SURFACE MODIFICATION FOR IMPROVED JOINING AND CORROSION RESISTANCE

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Presenter: Yong Chae Lim

DOE-VTO AMR

Project ID # MAT225

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OVERVIEW

Timeline

- Start: *Oct 2021
- End: Sept 2023
- 10% Complete

Budget

- Project Funding $3.225 M (3 years)
- FY 2021: $1.075M
  - ORNL: $475K
  - PNNL: $550K
  - ANL: $50K

* Funding Received Jan 2021

Barriers

- Multi-Materials Systems: Engineered Surfaces (corrosion)
- Multi-Materials Systems: Predictive Modeling (corrosion)
- Multi-Materials Systems: High volume joining
- Lack of robust solutions to address materials incompatibilities when designing multi-materials vehicles
- Fundamental understanding and modeling tools for optimizing joining methods and interfaces for multi-material components

*2017 U.S. DRIVE MTT Roadmap Report, (currently being updated)

Partners

- Pacific Northwest National Laboratory (PNNL)
- Oak Ridge National Laboratory (ORNL)
- Argonne National Laboratory (ANL)

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RELEVANCE: AI-STEEL AND AI-CFRP JOINTS TO ACHIEVE VEHICLE LIGHT WEIGHTING NEED BETTER GALVANIC CORROSION RESISTANCE

Objective: High-Quality, Corrosion-Resistant Joints with 3x Longer Lifetime with Surface Modification Treatment vs. Baseline Joints with No Surface Modification Treatment

- Develop novel surface modification techniques to optimize joint quality and adhesion, and provide electrical insulation to improve galvanic corrosion resistance
- Systematically understand (processing)-(interface chemistry)-(joining-corrosion) relationships
  - The potential of the surface modification(s) to improve adhesion and mitigate galvanic corrosion
  - The impact of these surface-modified phases on electric insulation, bulk corrosion resistance, joint quality, and mechanical behavior

Corrosion mitigation (general and galvanic corrosion) in the joints of dissimilar materials is a key technical challenge that must be overcome to successfully integrate candidate lightweight autobody structures from Al alloys, carbon-fiber reinforced polymer (CFRP) composites, and steels

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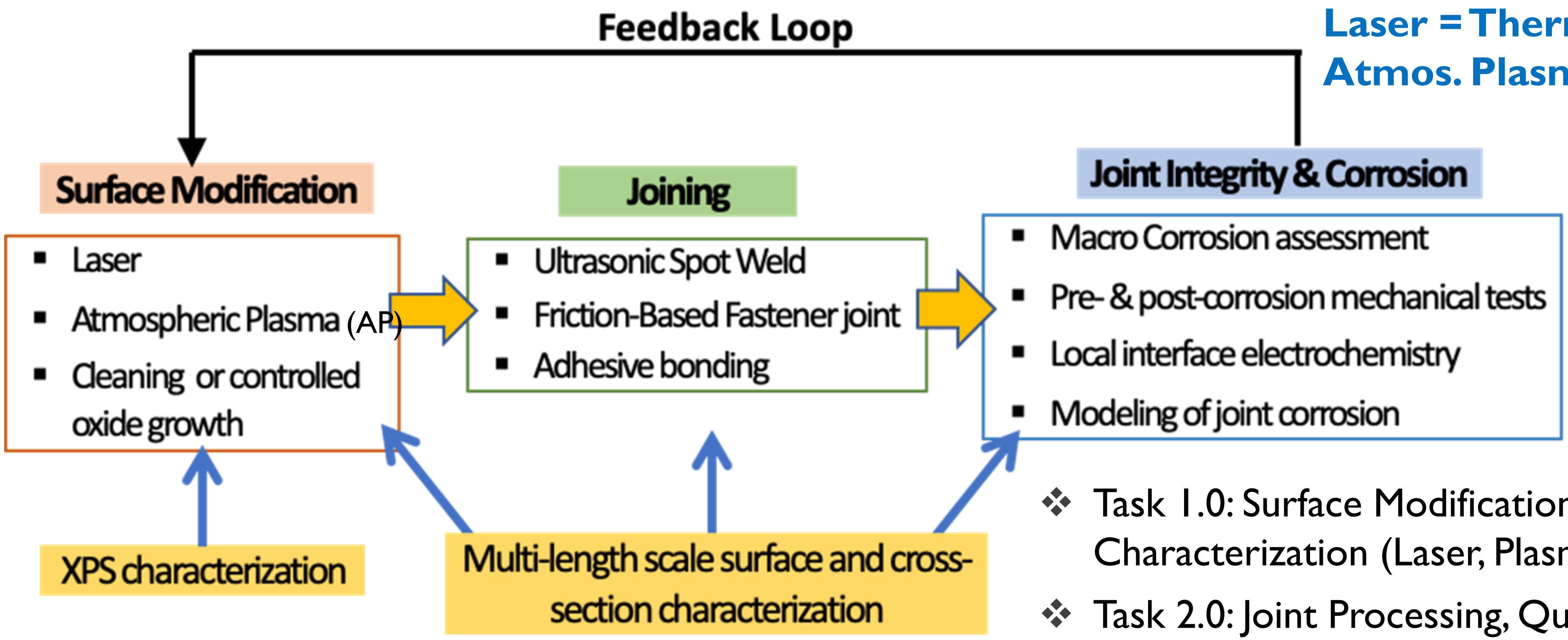
OVERALL APPROACH: SURFACE MODIFICATION-JOINING-CORROSION PERFORMANCE

