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Strategies for Cost-Effective Lightweighting of Vehicle Structures

Future Composites Symposium

November 13 - 14, 2024

Marcelo Dapino
Honda R&D Americas Designated Professor

Department of Mechanical and Aerospace Engineering
NSF IUCRC Smart Vehicle Concepts
The Ohio State University

Co-Sponsors: AIM for composites; University of Delaware Center for Composite Materials, Celebrating 50 Years; sme

Outline

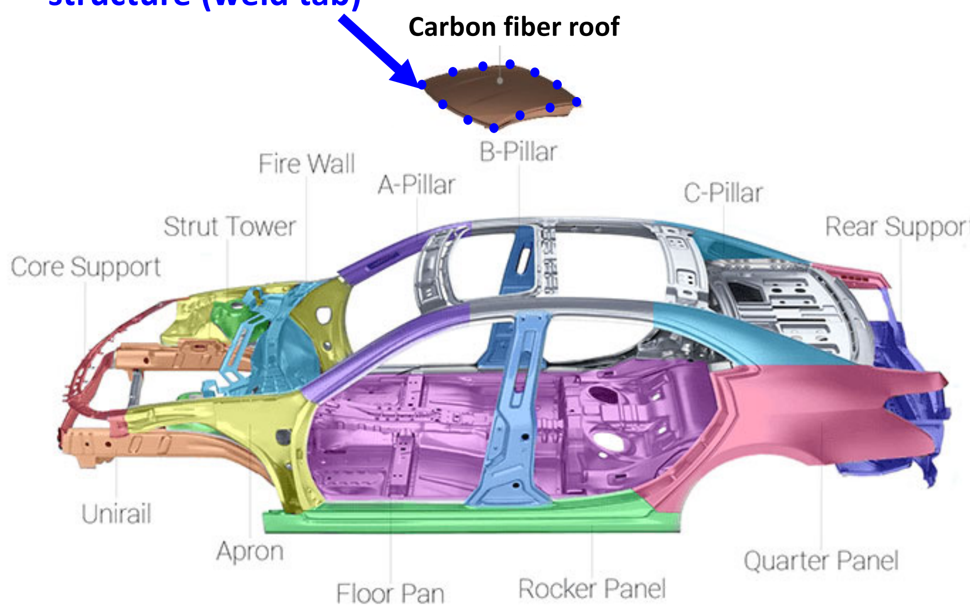
› Carbon fiber – metal joining for vehicle structures

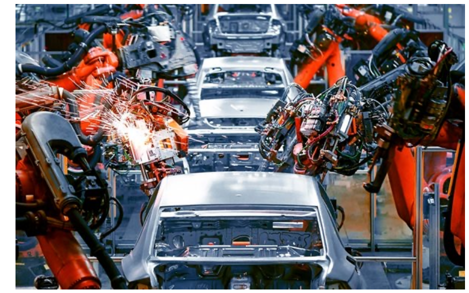
› Flexible and advanced manufacturing capabilities at OSU

Carbon fiber – Metal joining

CFRP-Al transition

FRP-metal transition structure (weld tab)



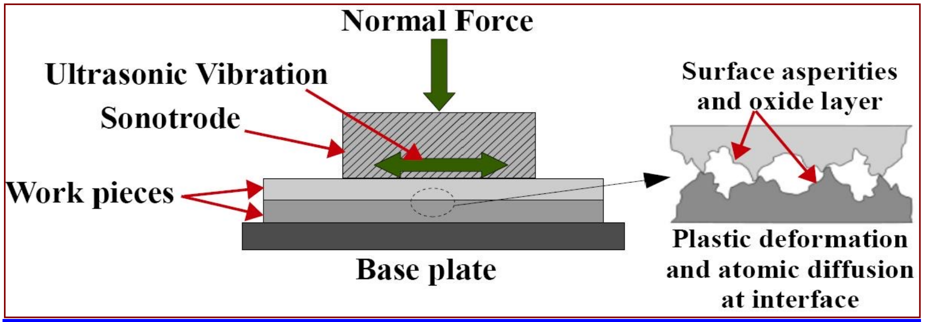


https://www.twi-global.com/technical-knowledge/faqs/what-is-spot-welding

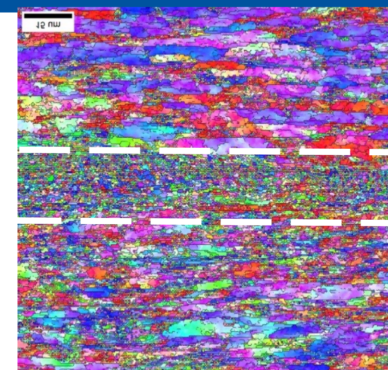
Material	Specific strength [kN·m/kg]
AA 6xxx, 7xxx	48, 220
Mild steel, Usibor	37, 190
CFRP, CF	556, 2580

Ultrasonic Additive Manufacturing - UAM

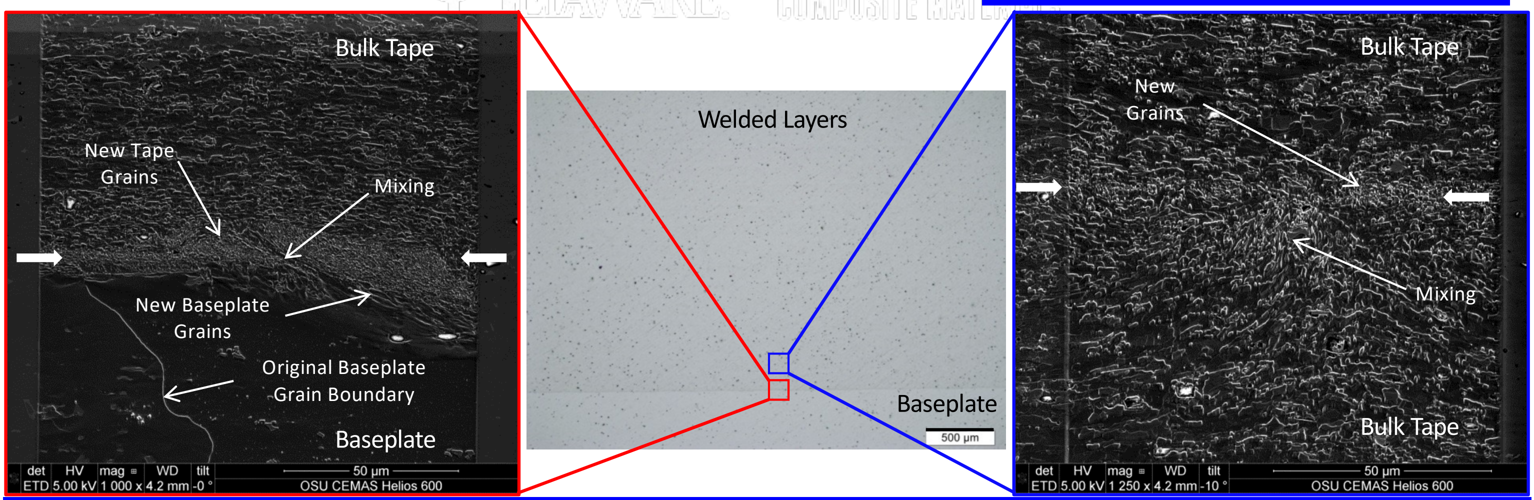
Weld Formation



Collapsing of Asperities and Local Plastic Deformation



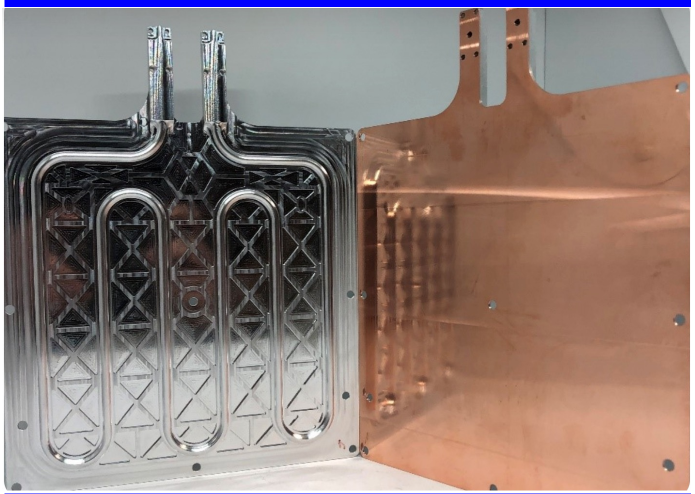
EBSD Image of UAM Interface



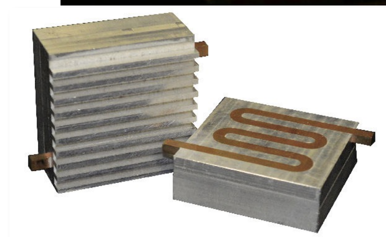
Gapless Metallic Joints

Commercial Uses of UAM

Cooling / Heat management



Multi-material parts



Fabrisonic Inc.

