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Shock Thermodynamics Applied Research

Equation of State of an Aluminum-Teflon Mixture

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Harnessing Extreme Environments

U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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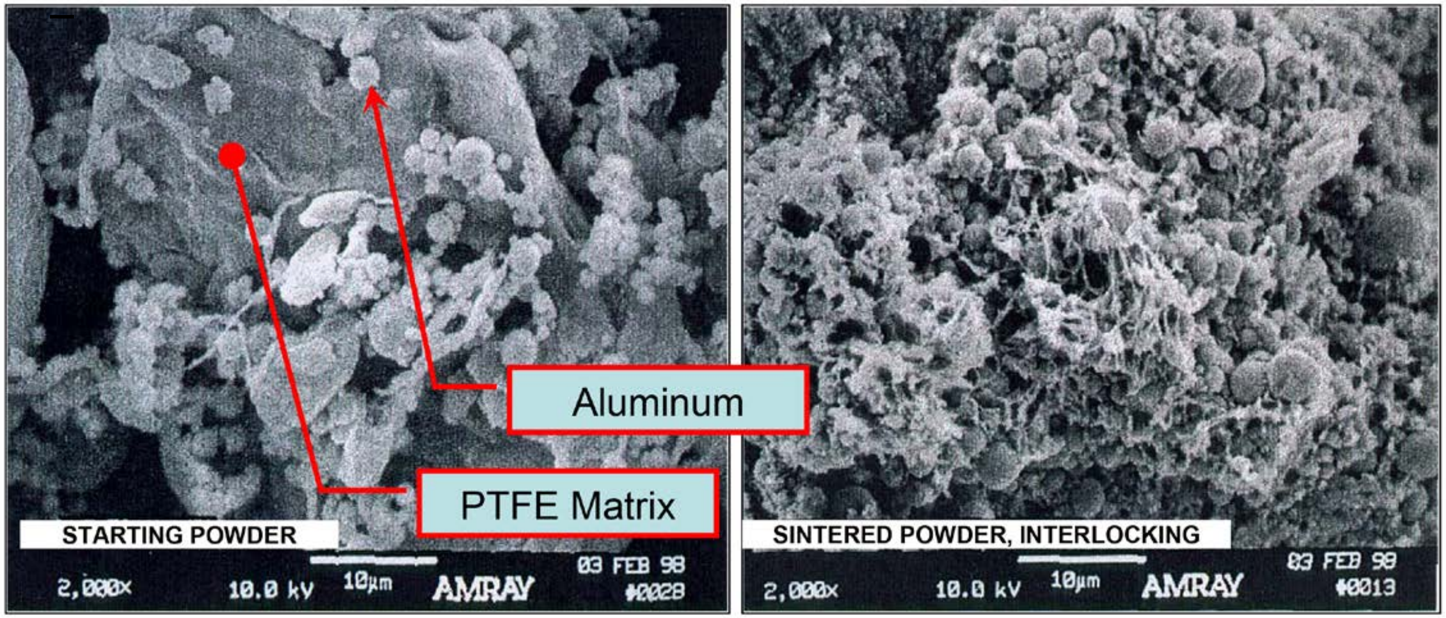
Introduction: Material Properties of Aluminum-Teflon

- *Physics based modeling to capture deformation process resulting from Impact Shock effects*
- *Equation of State (Hugoniot) experiments to provide parameters needed for developing physics based models*
- *Compare experimental results with model*
    - *Experimental data comparison in unreacted/reacted regime*
- *Assess materials for EOS data for shock-induced chemical reactions*
    - *Is there evidence of exothermic solid-state reactions in the experimental data?*

Material[1]

- Pressed and Sintered PolyTetraFluoroEthylene(PTFE) - Teflon®
  - Dupont 7C
- Filler Material
  - 5 µ Spherical Aluminum Powder
  - 25% Weight

