Oak Ridge National Laboratory

Project: mat185

2020 DOE Vehicle Technologies Office Annual Merit Review Poster

Hybrid Manufacturing of Additive Manufactured Interpenetrating Phase Composites (AMIPC)*

**** Subtask 3A2 under the** Powertrain Materials Core Program (PMCP)*

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6/3/2020

Powertrain Materials Core Program & Subtask 3A2

Timeline/Budget

- Budget: $220K/5 years
- Program Start: Oct 2018
- Program End: Sept 2023*
- 30% Complete

FY20 Program Research Thrusts	FY20 Budget	Participating Labs
1. Cost Effective LW High Temp Engine Alloys	$1.05M	ORNL
2. Cost Effective Higher Temp Engine Alloys	$1.525M	ORNL, PNNL
3. Additive Manufacturing of Powertrain Alloys	$1.075M	ORNL
Subtask 3A2 Hybrid Manufacturing of Additive Manufactured Interpenetrating Phase Composites (AMIPC) (This Project)	**$220K**	**ORNL**
4A. Advanced Characterization	$1.025M	ORNL, PNNL, ANL
4B. Advanced Computation	$0.60M	ORNL
5. Exploratory Research: Emerging Technologies	$0.75M	ORNL, PNNL, ANL

Barriers and Technical Targets

- High energy impact for piston survivability of knock and SPI
- Conventional material property relations limiting material selection
- Heterogeneous material systems are promising technologies with further exciting opportunities for development

Partners

- Program and Subtask 3A2 Lead Lab
  - Oak Ridge National Lab (ORNL)
  - Thrust 4 (ORNL)
- Partners on Subtask 3A2 (this project)
  - Rice University
  - Bechtel (broader AMIPC work)

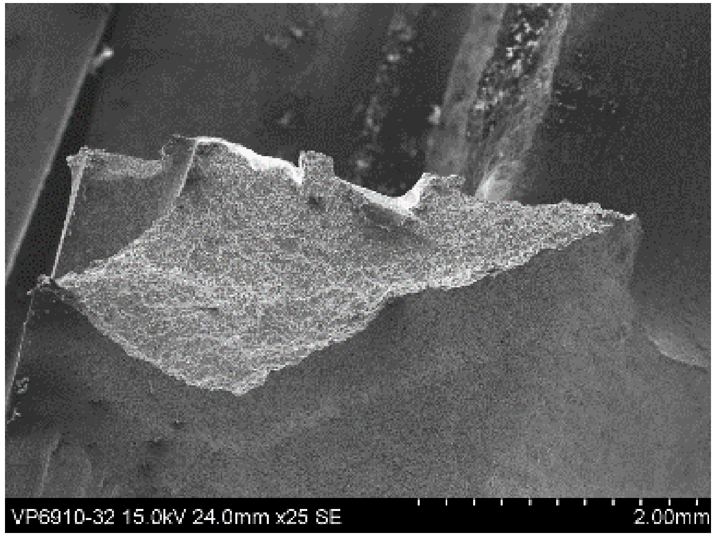
*pending yearly project review and continuation determination

Projects Aims to Address Piston Failure from Knock/SPI

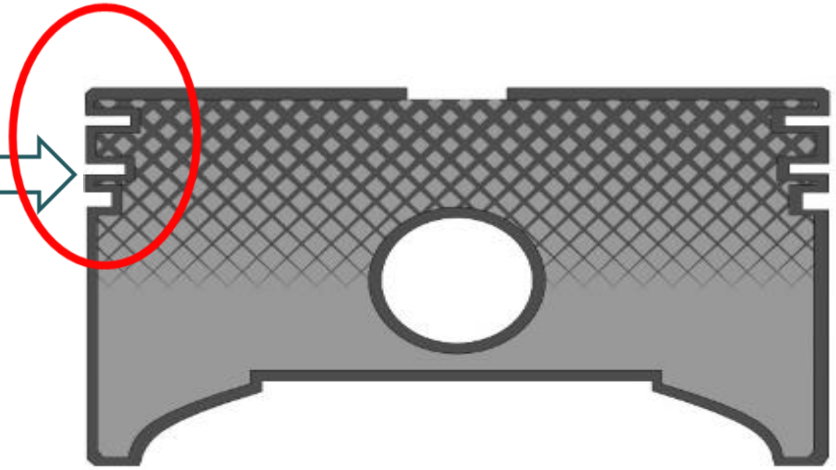
- US O.E.M. USDRIVE roadmap shows increased reliance on high efficiency
- High load survivability of knock and stochastic pre-ignition (SPI) in high-efficiency engines is lacking, in-field warranty issue from material failure
- Direct approach to produce multi-metallic components while enabling opportunities for lightweighting

Broken Piston (knock and SPI)