Precision electrical connectors

Wiegel Tool Works

Cladding / Repair

The Ohio State University

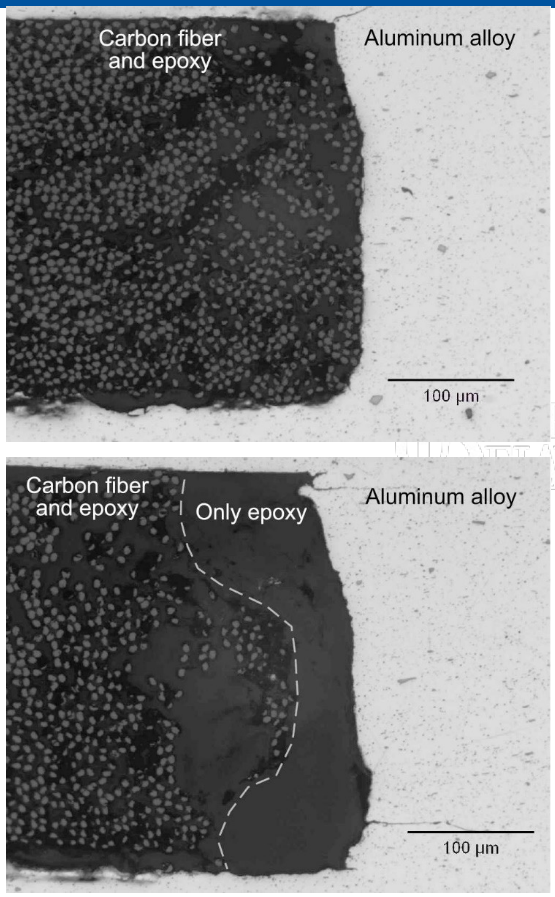
UAM CENTER

Carbon Fiber Integration using UAM

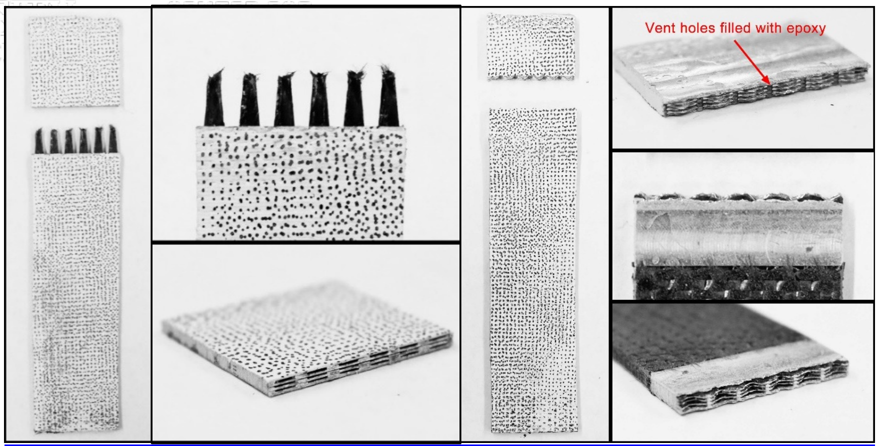
Center for Ultrasonic Additive Manufacturing
The Ohio State University

PI: Marcelo Dapino
dapino.1@osu.edu

Tailorable Failure Models



Failure mode	Joint strength	Energy absorption	CF:AA bearing area ratio
CF tow failure	102.3 MPa	3.96 J	0.33:1
AA matrix failure	129.5 MPa	0.9 J	0.38:1



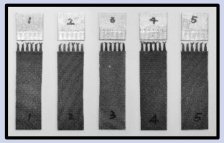
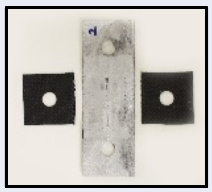
CF tow failure AA matrix failure

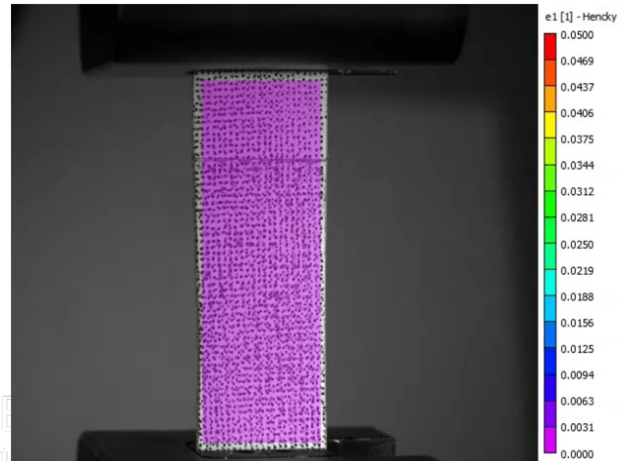
The joint relies on mechanical interlocking, which provides direct load transfer between the CF and AA matrix. Joint strength is dictated by the ratio of CF to AA.

Strength Comparison

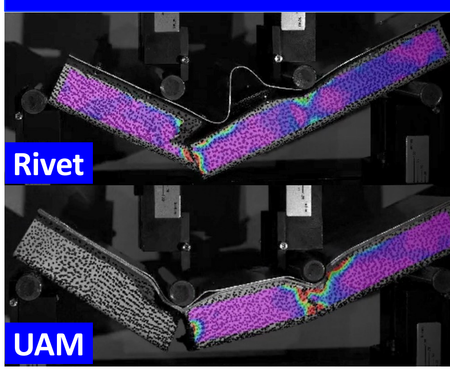
Joining method	Strength	Features
Adhesive	12.42 MPa[1]	Long curing time, weak peel strength
Induction spot welding	14.5 MPa[2]	High temperature
Ultrasonic welding	34.8 MPa[3]	Spot welding
Friction spot joining	112 MPa[4]	Spot welding
Mechanical fastener	5 kN[5]	Extra material, damage to the CFRP
UAM	129.5 MPa	Continuous, solid state

Strenght and Energy Absorption Benchmarking

Test	Config.	Peak load
Tensile tests		**4.2 kN** (32% higher than OEM spec)
Cross-tension tests		**2.3 kN** (53% higher than OEM spec)

