EXTENDING HIGH-RATE RIVETING TO NEW MATERIAL PAIRS

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DOE-VTO AMR

Project ID # MAT-223

OVERVIEW

Timeline

Start date: October 2020

End date: September 2023

5% Complete

Barriers

- Lack of flexible methods for high-rate riveting of multi-material multi-stack joint configurations
- No high-fidelity models exist to aid engineers in joint and process design

Budget

Total project funding: $2,049,000

Fiscal Year 2021: $683,000 (ORNL $150,000)

Partners

Pacific Northwest National Laboratory (PNNL)
Oakridge National Laboratory (ORNL)
Argonne National Laboratory (ANL)

RELEVANCE: MULTI-MATERIAL JOINTS WITH HIGH-SPEED JOINING TECHNIQUES TO ACHIEVE VEHICLE LIGHT WEIGHTING

Impact

Light weighting vehicles requires complex joints of multiple dissimilar materials of aluminum, steel, and composite materials. We aim to increase the applicability of a versatile joining method to a variety of material stack-ups

Successful demonstration of these technologies will increase process efficiency, enable innovative and sustainable manufacturing process and joining of dissimilar materials into hybrid joints for the creation of high-performance lightweight structures.

Goal

- Demonstrate joining multimaterial systems in solid phase using high rate riveting processes in combination with adhesives to improve the joint strength, processing cycle time, corrosion resistance and address the end-of-life recycling challenges
- This thrust will bring together PNNL, ORNL and ANL to develop scalable and cost effective processing methods to improve the properties of the joints in multimaterial systems to enable broader implementation of lightweight materials in vehicles

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OVERALL APPROACH:
SURFACE MODIFICATION-JOINING-CORROSION PERFORMANCE

Mechanical Fastening
High-Velocity Riveting
High-Rate Friction Riveting

Hybrid Joining
Adhesive- Hybrid bonding
Effects of velocity on adhesive joint quality

Modeling
Model the riveting process
Joint Optimization
Shear stress and Temperature distribution in adhesives

Mechanical Testing
Lap shear
Peel Testing

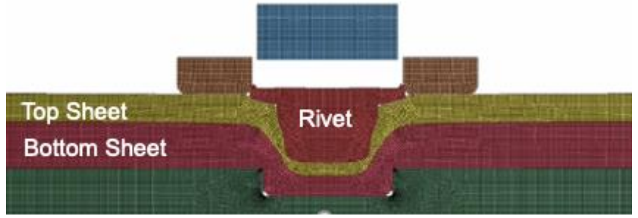
Characterization
SEM
X-Ray CT

Development of new and novel high-speed joining techniques with multi-material systems

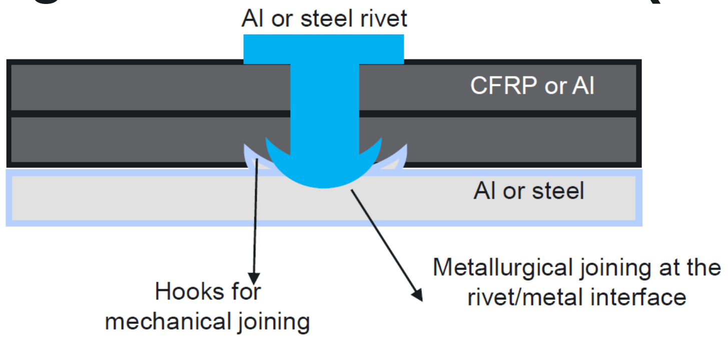
Correlate the effect of processing on joint microstructure and bond strength:

- The near-joint, joint, and interface microstructure
- The effects of adhesive hybrid bonding and high-velocity processing on adhesive joint quality
- The impact of these microstructures on the galvanic corrosion behavior in Thrust 3

High-Velocity Rivet (HVR)



High-Rate Friction Rivet (HFR)