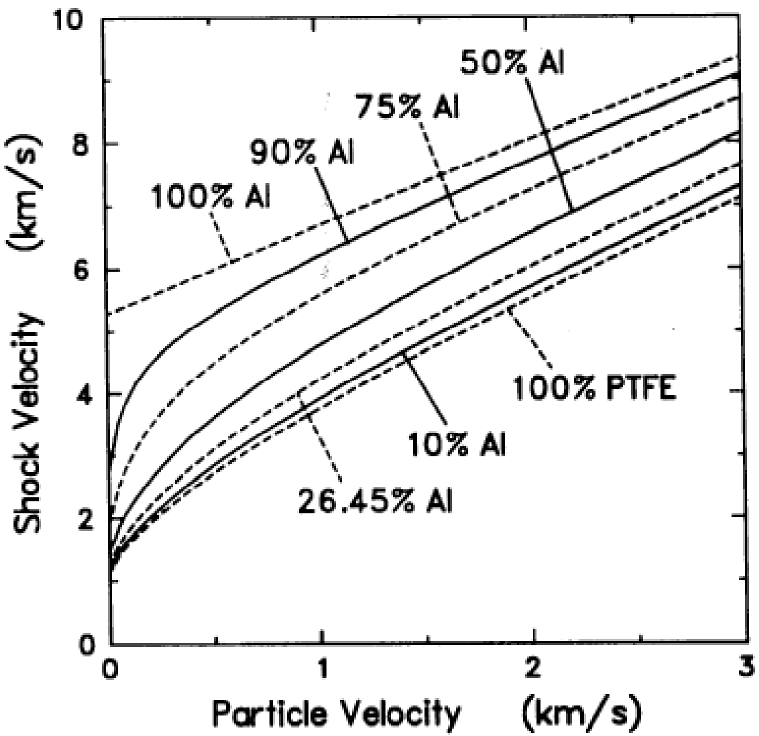


- Aluminum (~5um) initially mixed with PTFE (~35)
- Aluminum interlocked with PTFE matrix during sintering process
- PTFE matrix provides primary load path and dominates mechanical response
- Aluminum inhibits motion of PTFE matrix during load[2]

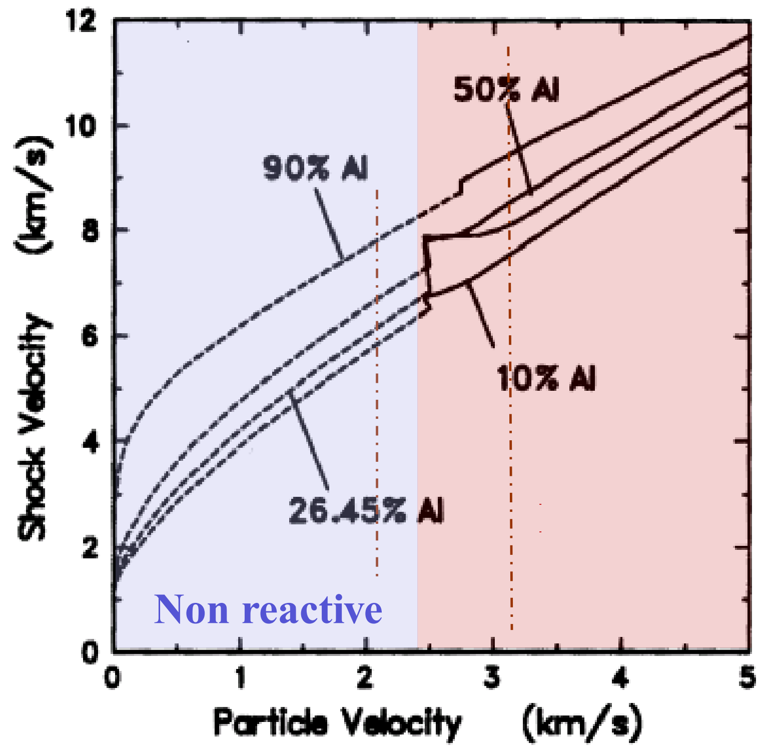
[1] G. Kirby, R. et. al., NSWC Dahlgren, VA,International Conference on Plasticity, July 7-10, 2003, Quebec Canada
[2] Patent US 6547993 B1, Process for making polytetrafluoroethylene-aluminum composite and product made, Apr 15, 2003

Kerley EOS Model for Al/PTFE [3,4]

Calculated Hugoniot for Al-PTFE mixtures



Calculated Hugoniot for Al-PTFE mixtures with no chemical reaction and chemical reaction zone



- Kerley's Equation of State model: Experiments must be spanned over a wide range of pressure states to obtain material property data of complex mixture
- Model suggests, 26.45% mixture yields largest jump in shock velocity—Reaction?

[3] Equations of State for Aluminum-Teflon Mixtures, a report prepared for NSWC, Dahlgren Division G. I. Kerley, Consultant, November 1997, (KPS97-7)
[4] A Reactive Equation of State Model for Teflon, a report prepared for NSWC, Dahlgren Division G. I. Kerley, Consultant, October, 1996, (KPS96-10)

Material Property Study

Shock Loading and Release Experiments

Symmetric impact experiments to 10 GPa
(Impactor and specimen are of the same material)
Simple Hugoniot tests

Shock Loading, Release, Reload Experiments

Comprehensive study of material up to 14 GPa
Reverse Ballistic – Impact of standard Window/Plate
Accurate Sound Speeds in the Shocked State
Goal: Estimates of strength of material in the shocked state