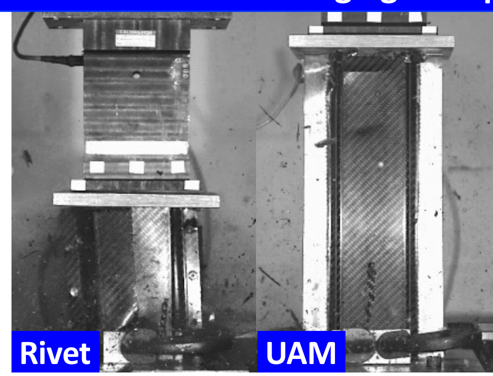


Structural tests benchmarking against pop rivets



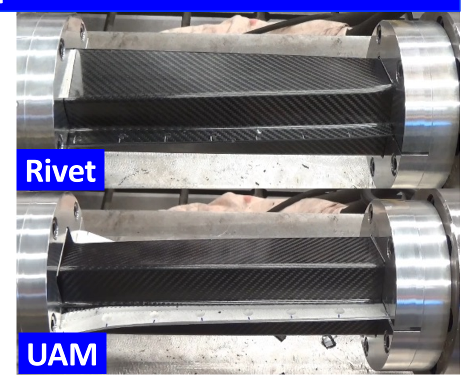
Four-point bend

Similar peak load
69% higher SEA



Axial crush

63% shorter crush distance
32% higher energy absorption



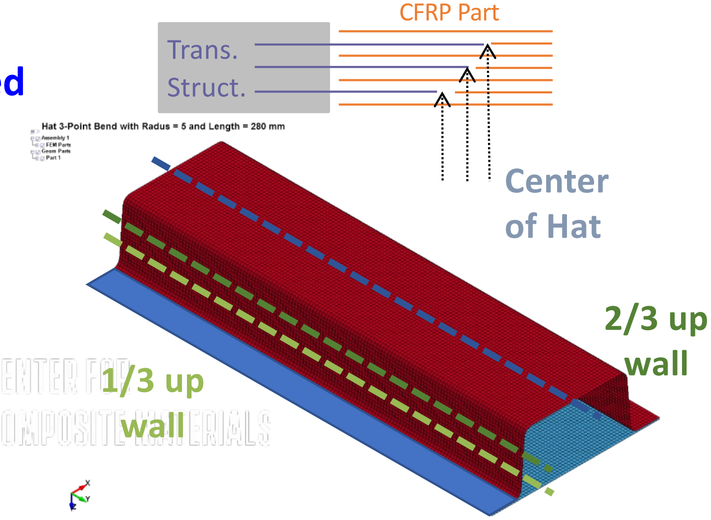
Torsion

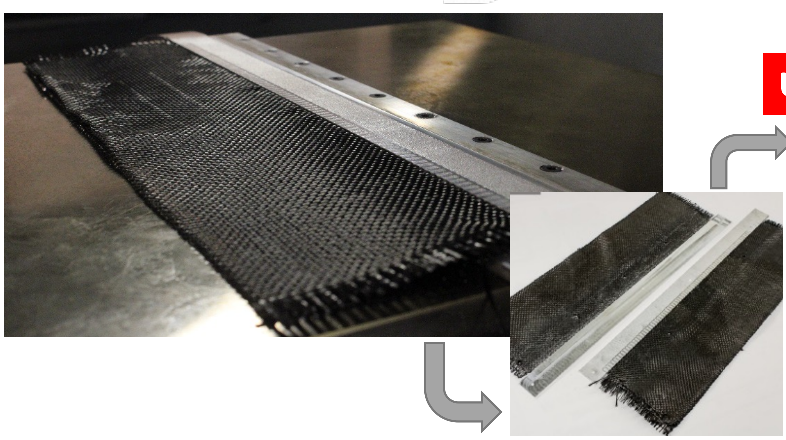
17% larger twist angle
13% higher SEA

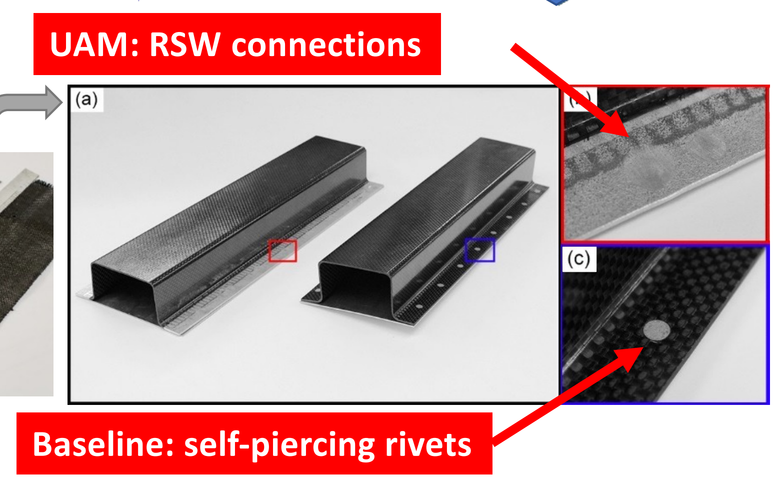
Four-Point Bend Testing

CFRP hat - Al plate pairs

- Baseline hat joined to Al plate via **Self-Pierced Rivets (SPR)**
- UAM Flange Transitions/RSW
  - **3 dry biaxial fabrics** integrated into flange
  - Fabrics **spliced at different places** within hat
  - Same number of joints in each hat

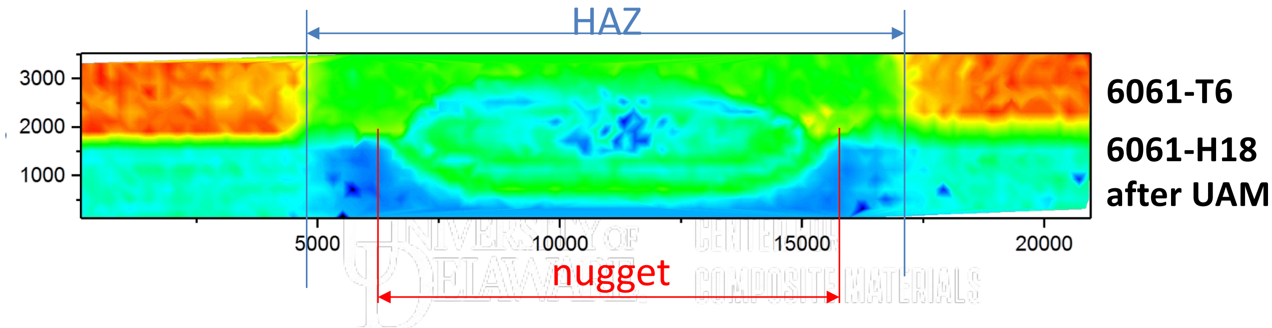




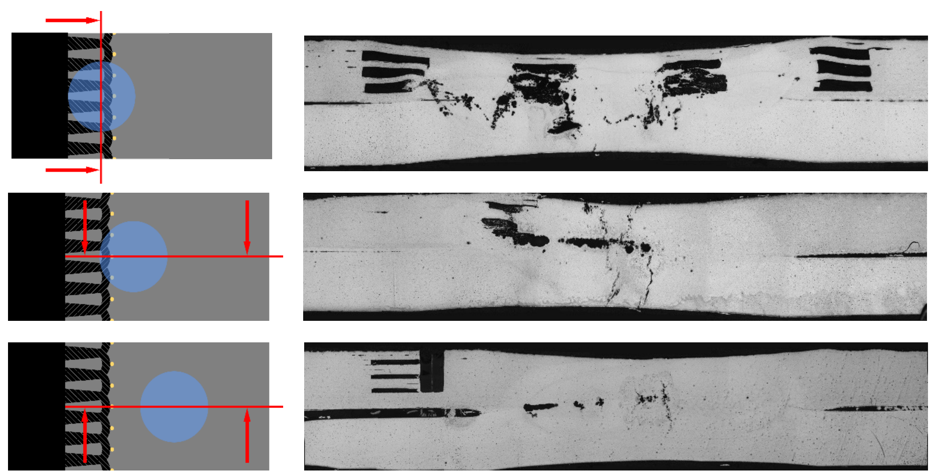


RSW Spot Location Studies

- The **diameter of the heat affected zone** (HAZ) for an RSW between a 6061-T6 sheet and a UAM build of 6061-H18 is measured as **12.5 mm** from the **microhardness map**