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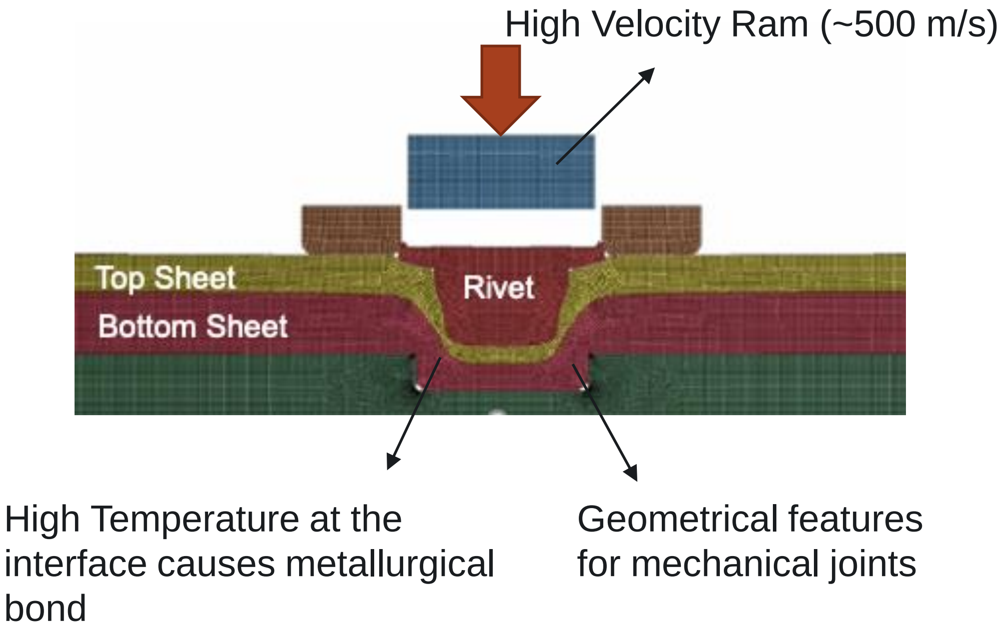
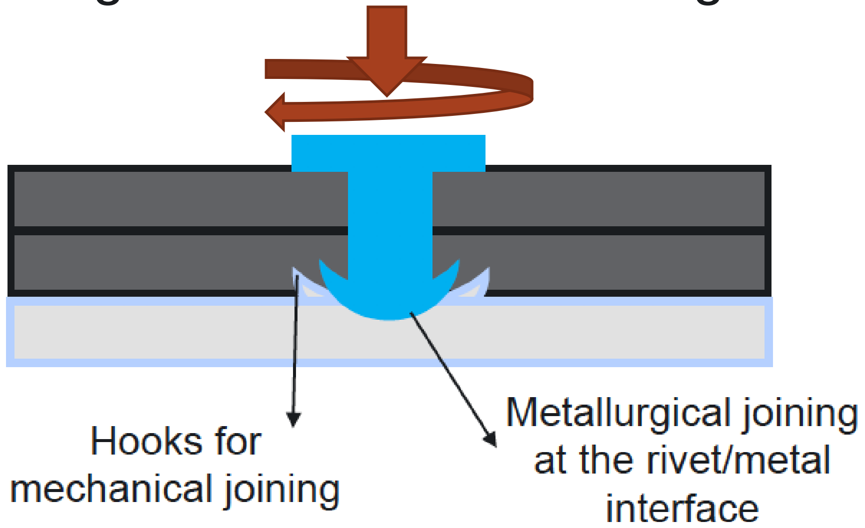
PROJECT- BACKGROUND

- Developed as a part of JCP 1.0 seedling project
- Successfully demonstrated joining Mg and aluminum sheets along with thick castings using aluminum and steel rivets at room temperature
- Utilized a hand-held system to join the two materials using aluminum rivet
- Designed dies that created a flared/hook/mushroomed interface
- Fast and robust process
- Shear strength comparable with SPR rivets
- Address end of life recycling issues