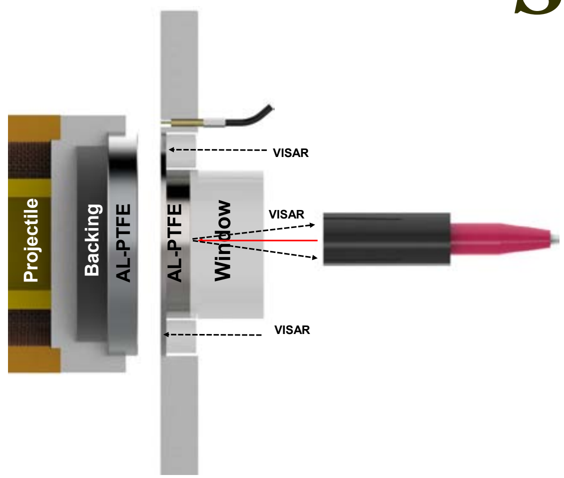
Simple Plate Reverberation experiments

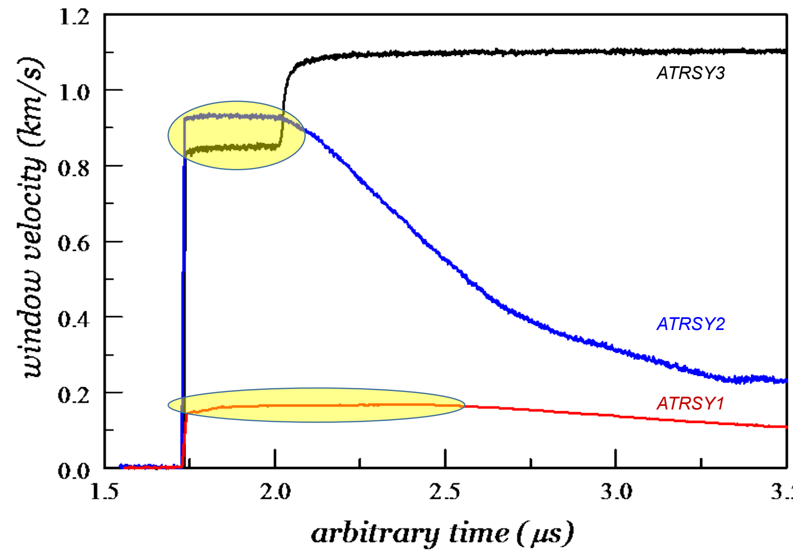
Limited study of material at high pressure where phase change may occur:
- *22 and 76 GPa*

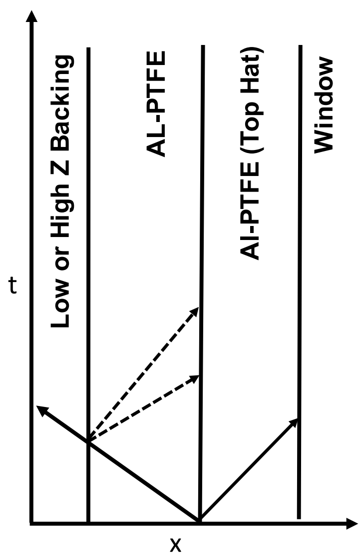
Reverse Ballistic – witness plate of know material properties
Accurate Hugoniot state
Information on average release states of material

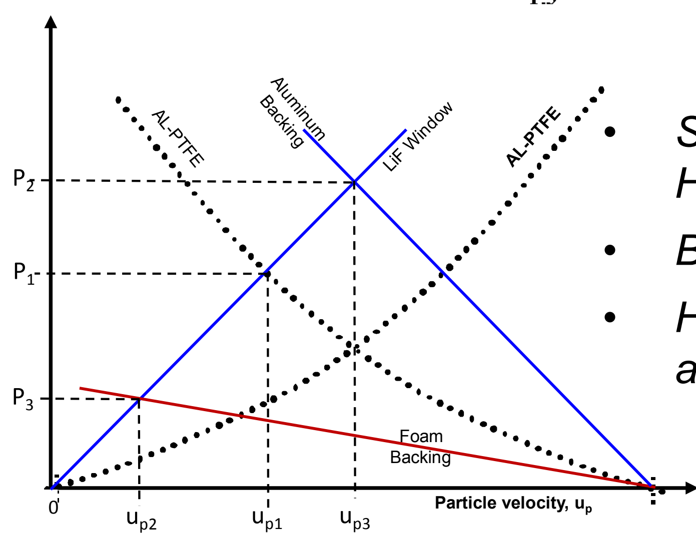
Herein, Hugoniot states only are discussed

Symmetric Impact: Shock loading-Release, Reload







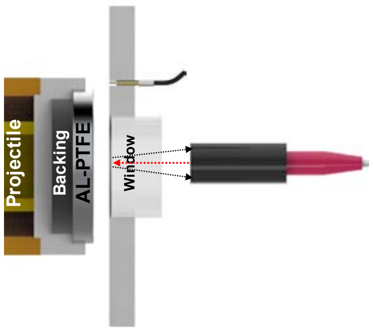


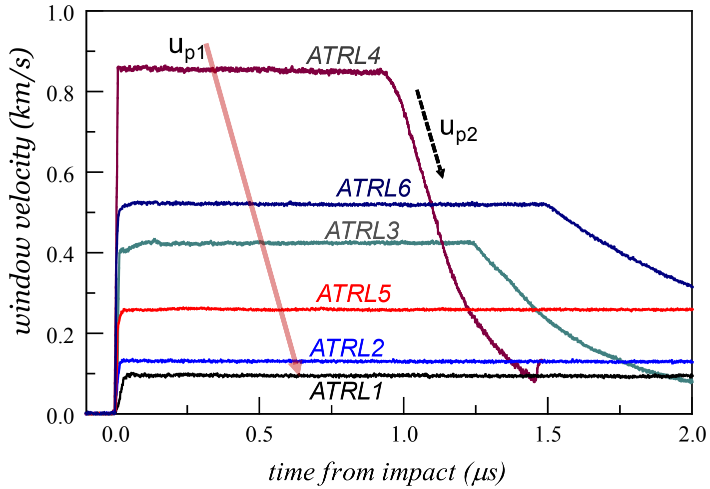
- Symmetric impact provides accurate Hugoniot properties
- Backing determines release or reload
- Hugoniot states defined by (eq. 1,2) and shown in wave profiles.