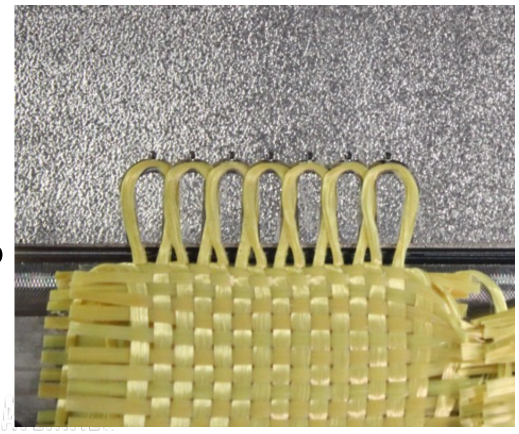


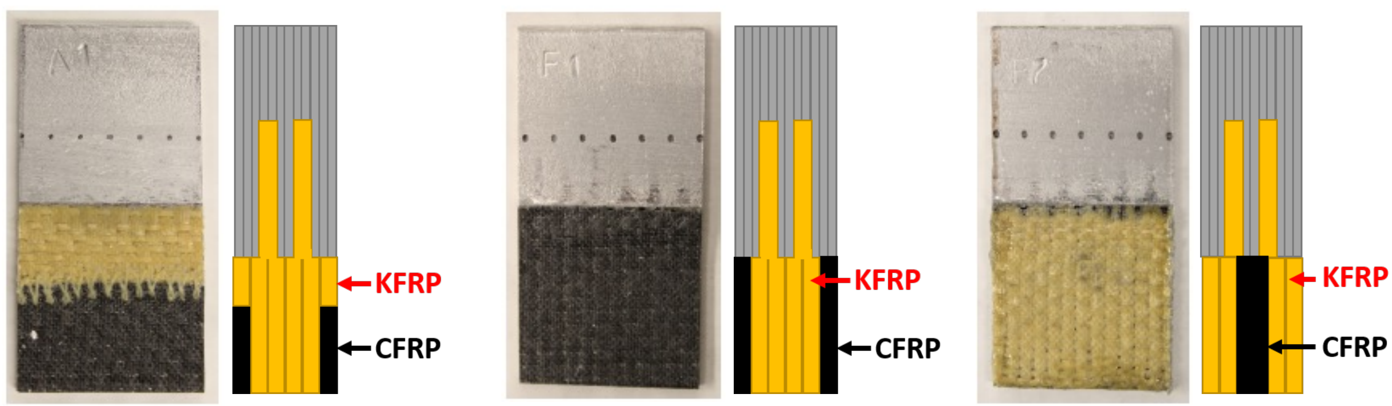
- RSWs were performed on CFRP-AA joint samples with different **distance between the RSW center and the embedded CF tows**. Observing from the microstructures, a **16.5 mm** RSW offset is sufficient to keep the CF intact.



Corrosion Studies

- **Kevlar fibers** are embedded in the AA matrix to create **insulation** between CFRP and AA
- The channels to embed Kevlar is **deeper** than those for CF to house the thicker Kevlar tow
- To verify the effectiveness of the insulation method, samples were prepared for CCT tests by embedding two layers of Kevlar in twelve layers of AA and laid up with **three configurations**
- Five buffer samples were **E-coated** before CCT

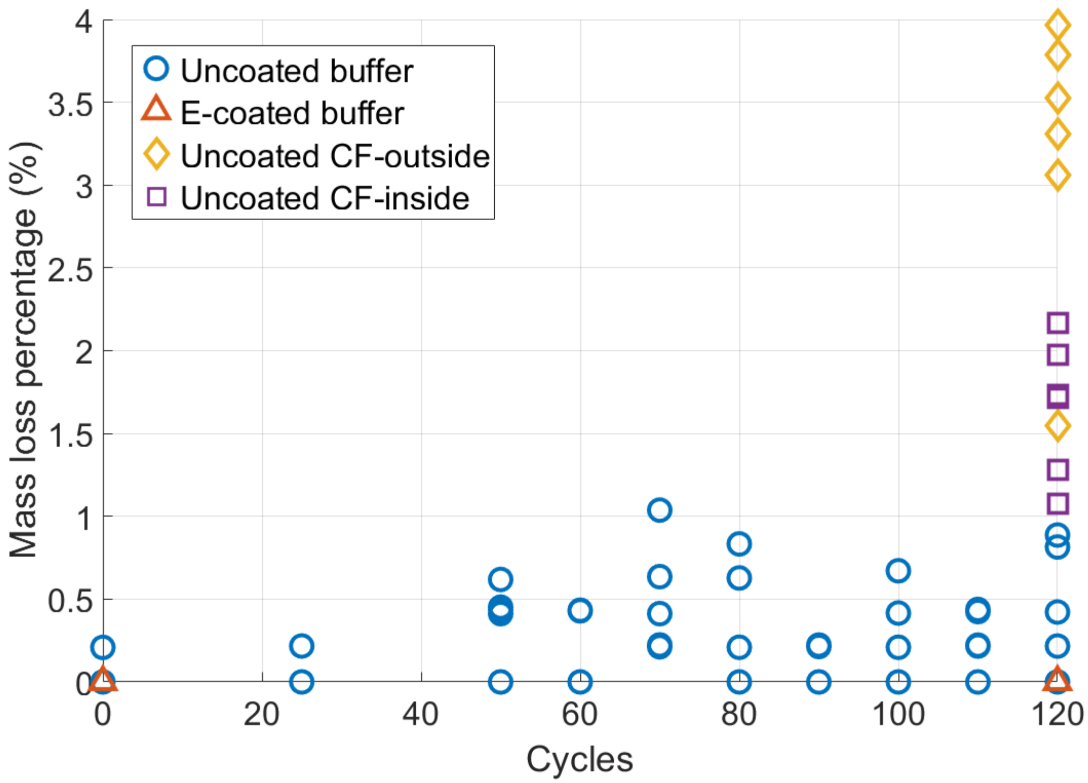




Mass Loss After 120 Cycles

- Samples were **cleaned chemically** after the 120-day CCT
- **CF-outside** and **CF-inside** samples have small mass loss
- **Buffer** samples exhibit negligible mass loss and achieve zero mass loss with **E-coat**

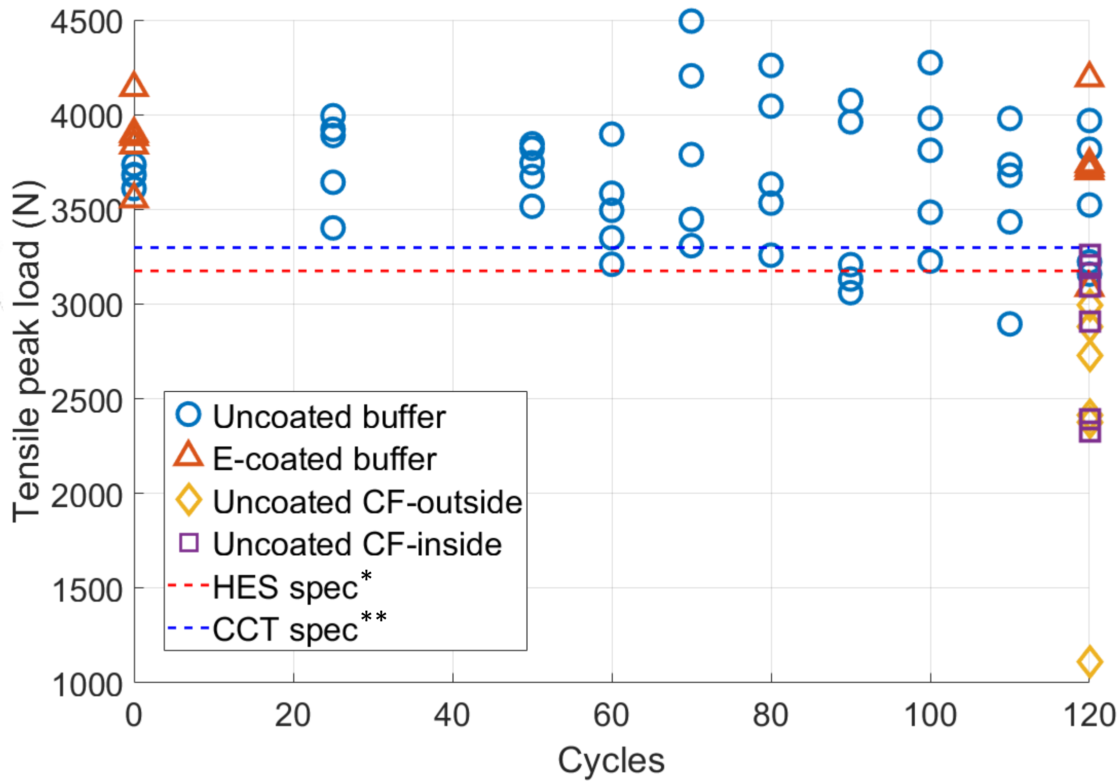
	Average mass loss
Uncoated buffer	0.5%
E-coated buffer	0
Uncoated CF-outside	3.8%
Uncoated CF-inside	2.2%