High Velocity Riveting*



High-Rate Friction Riveting



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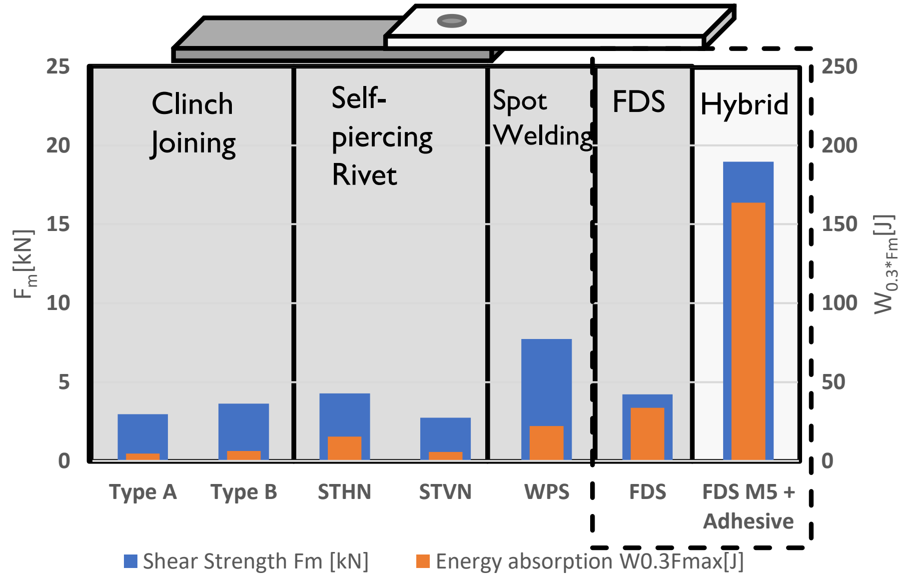
* A patent application has been filed based on the work performed in the first phase of JCP 1

BACKGROUND: MATERIAL SYSTEMS

- Baseline processing and strength data for Self Piercing Riveting and Flow Drill Screw will be evaluated with and without adhesives and compared for shear and peel strengths
- Joints with multiple material thicknesses in 2- and 3-layer designs



University of Paderborn, Germany

- 2T with aluminum rivets (7075 and 6061-T6 Conditions)
  - 5052-H32 (2.5 mm) with 6061-T6 (2.5 mm)
  - 3 mm 6061-T6 with 4 mm A356/ HPDC casting
  - 6061-T6 with 6061-T6 both 3 mm
- 3T with Aluminum/ Steel Rivets
  - 2, 2.5 mm stacks of 5052-H32 with 1, 3 mm of 5052-H32
  - 2.5 mm, 6061-T6 + 2.5 mm 6061-T6+ 3 mm AA6061

- 2T with steel rivets
  - DP590 1 mm with 2.5 mm 6061-T6
  - DP590 1 mm with 3 mm 6061-T6
- 2T with aluminum rivets
  - 40% CF/PA66 CFRP with 6061-T6 3 mm
  - 40% CF/PPA CFRP with 6061-T6 3 mm