Catastrophic failure (single event))



high energy absorbing material and manufacturing concepts



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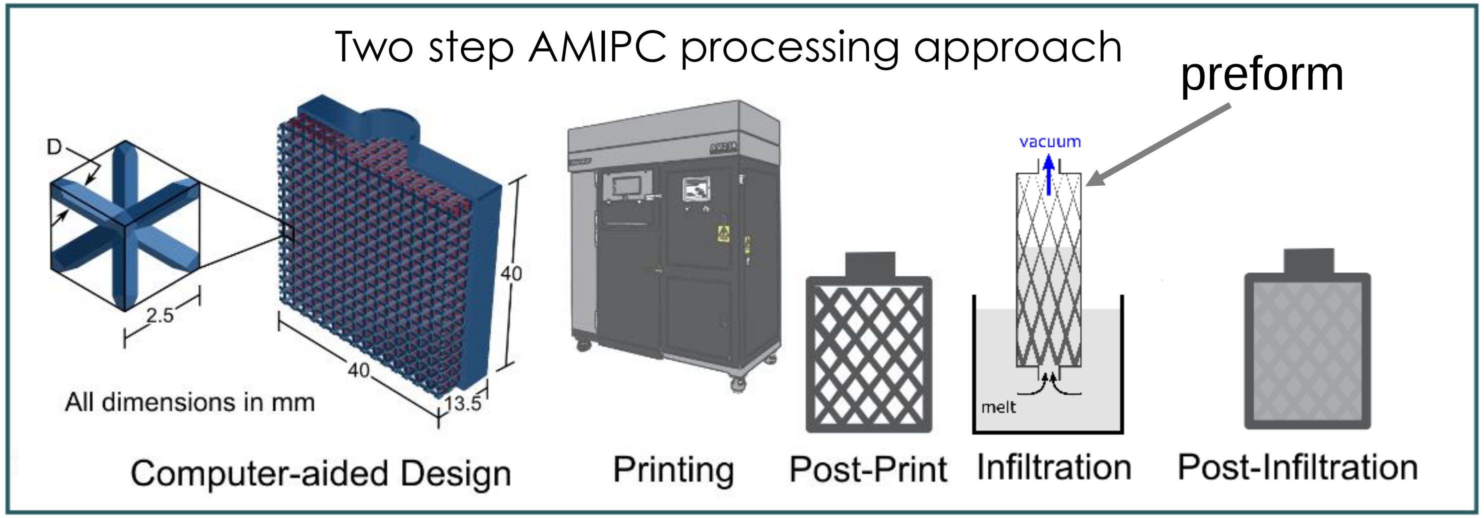
Milestones For Subtask 3A2

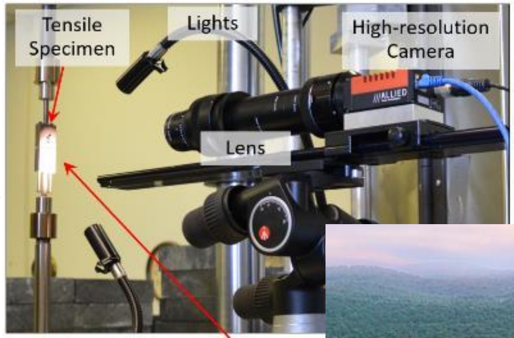
Milestone Name/Description	Planned End Date	Status
Submit manuscript to peer reviewed journal on results from measurements using DIC and corresponding simulation of AMIPC system in tension.	End of **Q2**, FY20	**Completed** Manuscript in review
Successful vacuum infiltration and specimen harvesting of aluminum in Titanium AMIPC geometries for tension and or compression testing.	End of **Q3**, FY20	**Completed** Specimens ready for testing

Hybrid Process Combining Additive Manufacturing (AM) & Melt Infiltration With Advanced Characterization at ORNL

- AM reinforcement & preform
- Infiltrate preform with lower melting temperature material
- Characterize behavior with laboratory resources
- Simulation tools used to iterate for optimization
- Scale up downselected design



