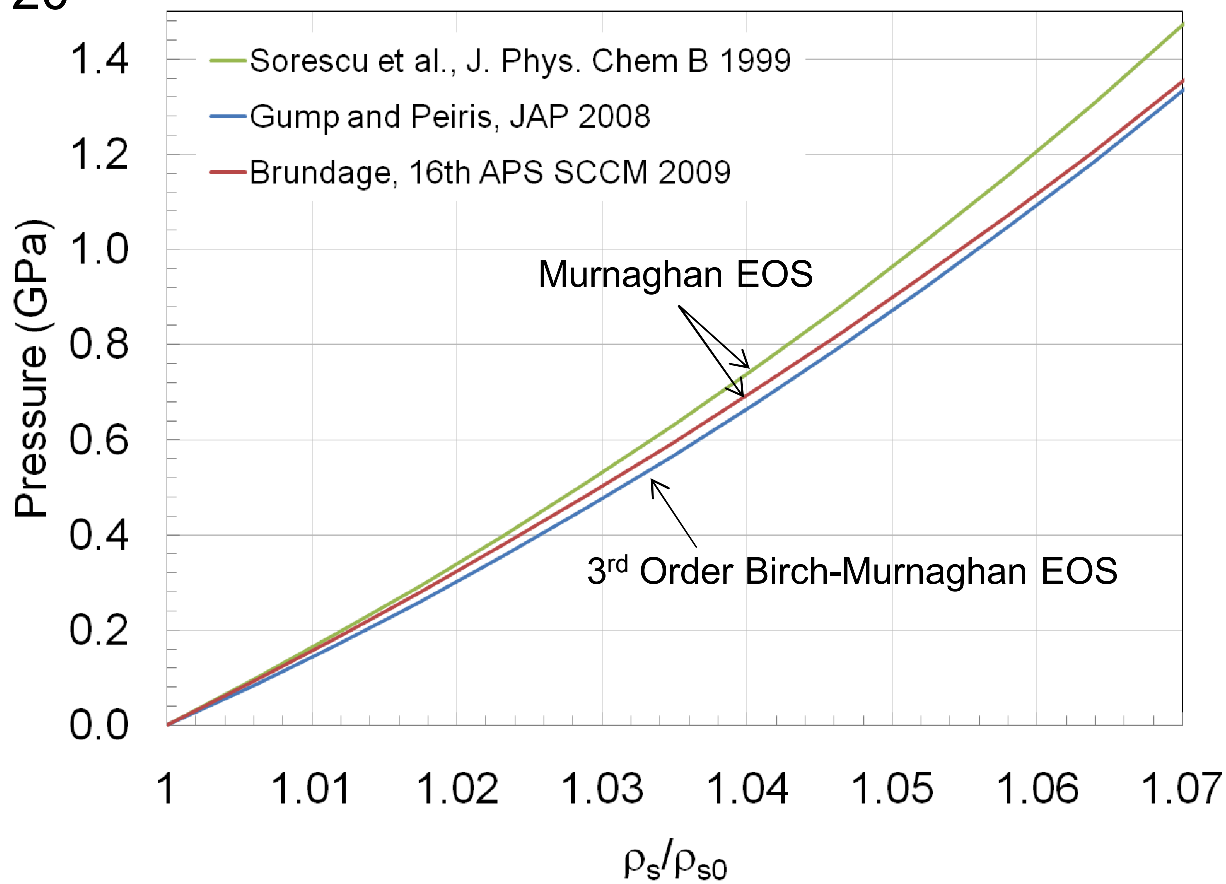
- Isothermal EOS for ε CL-20

$$P = \frac{B_0}{B_0'}\left[\left(\frac{\rho_s}{\rho_{s_0}}\right)^{B_0'} - 1\right]$$

$$B_0 = 15.03\ \text{GPa} \qquad B_0' = 8.07$$

- PMMA Hugoniot

$$U_s = 2.76 + 3.62u - 5.64u^2$$



Experiments measuring back-surface particle velocities

- Additional tests conducted with the pressed CL-20 powders installed in the target assembly.
- Impacted by a Kel-F impactor at velocities up to 0.7 km/s.
- Back-surface particle velocities compared to model output using the Baer-Nunziato Multiphase model implemented in CTH along with the CL-20 compaction data.
- Data show evidence of elastic precursors.