Strength Effect After 120 Cycles

- **CF-outside** and **CF-inside** samples exhibit substantial strength loss
- **Buffer** samples maintained more than 97% strength with and without **E-coat**

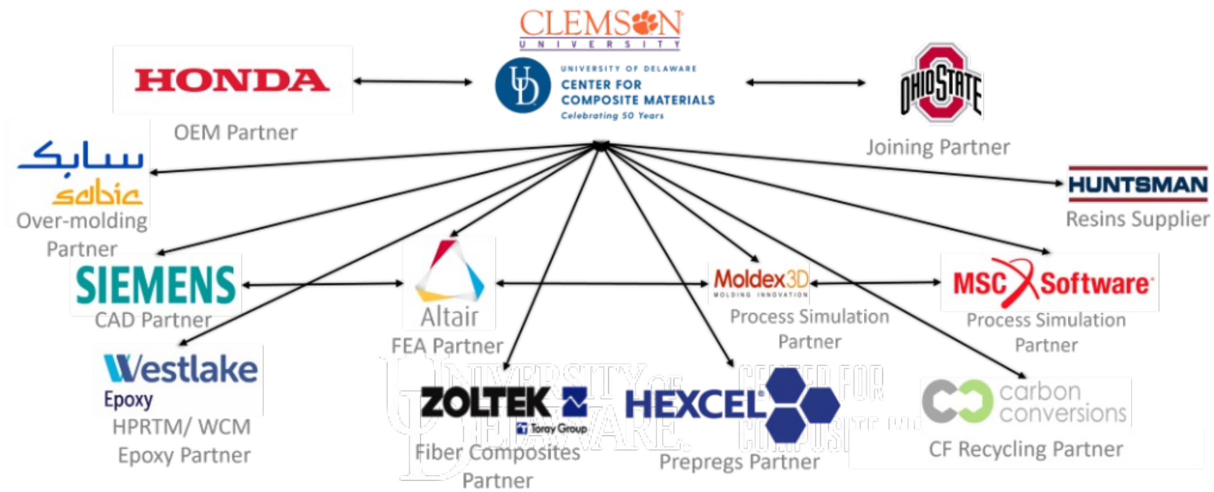
	Strength after 120 cycles/ 0cycle
Uncoated buffer	97%
E-coated buffer	95%
Uncoated CF-outside	66%
Uncoated CF-inside	78%



* HES spec: industry target for equivalent metal-metal joint tensile peak load

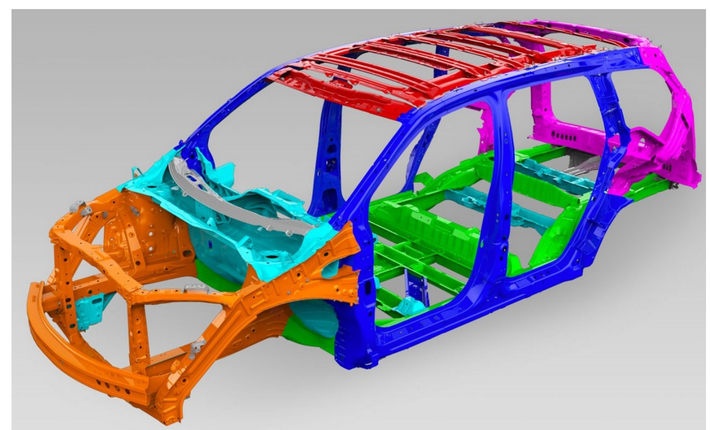
** CCT spec: 90% of 0-cycle samples

Collaboration

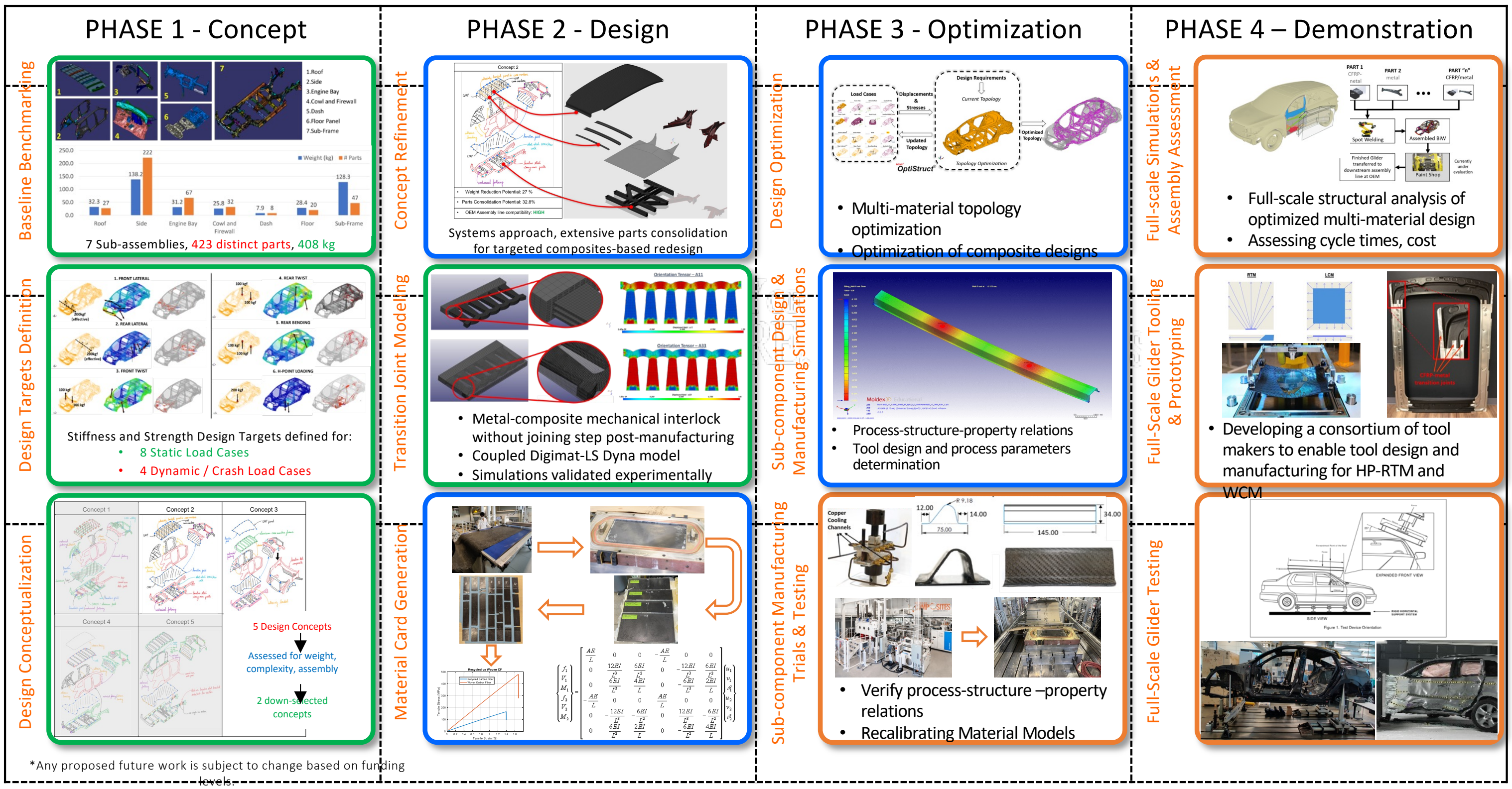


Department of Energy Vehicle Technologies Office
Award # DE-EE0009656

- Achieve **160 lb (73 kg)** glider weight reduction
- **No compromise** on performance targets
- Cost increment limited to **$5 per pound** (0.453 kg)
- Compatibility with OEM's **existing factory infrastructure** (joining and assembly)
- Scalable to **200,000 vehicles/year** production
- **Recyclability**