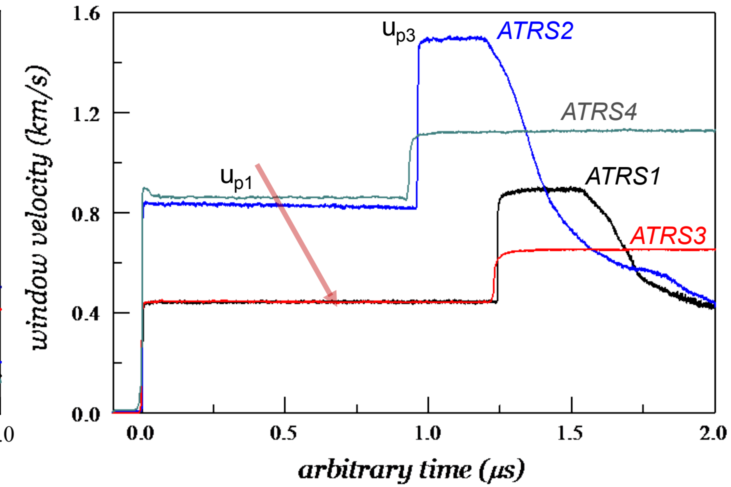
Eq. 1 $$P_{ALPTFE} = U_{sALPTFE}\ u_{pALPTFE}\ \rho_{oALPTFE}$$

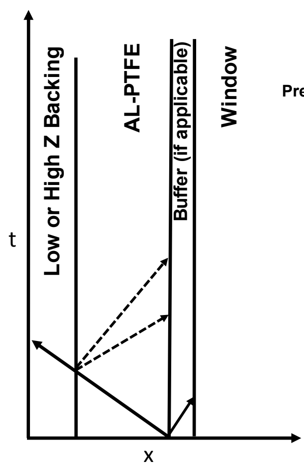
Eq. 2 $$u_{pALPTFE} = 1/2V_o \text{ (symmetric impact)}$$

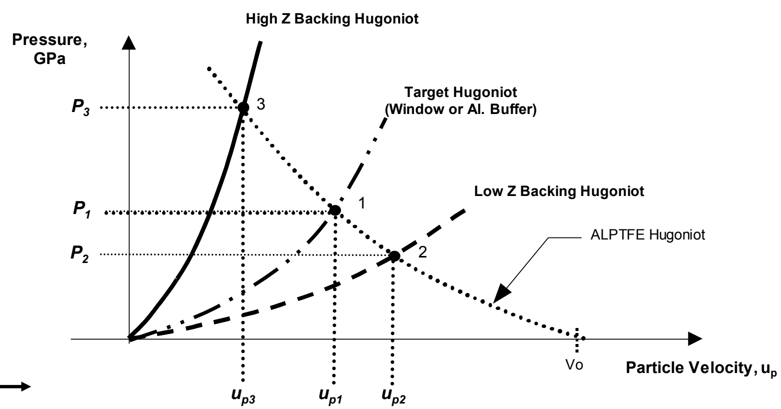
Reverse Ballistic: Shock loading-Release, Reload











- *ALPTFE impacting lithium-fluoride (buffered) window provides unperturbed shock loading*
- *Backing determines release or reload*
- *Arrival of release/reshock wave will yield wave/sound speed data in the shocked state*
- *Hugoniot states defined by (eq. 4,5) and shown in wave profiles*

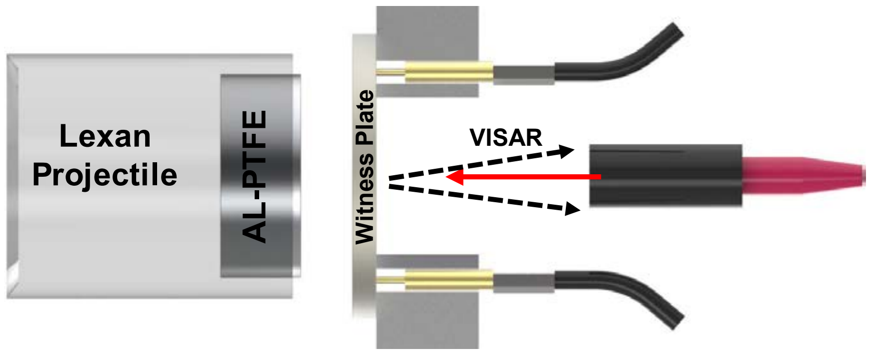
Eq. 3 $$P_1 = P_{window} = p_{window}(Cw_{indow} + Sw_{indow}\, u_{p1})up_1$$