Laser = Thermal Treatment
Atmos. Plasma = Chemical Treatment



Selected materials

- Al 5052-H32, 5083, 6061-T6, 6063, 7075, A356(cast)
- PPA and PA66 carbon fiber composites
- Galvanized DP590 and 980

- Task 1.0: Surface Modification Process Development and Characterization (Laser, Plasma, Adhesives)
- Task 2.0: Joint Processing, Quality, and Adherence
- Task 3.0: Bulk Substrate and Macro-Galvanic Corrosion Assessment
- Task 4.0: Scanning Electrochemical Cell Microscopy (SECCM) for Micro-Galvanic & Interface Assessment
- Task 5.0: Modeling of Joint Corrosion Behavior

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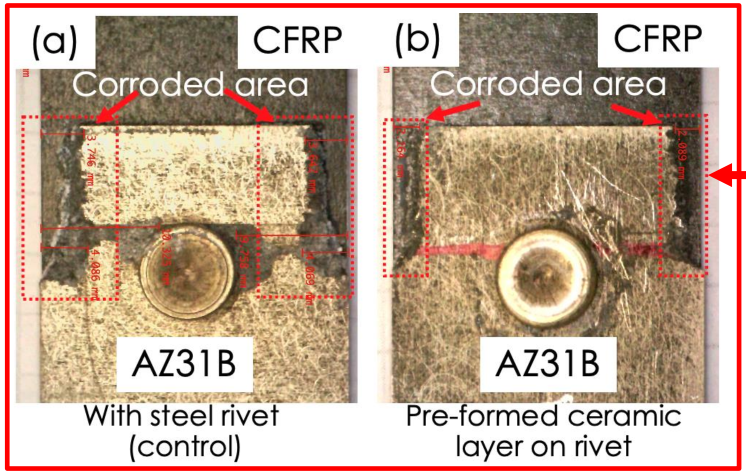