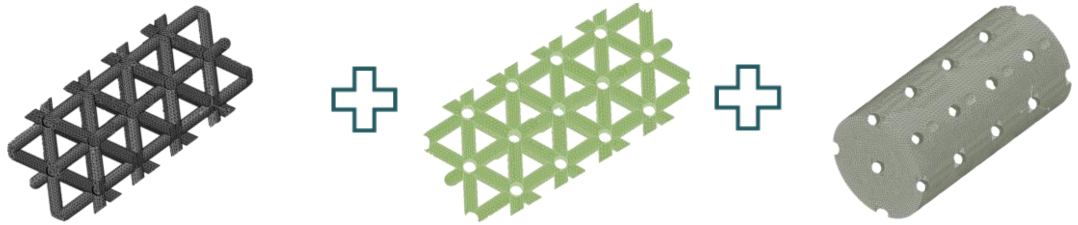
Digital Image Correlation testing



Advanced diagnostics (neutron) of stress states and constituent behaviors

Design approach Unique FEM

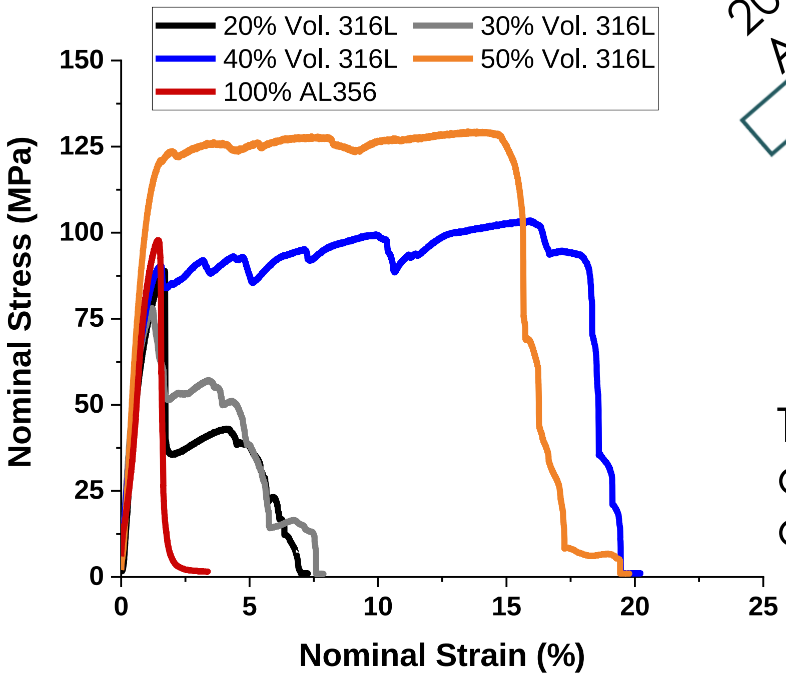
AM reinforcement interface Infiltrated matrix



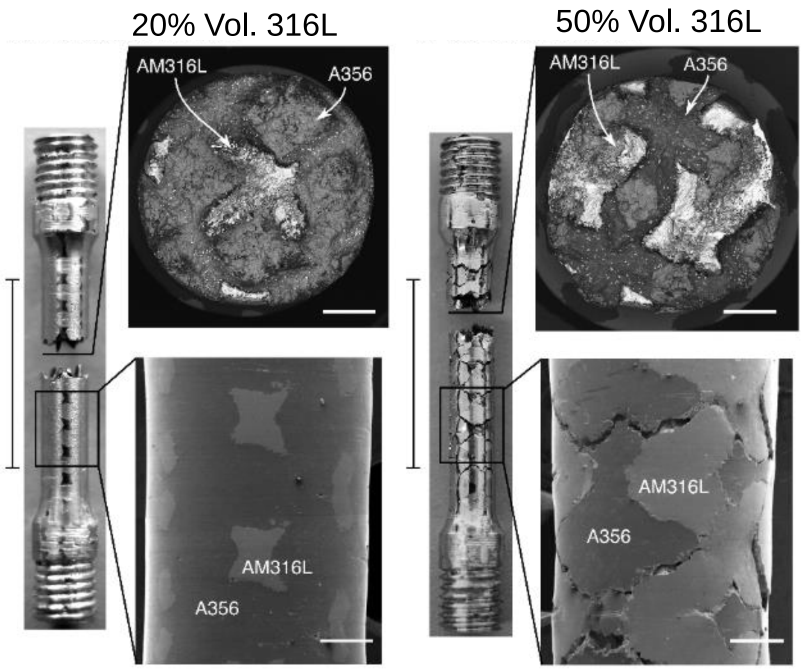
validation

AMIPC Composite Architecture Offers Dramatic Energy Absorption Increases

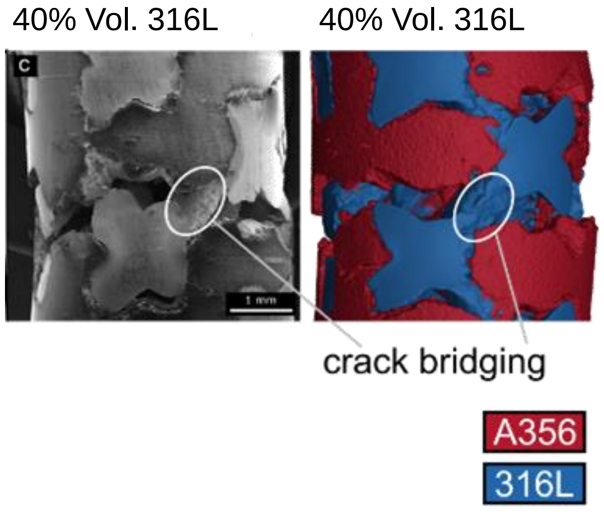
- Non-linear properties tradeoff observed
  - AM 316L Stainless Steel + melt infiltrated A356 aluminum alloy
- Directly related to energy absorption & crack arrest
- Behavior used to improve design iterations
  - Model based optimization



4X increase in strain (40 vs. 20 & 10X vs. A356)