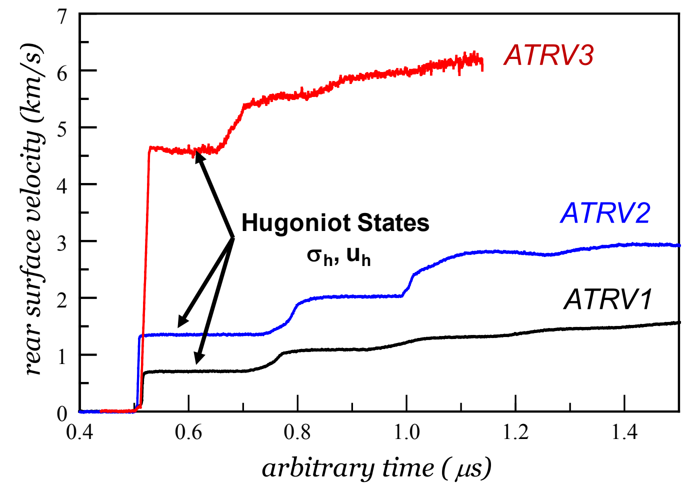
Eq. 4 $$\Delta u_p = V_o - u_{p1}$$

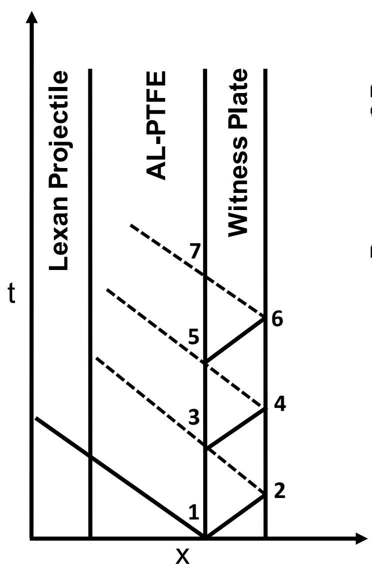
Continuity of stress, particle velocity across the impact interface describes the principle Hugoniot of ALPTFE. From this, shock velocity and relative dynamic compression can be obtained:

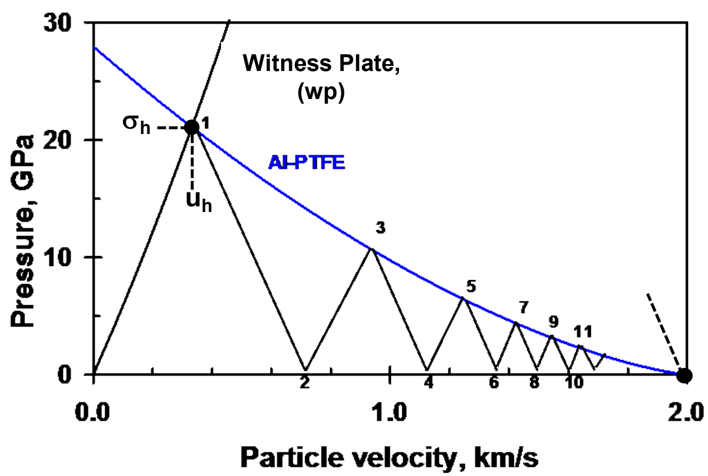
Eq. 5 $$U_{sALPTFE} = P_1/\rho_o(V_o - u_{p1}) \text{ and } \rho/\rho_o = 1/[1-(V_o-u_{P1})/U_{sALPTFE}].$$