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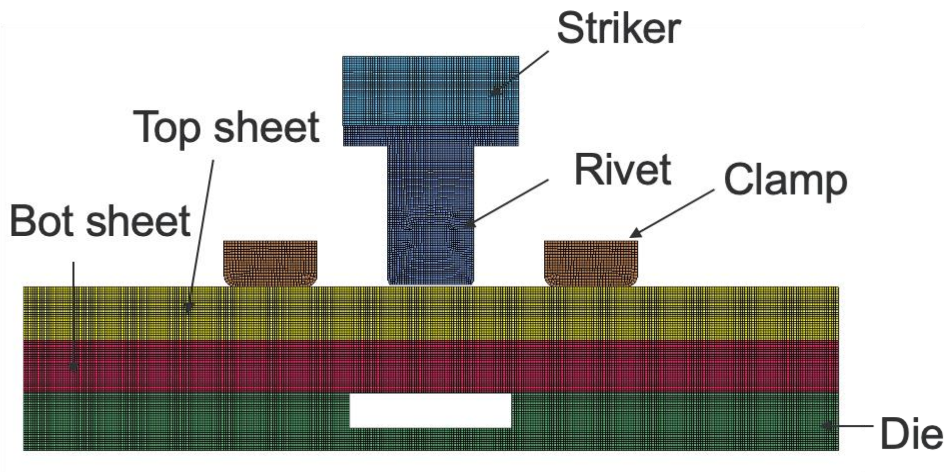
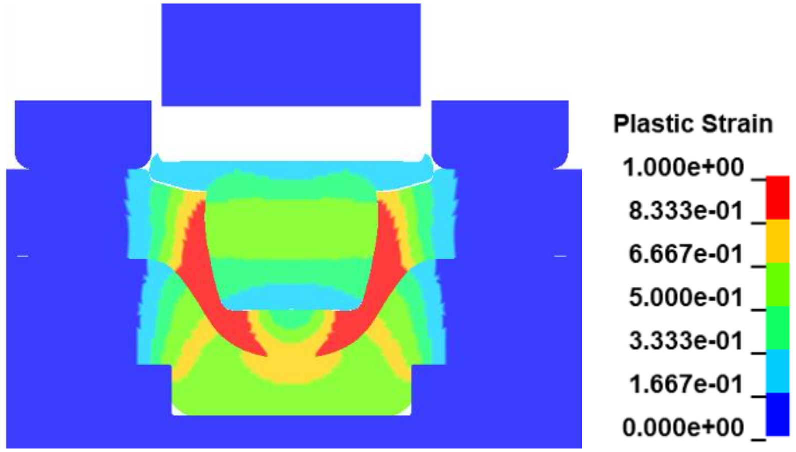
ACCOMPLISHMENTS: MODELING THE HIGH VELOCITY RIVETING PROCESS