Transition to delocalized damage



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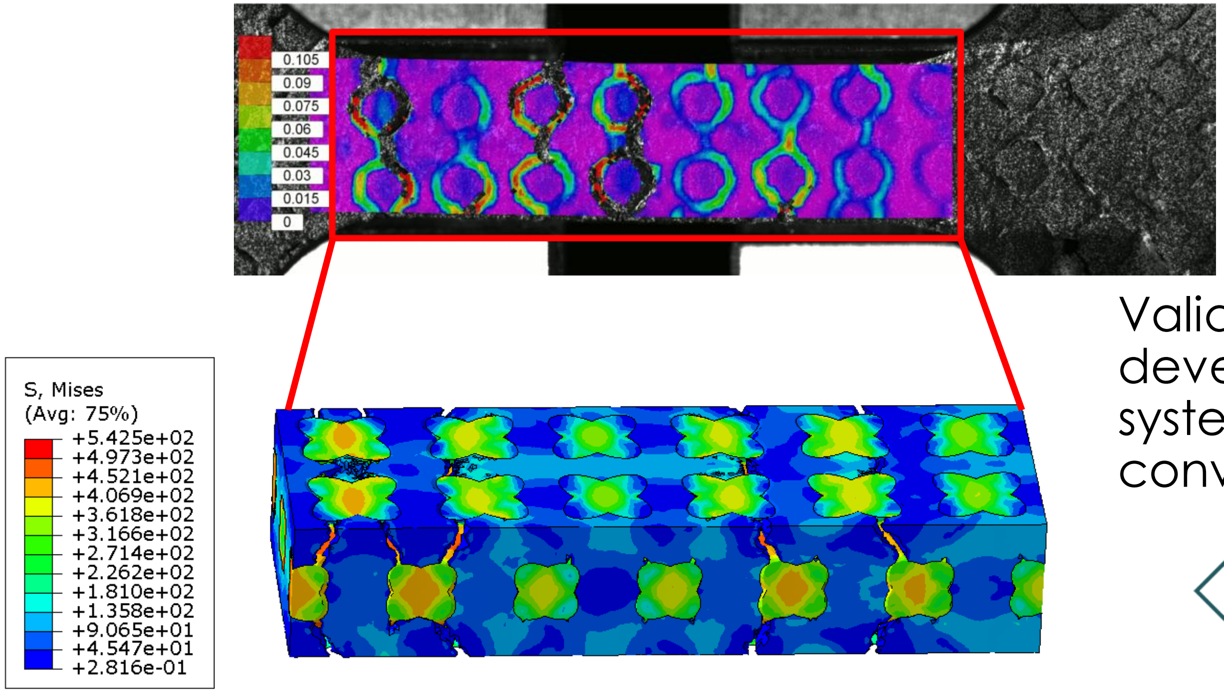
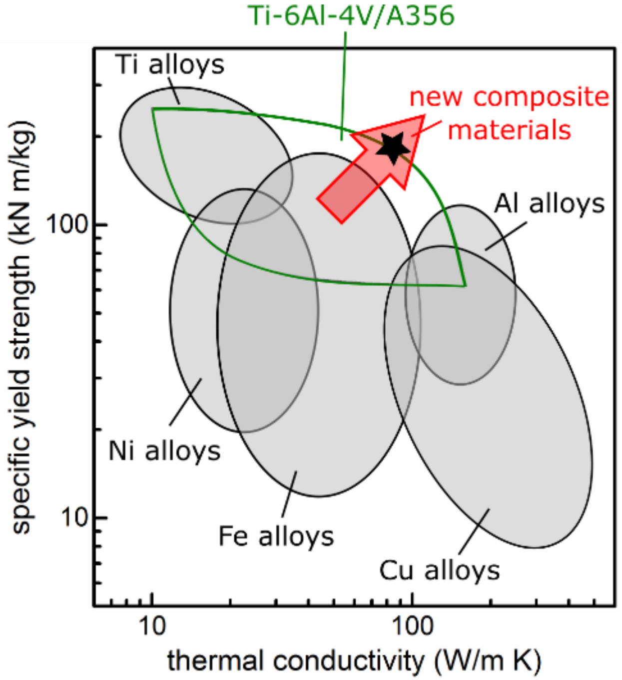
Digital Image Correlation Calibrated FE Model Highlights De-localized Failure, Mechanism(s) Under Exploration

- Delocalized damage greatly increases strain to failure
  - Directly applicable to survivability of brittle piston failure in ringland area
  - Coupling results to property relations relevant to pistons (thermal conductivity, strength) to develop new material systems



Validated FE model used to develop new material systems bridging conventional boundaries



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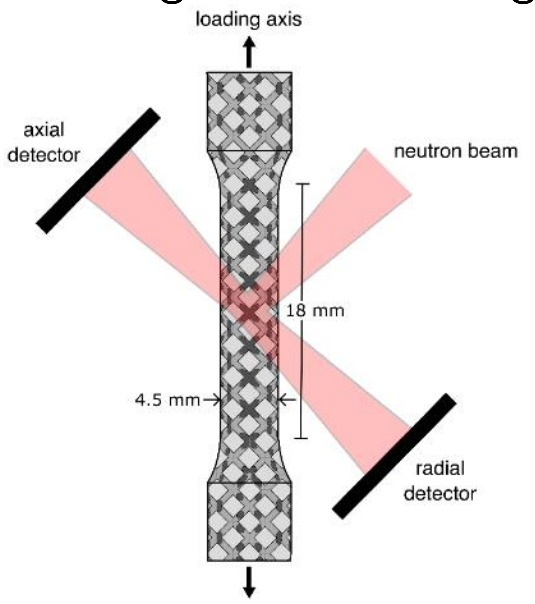
Neutron Diffraction Reveals "Finger Trap" Type Behavior in Tension, Significantly Increases Damage Tolerance