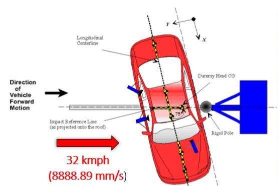


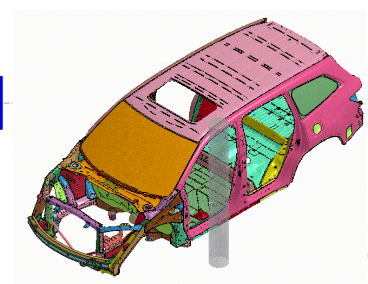
Technical Phases



Strength, Stiffness, and Crashworthiness

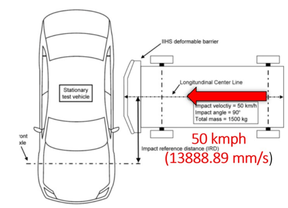
FMVSS 214 (Side Pole)

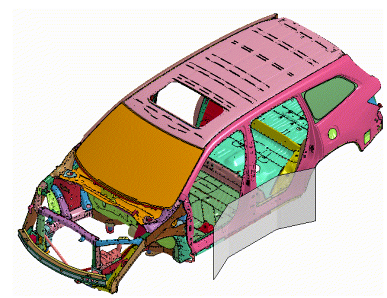




Termination time: 0.056s
Pole moves by ~50cm
Time-step used: 1e-6s

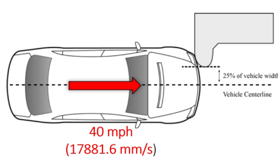
IIHS – Side Impact Crashworthiness Evaluation (SICE)

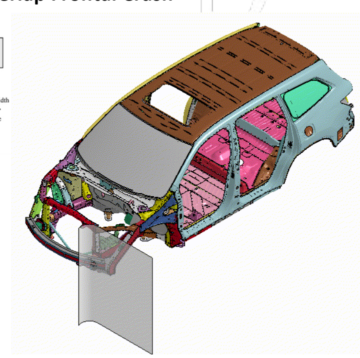




Termination time: 0.056s
Impactor moves by ~77cm
Time-step used: 1e-6s

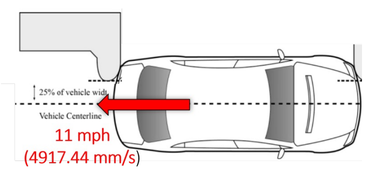
IIHS – Small Overlap Frontal Crash

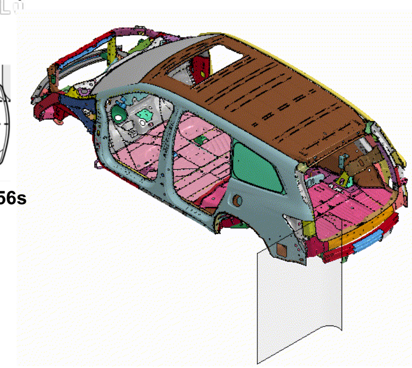




Termination time: 0.056s
moves by ~100cm
Time-step used:
1e-6s

IIHS – Small Overlap Rear Crash



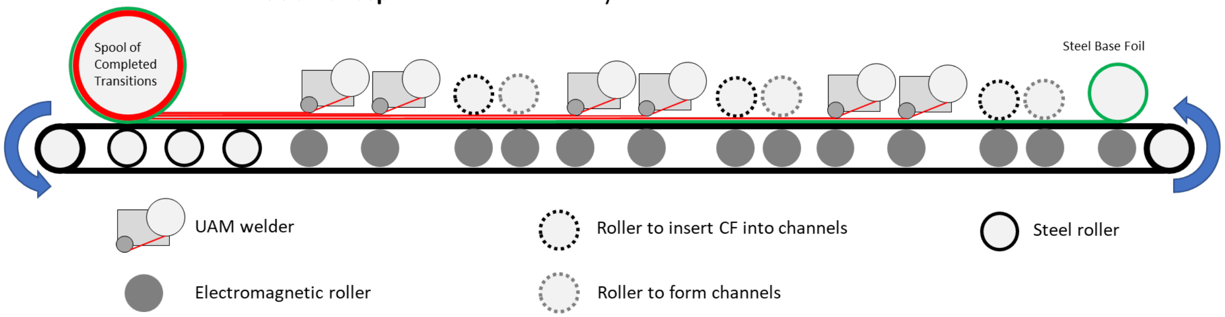


Termination time: 0.056s
moves by ~27cm
Time-step used:
1e-6s

Steel body-in-white (BIW) used as benchmark for structural and crashworthiness targets

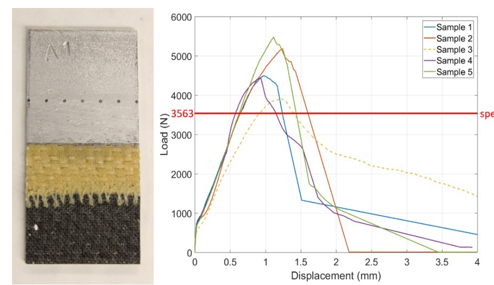
Continuous Offline Manufacturing

OSU Concept: Continuous UAM System for CFI Transitions

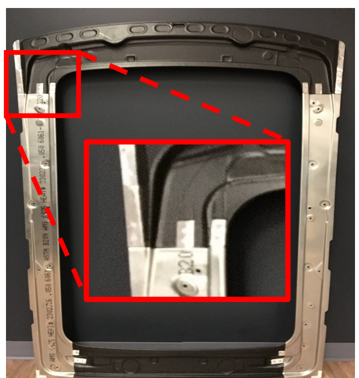


US Patent No. 11,724,334 B2, 8/15/2023.

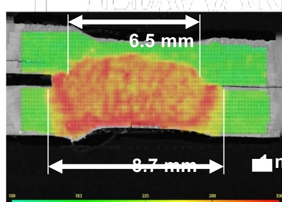
E-coated samples after 10-year equivalent CCT



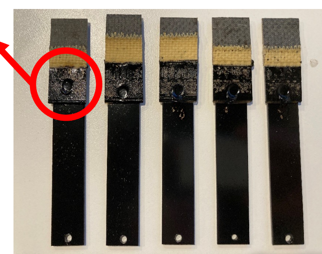
Kevlar (aramid) has roughly the same strength as CF, higher toughness, and it eliminates corrosion.