Finite Element Model

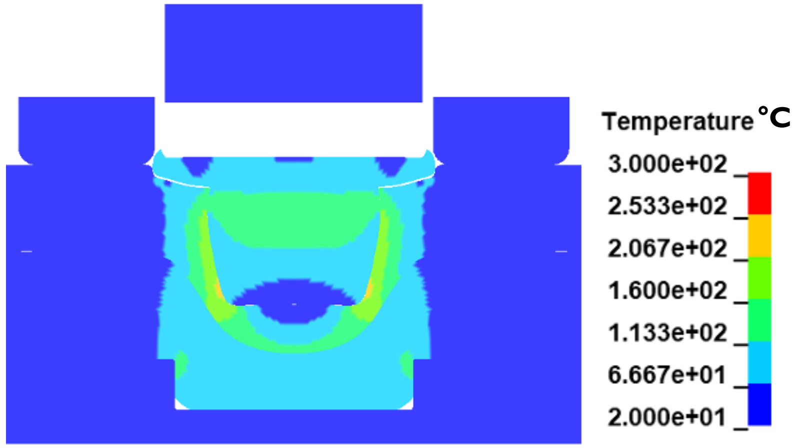


Deformed Shape

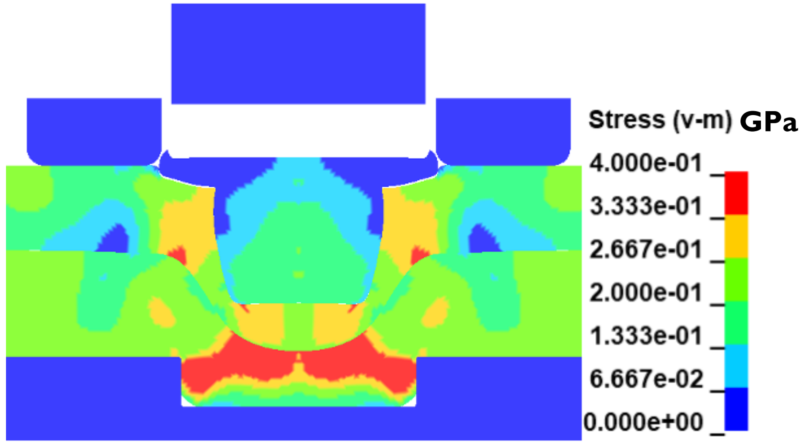


Eq. Plast. Strain

- The developed model can predict the joint's shape, plastic strain, temperature, and thermal stress during and the after the joining process
- The model will be used to investigate various process parameters and their impact on the joint quality, e.g., rivet geometry, striker weight and velocity, die shape, and sheets stacking order, etc.
- The model will also investigate hybrid joining and joints performance



Temperature



Resultant Thermal Stress

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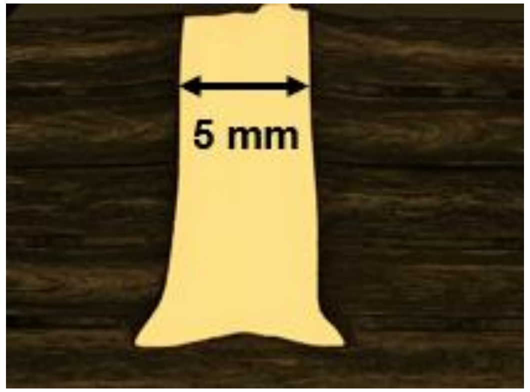
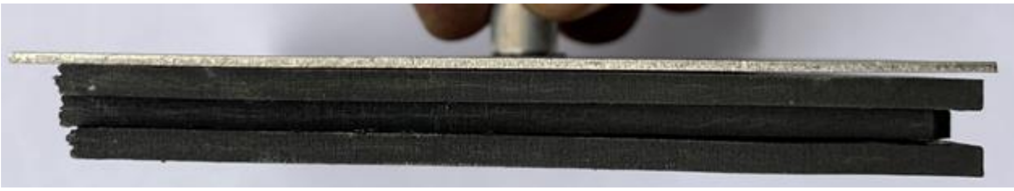
ACCOMPLISHMENTS:
HIGH-RATE FRICTION RIVETING (HFR)