Plate reverberation experiments







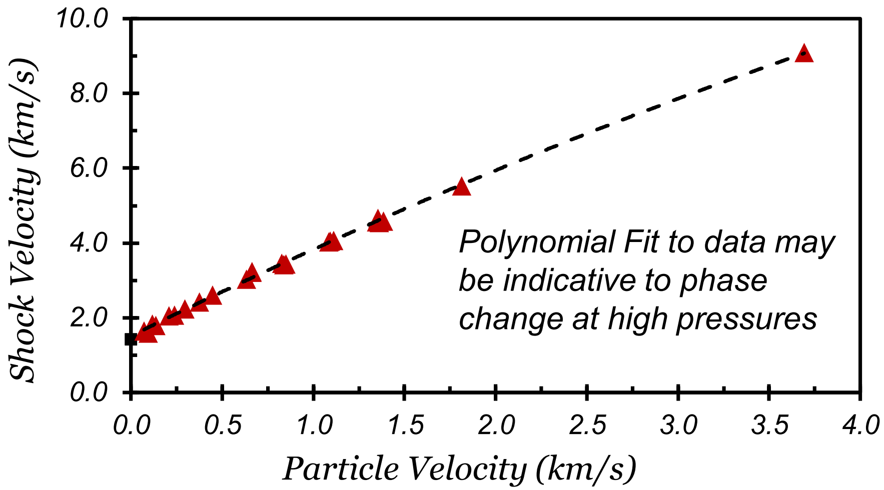


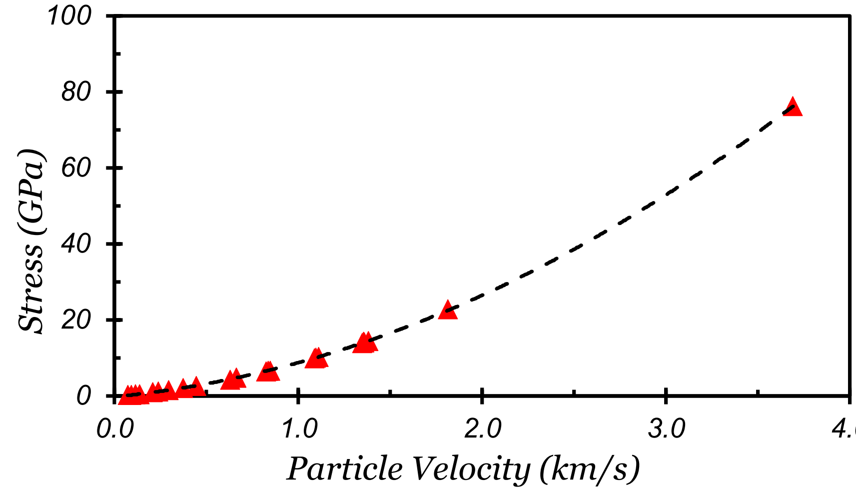
- *Extend shock loading data to above 22 GPa up to 76 GPa*
- *Velocity profiles contain detailed information regarding compression and subsequent average release properties of the ALPTFE.*
- *Hugoniot states defined by (eq. 5,6) and shown in wave profiles.*

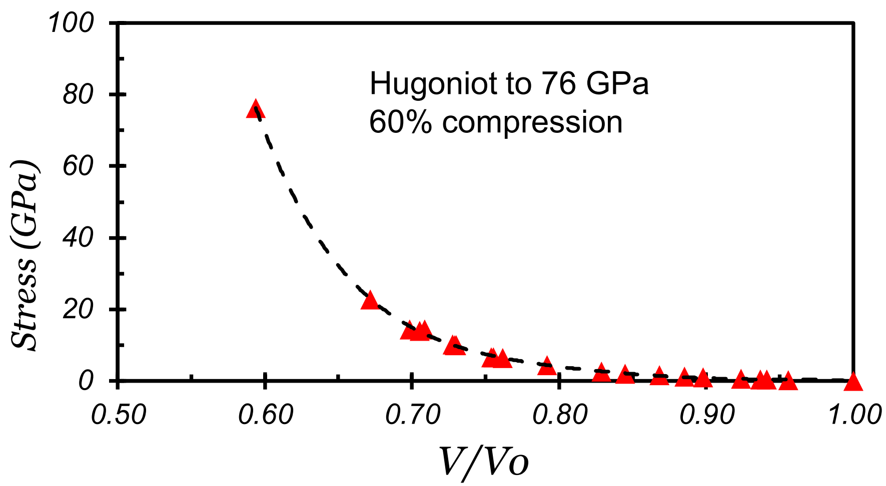
$$Eq.5 \qquad u_h = V_o - u_{wp} = V_o - \frac{u_2}{2}$$

$$Eq.6 \qquad \sigma_h = \sigma_{wp} = \rho_{wp} C_{wp} \frac{u_2}{2} + \rho_{wp} S_{wp} \left(\frac{u_2}{2}\right)^2$$