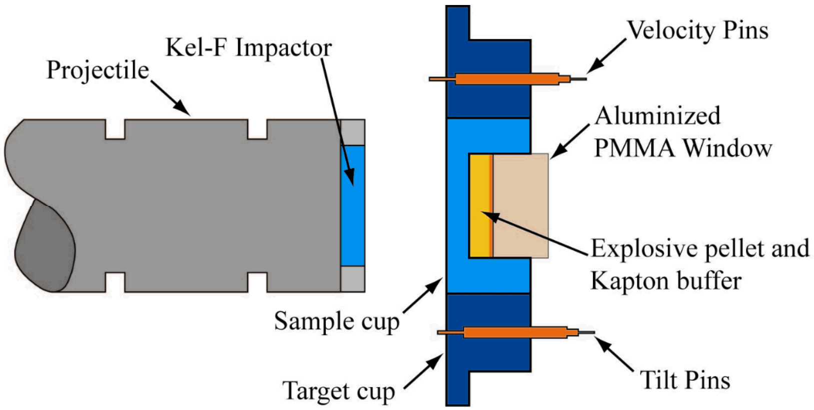
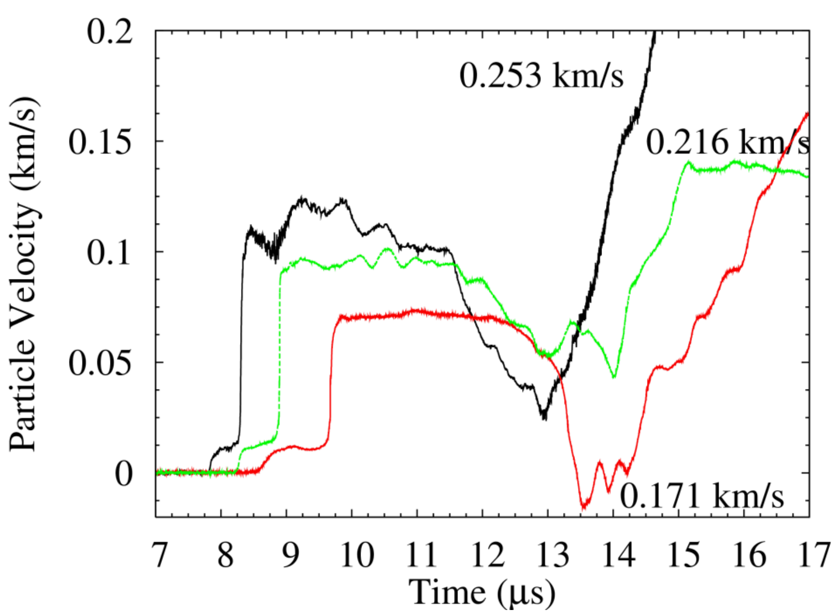
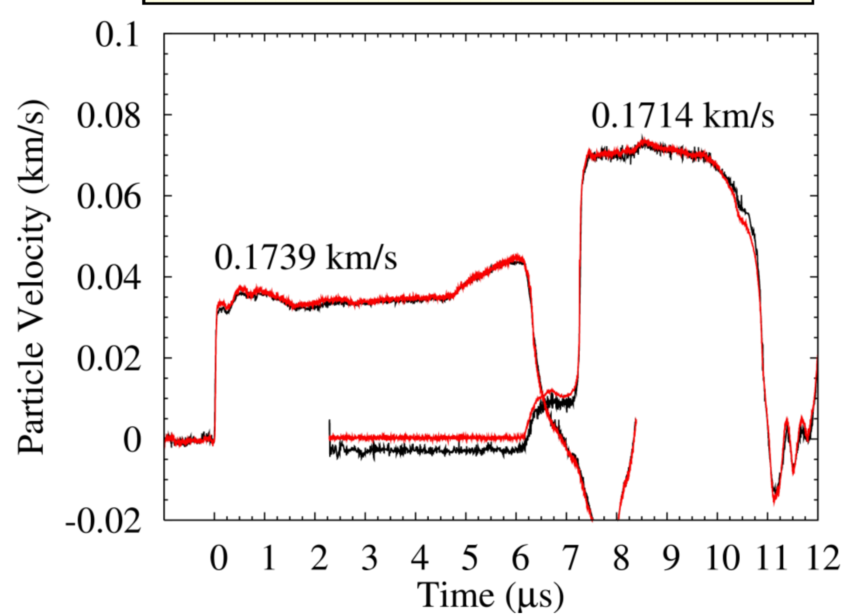


Illustration of projectile and target assembly to measure back-surface particle velocities.



Effect of impact velocity on back-surface particle velocities



Comparison of front and back-surface particle velocities