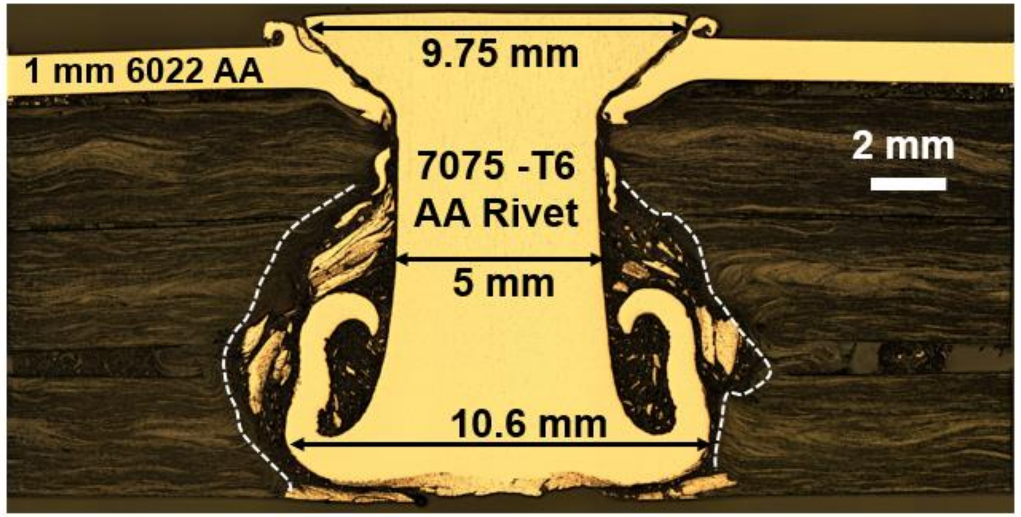
CFRP – CFRP joints with aluminum rivets



5 CFRP sheets joined with AA6061 rivet (5-mm-diameter)

Aluminum/CFRP joints with aluminum rivets





3 CFRP sheets joined to AA6022 with AA7075 rivet (5-mm-diameter)

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ACCOMPLISHMENTS:
CURE KINETICS OF ADHESIVES AND SURFACE MODIFICATIONS

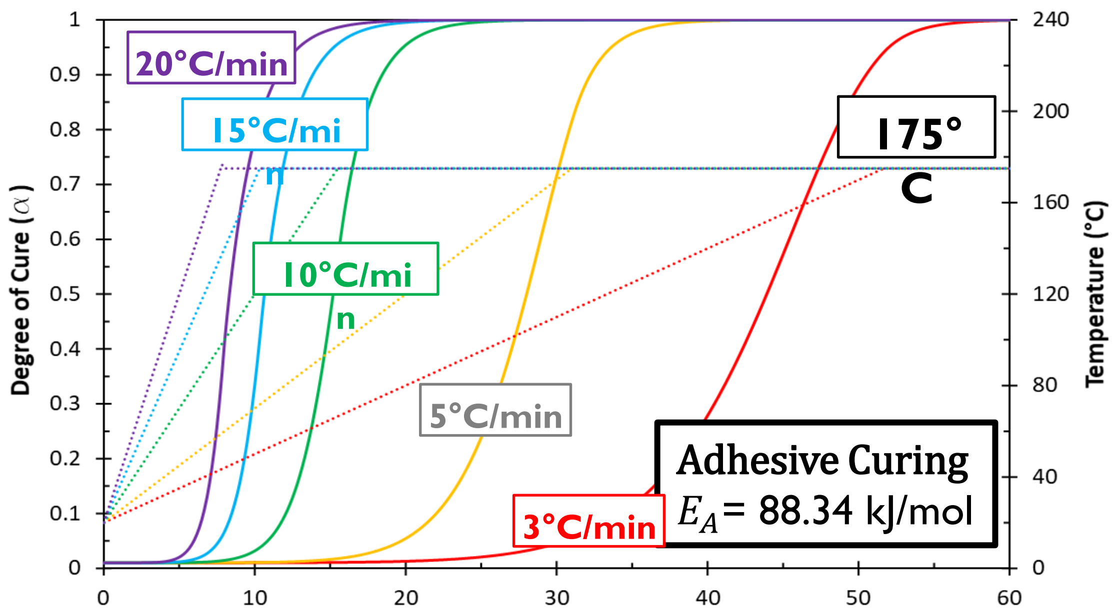
- Curing profiles are developed to evaluate against the heat generated during rivet forming process.

- Working on validating these models by obtaining experimental data. Fit can be adjusted by changing reaction order (n) or cure kinetics model.