Hugoniot Results

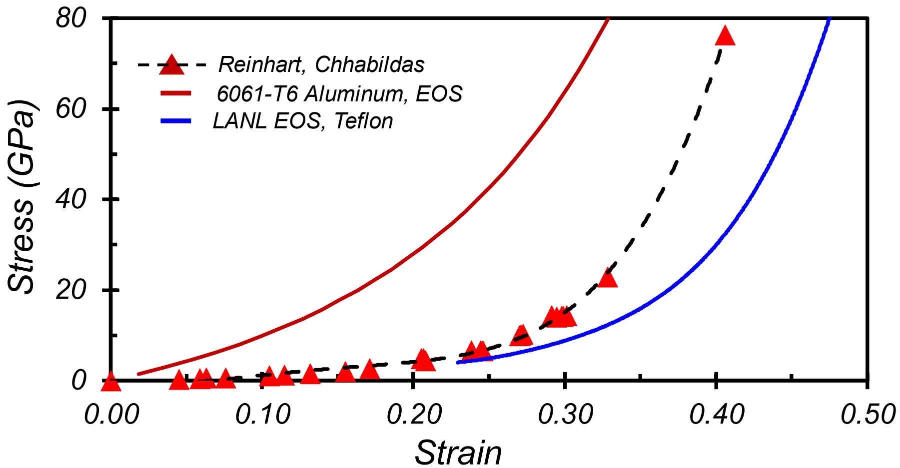


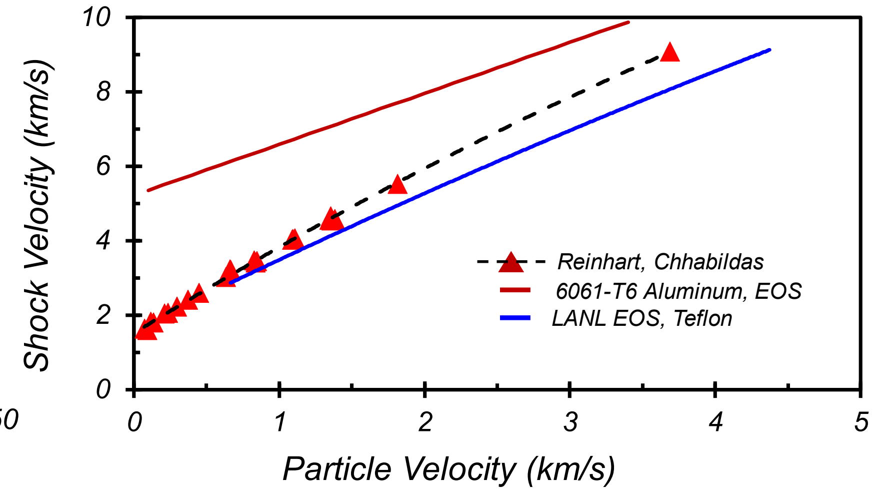


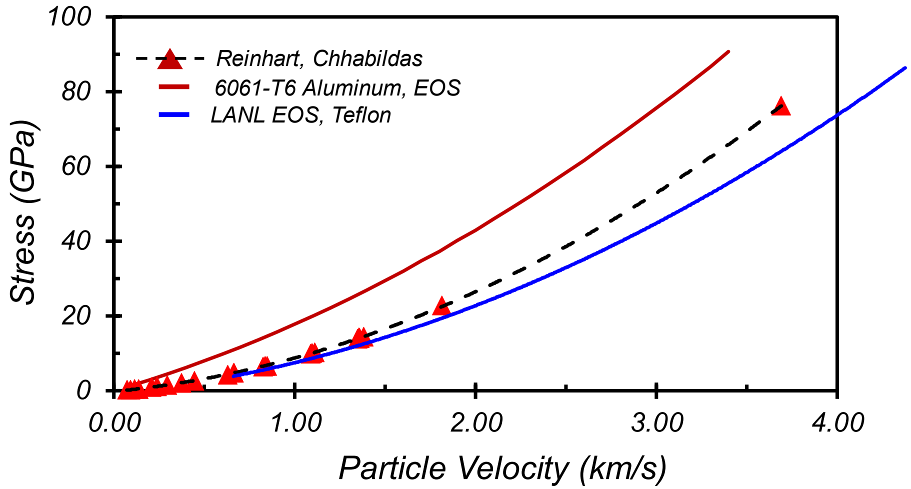


- Shock velocity, Stress vs. particle velocity appear well behaved
- *Volume compression determined to a stress and strain of 76 GPa and 0.6, respectively*
- *Acoustic velocity measured at 1.60 km/s*