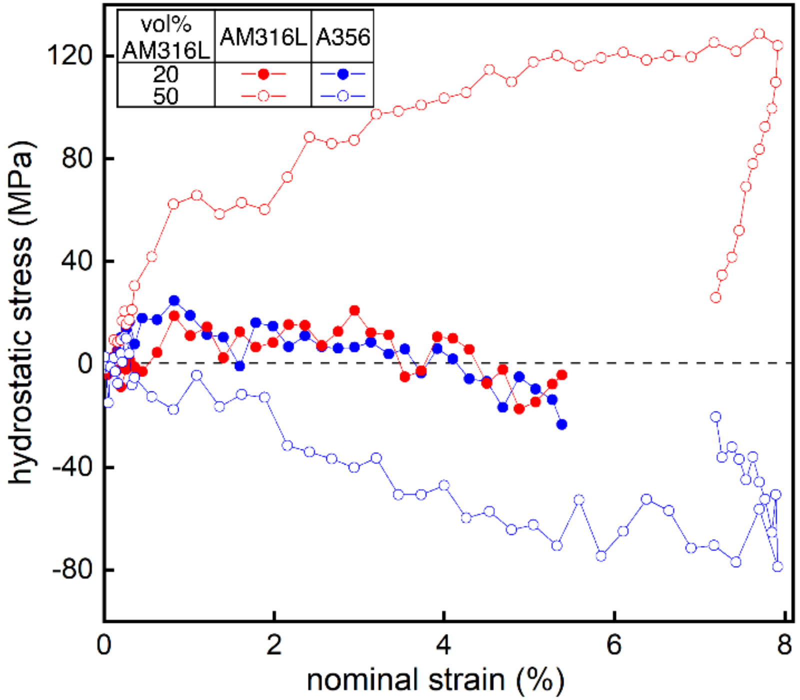
- In-situ neutron diffraction diagnostics highlight compressive stress state in aluminum reinforcement under tensile loading
  - tensile load only carried by 316L reinforcement
  - Potential to eliminate brittle failure of aluminum in piston ringland area

- Reinforcement alone must not surpass UTS to transition to high damage tolerance
  - Lattice geometry optimization is critical next step

Neutron diffraction during tensile loading



results for different 316L vol. %



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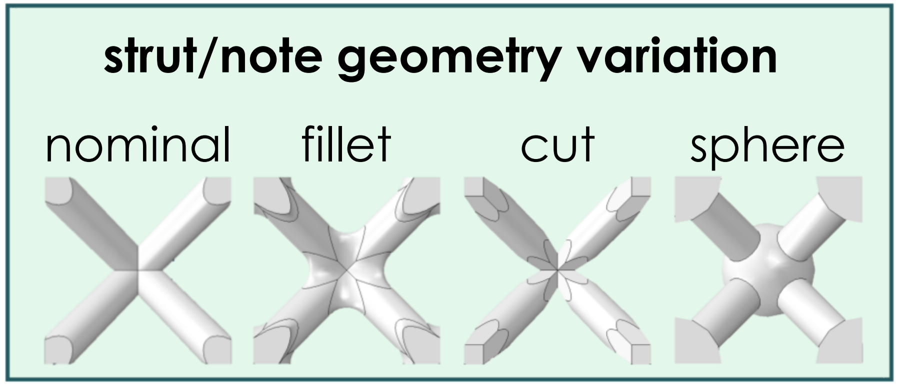
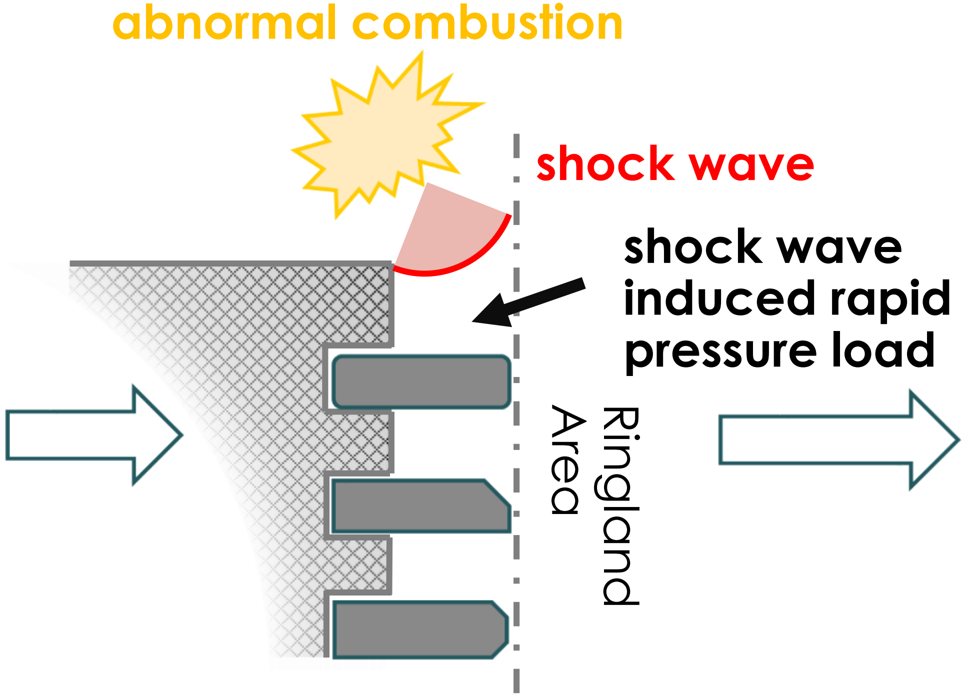
Collaboration and Coordination With Other Institutions