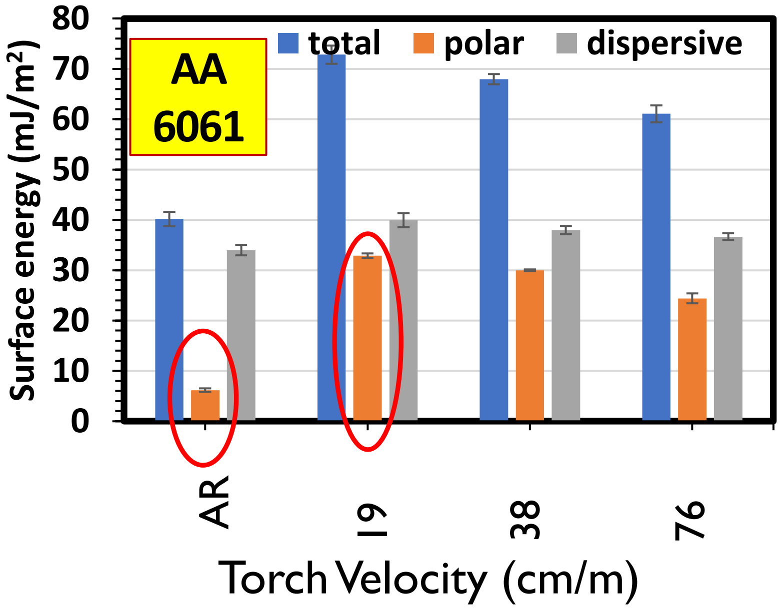
- This information can also be used to predict cure for various other heating rates and cure temperatures.

- Plasma surface treatments shown to increase hydroxyl groups for improved bonding with adhesives and will provide better bonding characteristics with the surface

- Working in collaboration with Joining Core Program Phase 2: Mat225 to investigate corrosion inhibition with plasma treatments and adhesive bonding



Supplier Cure Instructions: 25 min at 175°C.



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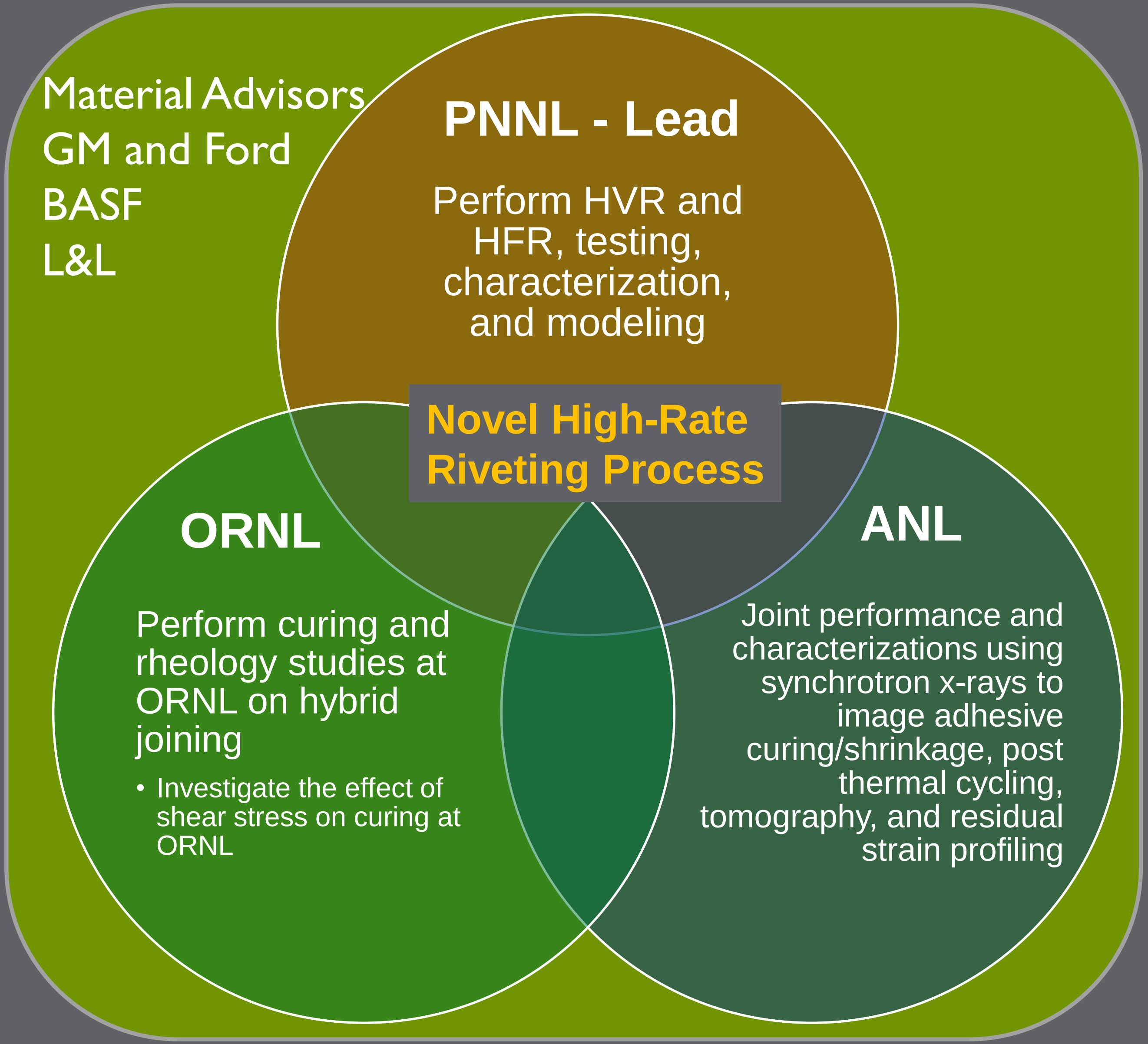
COLLABORATION AND COORDINATION WITH OTHER INSTITUTIONS