Results: Comparison of AL-PTFE to constituents

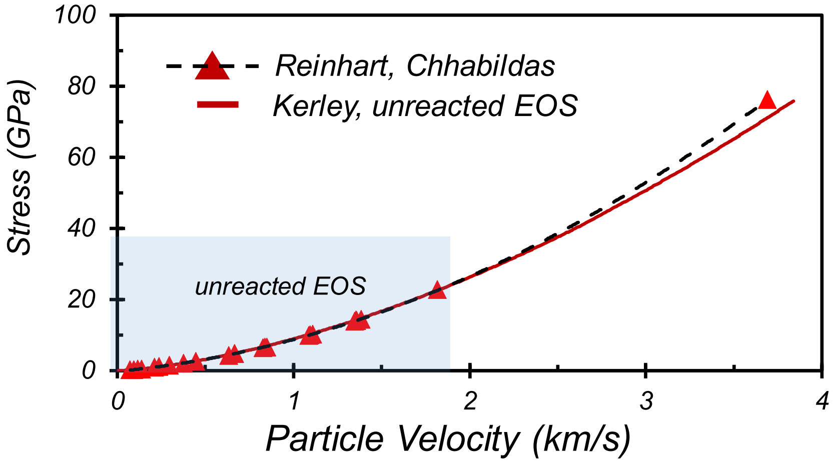


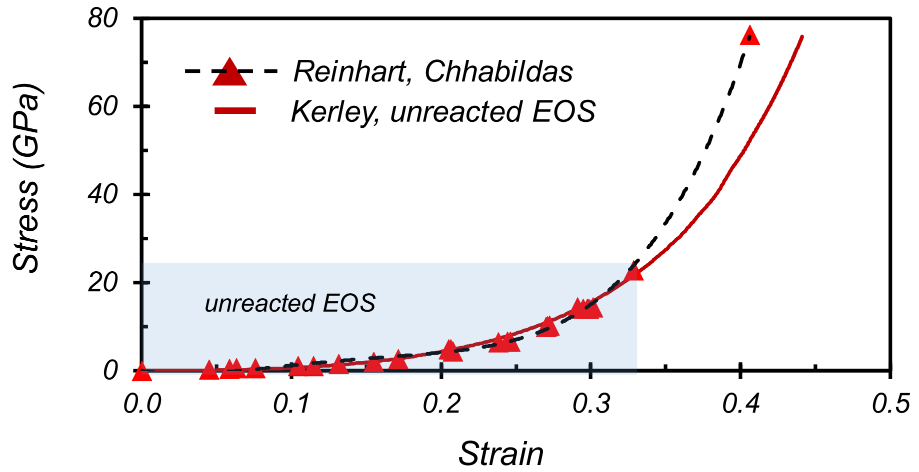


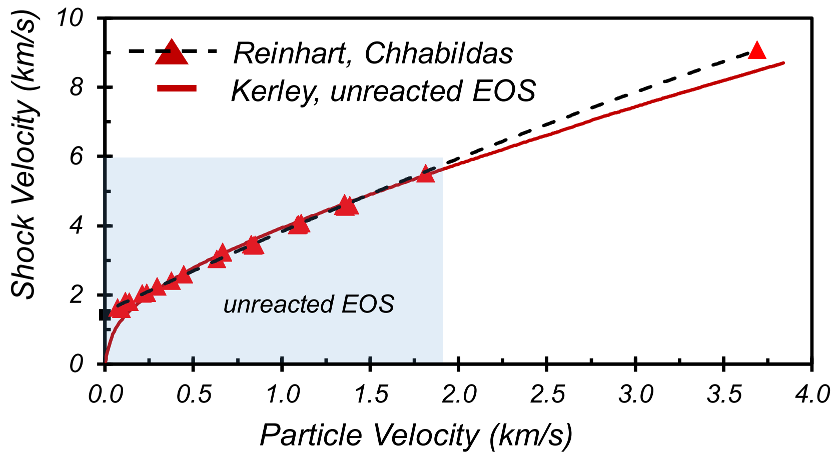


Mixture indicates stiffer response

Results: Comparing experimental data to model

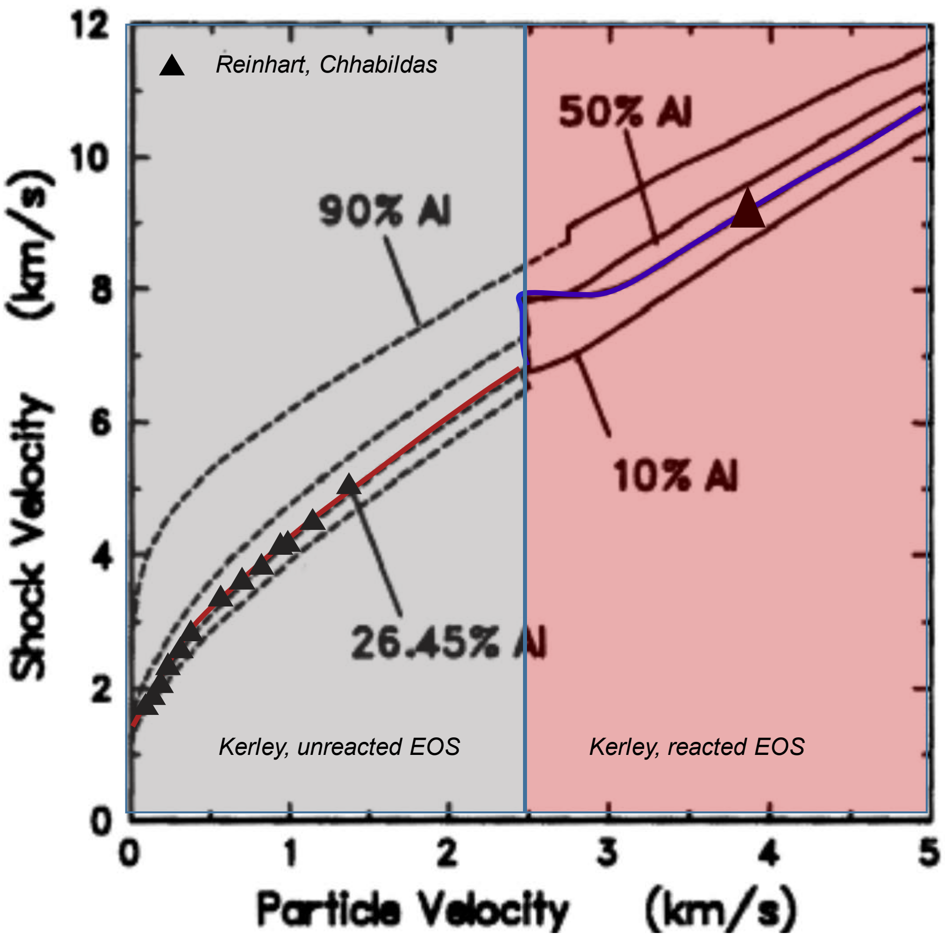






- Excellent agreement to particle velocities of ~2km/s & ~ 22 GPa
- Excellent agreement with model in unreacted regime
- More data required in region of suspected chemical reaction

Agreement with model



- Agreement with Kerley's EOS is excellent both in the unreacted and reaction regimes
- More experiments required in to probe reaction area

Conclusion

- *A Comprehensive study of Al/PFTE up to 76 GPa*
- *The EOS appears to be consistent with Kerley's predictions*
- *Stay tuned for additional results – reshock/release states*
    - *Strength Estimates*

- *Acknowledgements:*
    - *Leonard T. Wilson*
    - *John Cogar*