- Rice University
  - Vacuum casting technique development and
- VTO PCMP Core Task 4 work
  - Crystal plasticity modeling of aluminum matrix for optimization opportunity in tension loading
- Bechtel
  - Project direction advising and potential for expanded utility
- Internal ORNL collaborations
  - Spallation Neutron Source (SNS)
  - Manufacturing Demonstration Facility (MDF)
  - Advanced characterization

Shock Loading and Fatigue Guiding Future Program Path

- Lattice strut/node geometries for increased damage tolerance
- Assess geometries in mechanical testing and apply to FEM of piston geometry with parametric study of applied shock loading
- Assess fatigue properties of composite system and any geometric effects
- Physical piston build



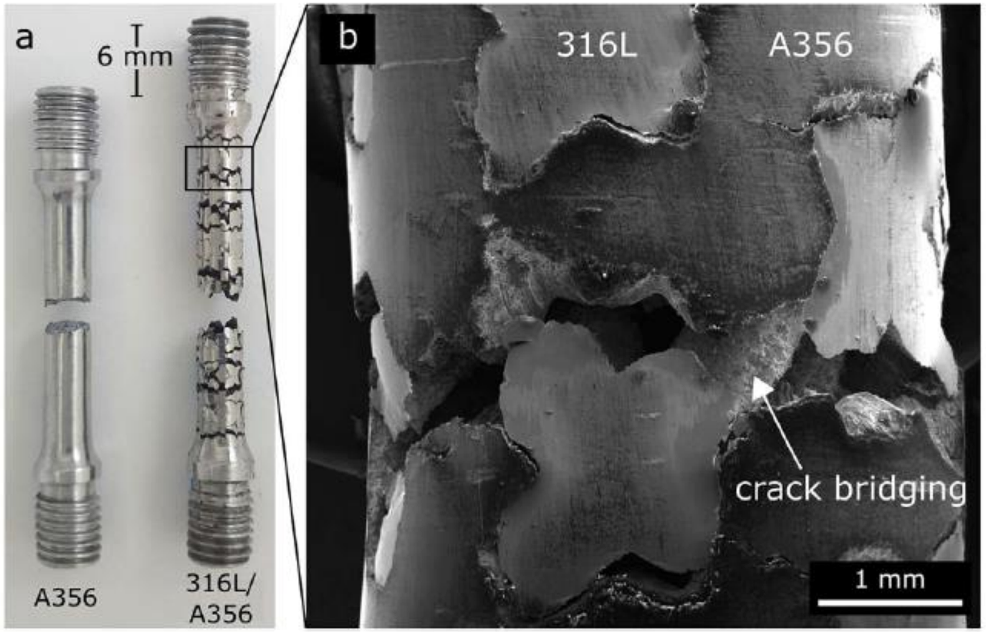


FEM of AMIPC in piston geometries with rapid shock loading applied coupled to engine measurements of knock and SPI at existing ORNL programs

Any proposed future work is subject to change based on funding levels.

Summary of Work Shows Progress to High Damage Tolerance With Novel Early-Stage Bi-Metallic System

- A bi-metallic approach combining AM and melt infiltration demonstrates very high damage tolerance
- Approach breaks conventional material tradeoffs and enables new design and efficiency opportunities
- Piston application where catastrophic local ringland failures are occurring is technology target
- Future work focuses on shock loading, fatigue, and scale up to component level problem