Roof stiffener with UAM CFRP-metal transitions



Microhardness map of JAC270-UAM 1010 RSW



CF-Kevlar-1010 steel joints with RSWs to JAC270 and E-coating

Flexible and Advanced Manufacturing at OSU

AIM for composites | University of Delaware Center for Composite Materials, Celebrating 50 Years | sme

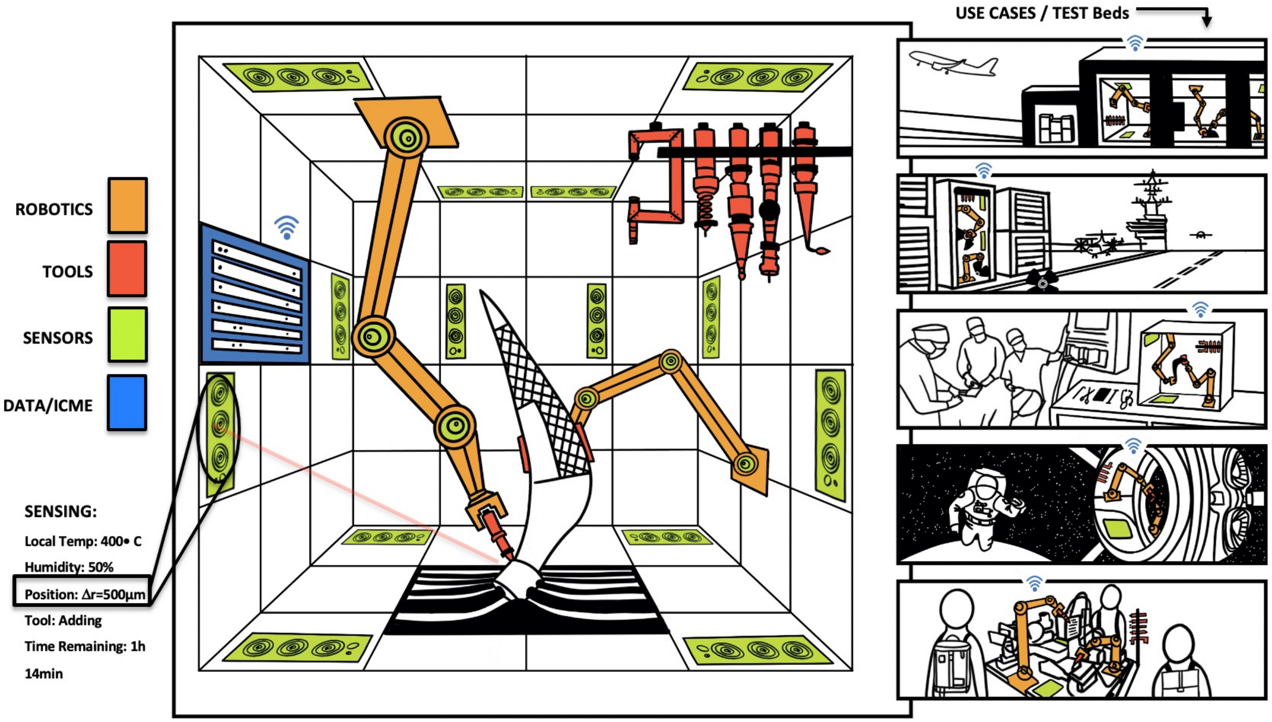
HAMMER – Hybrid Autonomous Mfg. Moving from Evolution to Revolution (an NSF Engineering Research Center)

- 10-year cooperative agreement +
- ~$5M/yr federal funds
- Foundational Components:
  - Convergent Research
  - Engineering Workforce Development
  - Culture of Diversity and Inclusion
  - Innovation Ecosystem

Diverse 5-institution team: Manufacturing, Metallurgy, Machine Learning, Controls, Education, Social and Policy.

HAMMER ERC | NSF | The Ohio State University College of Engineering | Case Western Reserve University Est. 1826 | North Carolina Agricultural and Technical State University | Northwestern University | The University of Tennessee Knoxville

Vision: Autonomous-Factory/Artisan Box (Auto-FAB)



Research Thrusts

T1: Design: product and process.

T2: Tools and Process Convergence: new tools and processes.

T3: Materials State Awareness: Enabling process- and model-based quality certification.

T4: Control, Intelligence, and Autonomy: Leveraging AI to control processes learn.

Commercialization

Structural overview of the public-private partnership with HAMMER and HAMICo

HAMMER
Federal NSF program

→ **Public entity aligned to NSF to source projects**

Inventions / R&D ↓ | ↑ Project funding + Process/property data

HAMICo
501(c)(3) Corp.

→ **Innovation platform manager housing the HAMMER IP and directing commercialization**

License / commission / incubate ↓ | ↑ License fees + Data

Field of Use Licenses

Startups / Studios / Industry

→ **Ecosystem of venture capital + corporate funding to accelerate adoption**

Space FABs Parts Medical Software

Ma2jic NSF IUCRC – Industry Consortium

Ma²JIC

MANUFACTURING & MATERIALS JOINING INNOVATION CENTER

IAB CHAIR:	Martin McDonnell (GVSC) to be voted
IAB VICE CHAIR:	Stephen Tate (EPRI) to be voted
DIRECTOR:	Antonio Ramirez (OSU)
CENTER MANAGER:	Heather Spisak (OSU)

NSF - IUCRC PROGRAM DIRECTOR
Dr. Prakash Balan

IUCRC ASSESSMENT COORDINATOR
Dr. Pete He

UNIVERSITY PARTNERS

The Ohio State University

PennState

TICKLE COLLEGE OF ENGINEERING
THE UNIVERSITY OF TENNESSEE, KNOXVILLE

COLORADO SCHOOL OF MINES
EARTH • ENERGY • ENVIRONMENT

UNIVERSITY OF WATERLOO

Scope

Ma²JIC MANUFACTURING & MATERIALS JOINING INNOVATION CENTER

THRUST AREAS AND PROJECTS

Thrust Area	Projects	Committee Chair / Vice Chair	Committee Co-Chair
Performance	7	**Michael Eff**, EWI Daniel Paolini, Honda	Boian Alexandrov (OSU)
Processes	10	**Andrzej Nycz**, ORNL Stephen Tate, *EPRI*	Bradley Jared (UTK)
Materials	8	**Jeff Rodelas**, SNL Ravi Menon, *ESAB*	Carolin Fink (OSU) Michael Benoit (UW)
Modeling (Cross Cutting)	-	**Adam Hope**, Thermo-Calc Andres Acuna, Lincoln Electric	Zhenzhen Yu (CSM)

25 ONGOING R&D PROJECTS

~$4.4M PER YEAR

IUCRC Benefit

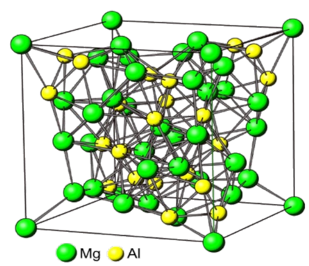
What makes Ma²JIC successful?

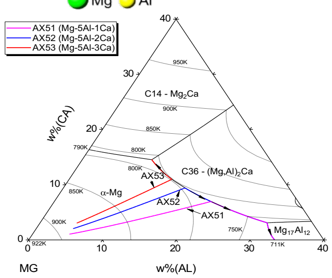
- Cutting edge, pre-competitive fundamental research in areas of interest to our members.
- Wide base of industry members *(energy fossil-nuclear-clean, automotive, aerospace, manufacturing, materials, software, Nat. Laboratories, welding supplies/equipment, etc.)*
- Strong alumni base *(Ma²JIC graduates bring new member organizations)*
- Flexible with engaging members *(example: in-kind donations and varying membership levels)*
- Two in-person meetings each year, which bring together all our students, members and faculty for a *two-day deep discussion of our research, training, center operation, and scientific/technological road-mapping.*
- Opportunity for our members to train and recruit talent for their organizations.
- Strong administrative team to support center operation, finances and planning (100% self-supported)

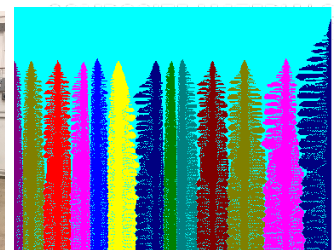
Office on the web Frame

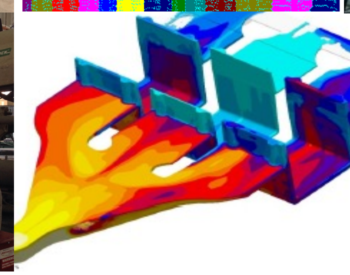
Luo Group – Lightweight Materials and Manufacturing

- Advanced lightweight materials: Al, Mg, Ti & high-entropy alloys, bio-metals, super-wood, and metal matrix nano-composites.
- Innovative and sustainable manufacturing processes: casting, forming, additive and multi-material manufacturing.
- Lightweight and multi-material solutions using integrated computational materials engineering (ICME) tools for structural and bio-medical applications.