Collaboration between PNNL/ORNL/ANL on the hybrid joining task



- This task will work closely with PNNL/ORNL teams in Thrust 3 for corrosion analysis
- Team meetings on bi-weekly basis to discuss current results, coordination between teams, and next steps
- Information from modeling tasks feed experimental designs and vice versa

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MILESTONES

Milestone	Due Date	Type	Milestone	Status
M1.0	12/31/2020	Quarterly Progress Measure (Regular)	Establish baseline performance for 2T lap joint using flow drill screw and adhesive.	Milestone Achieved
M2.0	3/31/2021	Quarterly Progress Measure (Regular)	Develop a thermo-mechanical model to predict thermal stresses occurring during riveting and impact on joint integrity.	Milestone Achieved
M3.0	6/31/2021	Quarterly Progress Measure (Regular)	Complete initial joining trials of lap configuration using high velocity riveting between Al-Al, Al-steel, composite-steel, and composite-Al substrate combinations.	In-progress
M4.0	9/30/2021	Quarterly Progress Measure (Regular)	Develop high-rate riveting model to predict joining of 2T stacks of similar and dissimilar sheet/casting materials	In-progress
M5.0	9/30/2021	Go/No-Go	Assessment of high-rate pierce and friction riveting variants of HVR process.	In-progress

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PROPOSED FUTURE RESEARCH

- Complete initial joining trials of lap configuration using high velocity riveting between Al-Al, Al-steel, composite-steel, and composite-Al substrate combinations.
- Identify the adhesives compatible with these systems and perform joining trials
- Assess the joint strength of the HVR processed materials and downselect the processes for a typical application/ joint configuration for further development
- Modeling these processes to provide a feedback loop that will assist in guiding experimental direction in process variables
  - Determine the mechanisms of joining between the variances of the process
- Evaluate adhesive bond strength relative to plasma surface modifications
- Evaluate adhesive bond line quality with ANL tomography system after rivet formation
- Coordinate with Thrust 3 project to optimized the joints for corrosion resistance

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

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SUMMARY SLIDE

- Established a baseline of materials and rivets relevant to the automotive industry along with the desired joint strengths
- The modeling task is providing unique insights into the velocities, die and rivet geometries to optimize and better understand the high velocity riveting process
- Air plasma surface modifications significantly increase the surface energy through more than doubling the polar energy component indicating an increase in hydroxyl content
- Kinetic reaction model developed for adhesives for assisting modeling and experimental designs on heat flow from rivet formation and curing kinetics.

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PREVIOUS YEAR REVIEWER COMMENTS

Not reviewed last year

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THANK YOU

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BACK UP SLIDES

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