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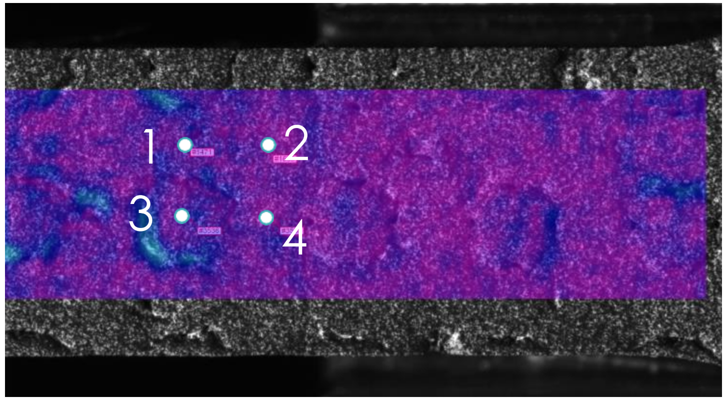
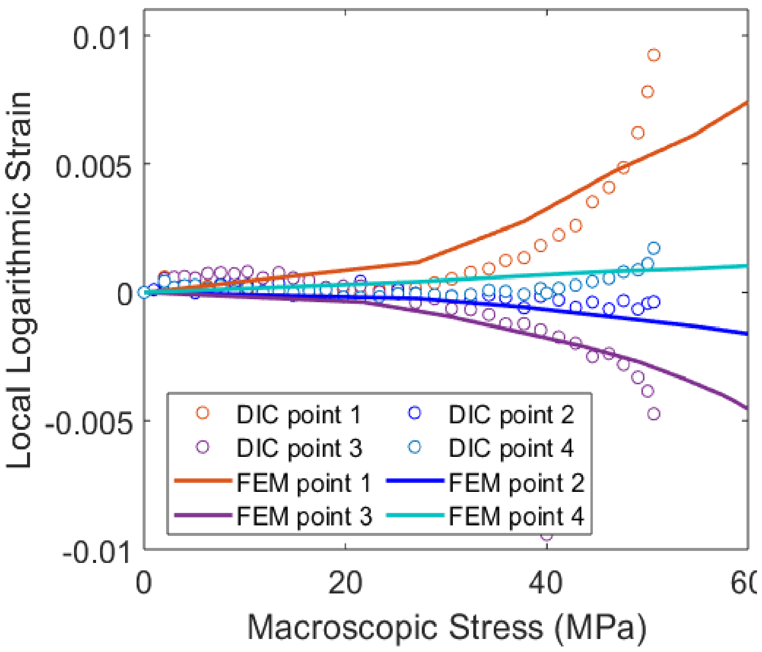
Technical Backup Slides

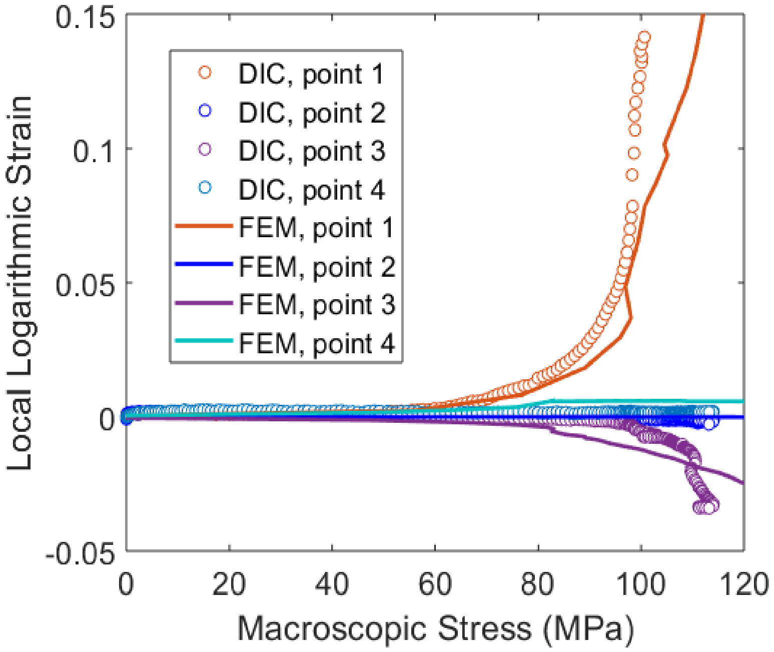
Digital Image Correlation Calibration of FE Model Shows Strong Agreement in Macroscopic Stress/Strain

- 4-point DIC calibration used for FEM tuning
- Good agreement between measurements and FEM predictions
- Tuning applied to FEM for internal geometry inaccessible to Digital Image Correlation



4 calibration points spanning lattice locations





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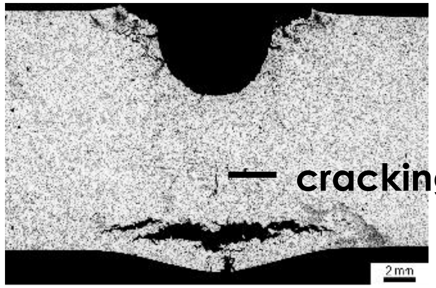
Hypervelocity impact shows high survivability increase

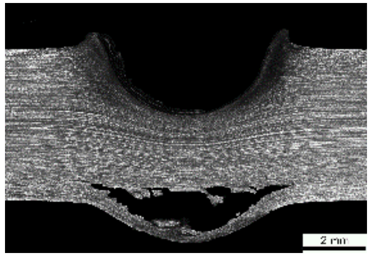
- Hypervelocity projectile impact (Mach number > 5), shows promise for high rate of energy dissipation
- Apply results to FEM of geometry and piston in future work

Monolithic Material

A356



316L (cold rolled)