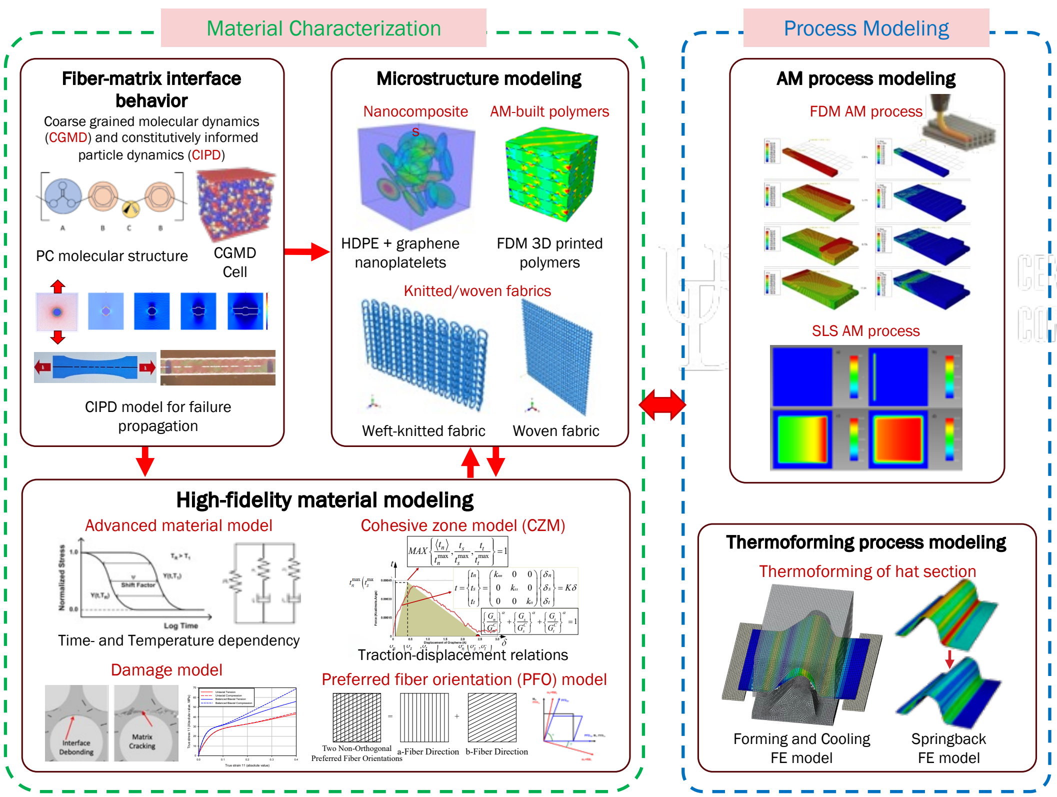




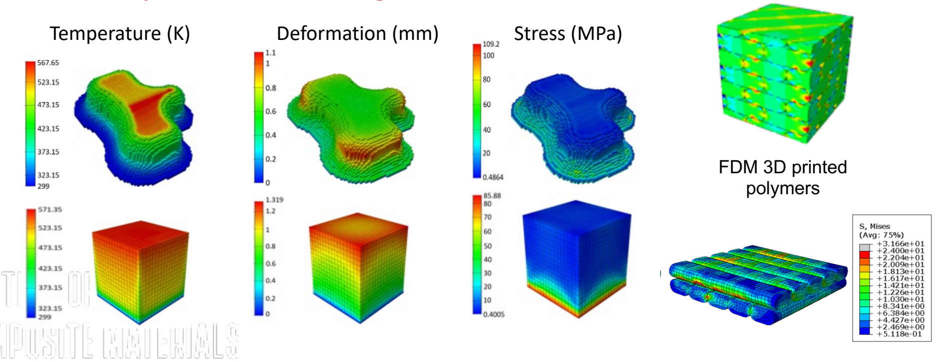


Pourbhograt Group – Modeling of Manufacturing Processes

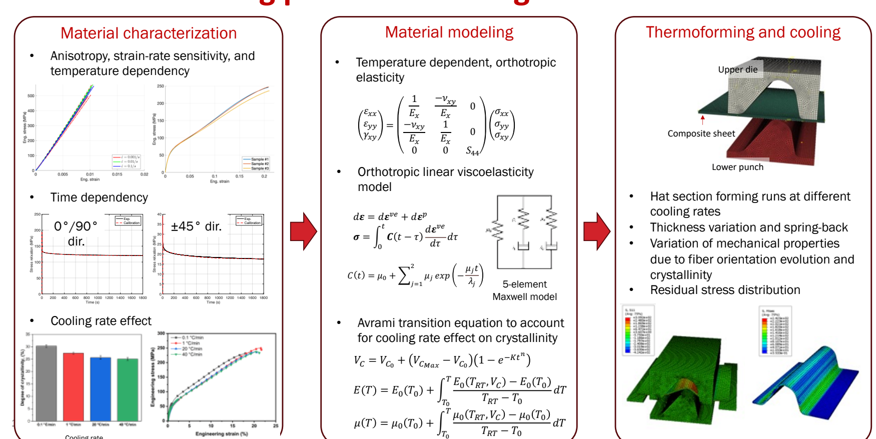
Multi-scale Computational Framework to Correlate Material-Process-Microstructure-Performance Relationships



AM process modeling



Thermoforming process modeling



NSF IUCRC Smart Vehicle Concepts Center

National Science Foundation
Industry-University Cooperative Research Center (NSF IUCRC)

- **Research**

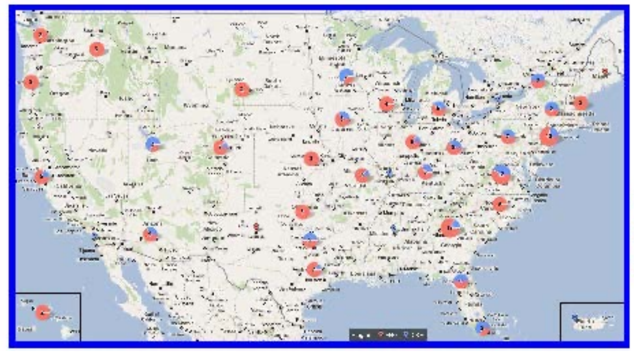
  Conduct basic and applied pre-competitive research on smart materials and emerging technologies applied to ground and air vehicles

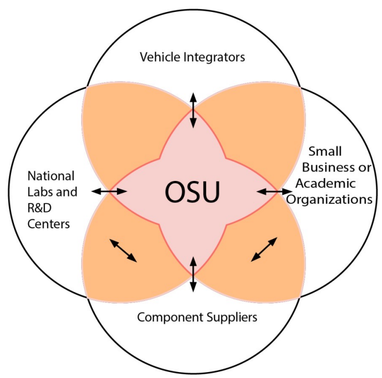
- **Education**

  Prepare next-generation engineers who possess both theoretical and experimental expertise developed through industry-relevant research

- **Technology transfer**

  Development of technologies to enable the design and manufacturing of multi-material, lightweight, and multi-functional systems





Phase I: 2007 – 2012
Phase II: 2012 – 2017
Phase III: 2017 – 2022
Graduated Status: 2022 – 2027

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- **Pre-competitive model**
- **Long-term research with industrial viewpoint**

Thank You