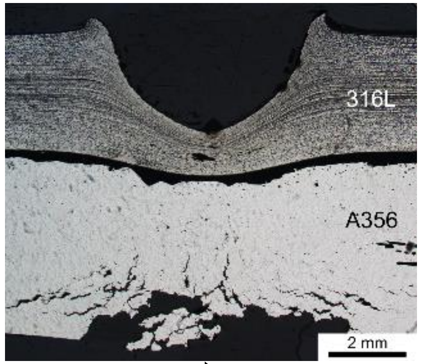


Significant deformation

Clad Designs

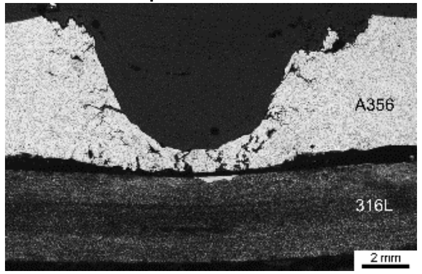
(i.e., steel ring carrier)

316L top / A356 bottom



Spall failure

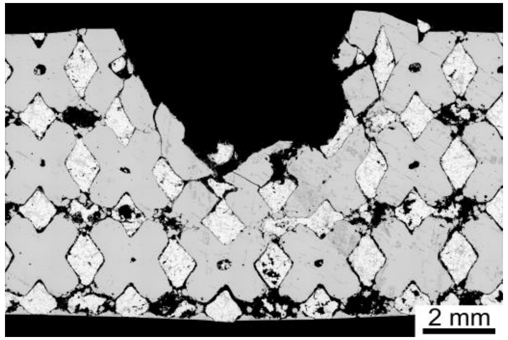
A356 top / 316L bottom



Significant deformation

This Technology

(not optimized)

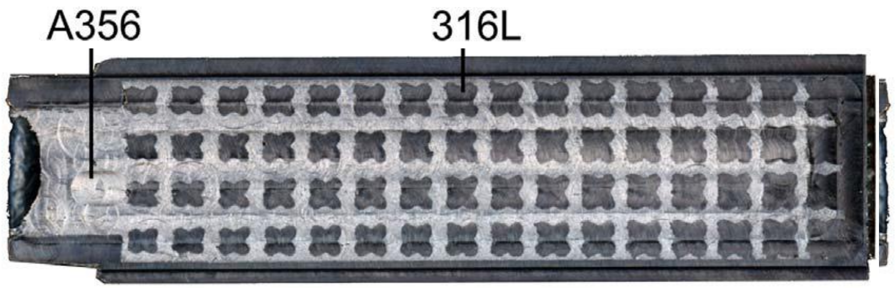


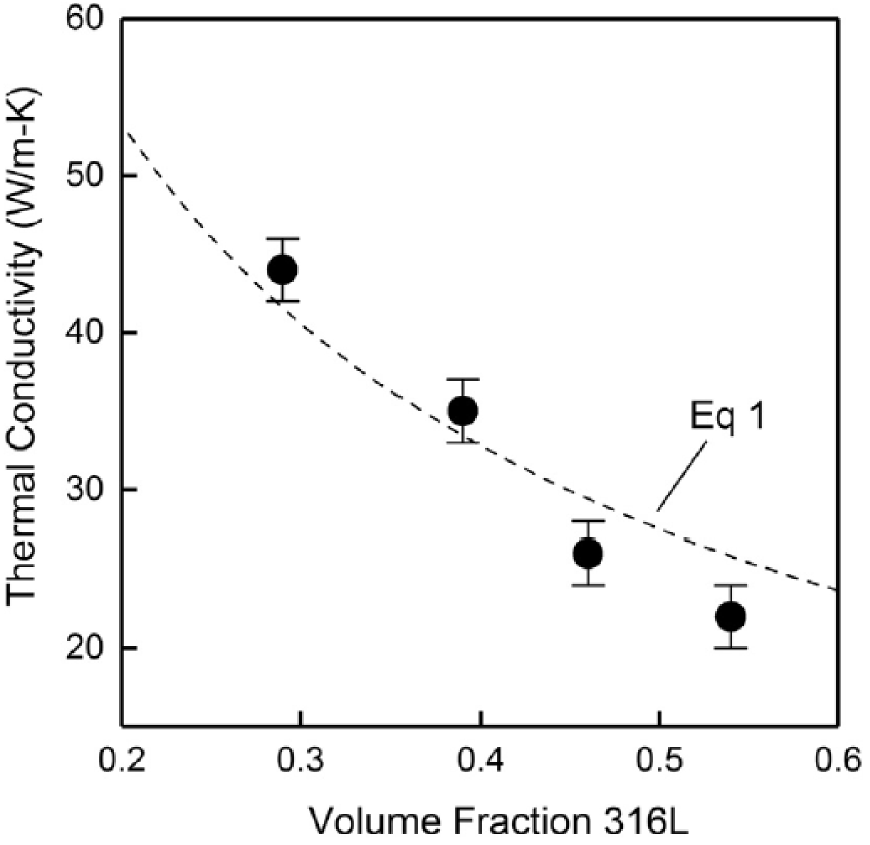
No Spalling
Reduced deformation

Images from Rice University collaborators

Non-linear thermal conductivity relation with constituents

- Non-linear blending relation of constituents enables optimization potential of thermal-mechanical behaviors
- Functionally graded material or local changes in reinforcement possibility further enhances optimization potential at local level
- Ideal relation for high strength and good thermal conductivity needed in piston top ring zone





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