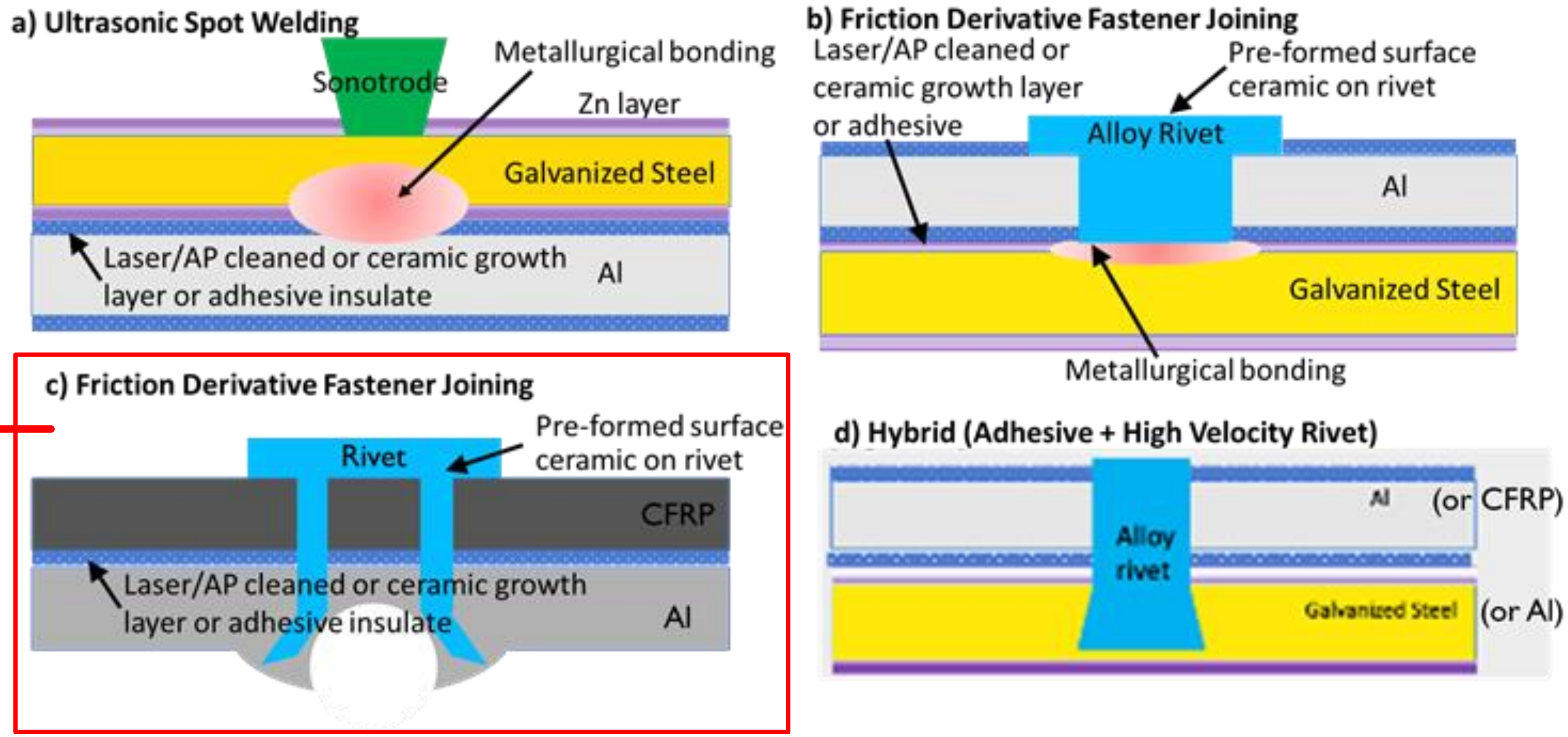
SURFACE MODIFICATION-JOINING STRATEGIES: ATTEMPT ELECTRIC INSULATION BY GROWTH OF OXIDES ON AL OR USE OF ADHESIVES





- Can the joining accommodate submicron oxide layers to reduce galvanic coupling?
  - Successfully demonstrated pre-formed surface coating rivet improved galvanic corrosion resistance for Mg-CFRP by friction self-piercing riveting process from Joining Core Program (JCP) Phase 1
- Collaboration with other thrusts in Joining Core Program Phase 2: MAT222, MAT223, MAT224

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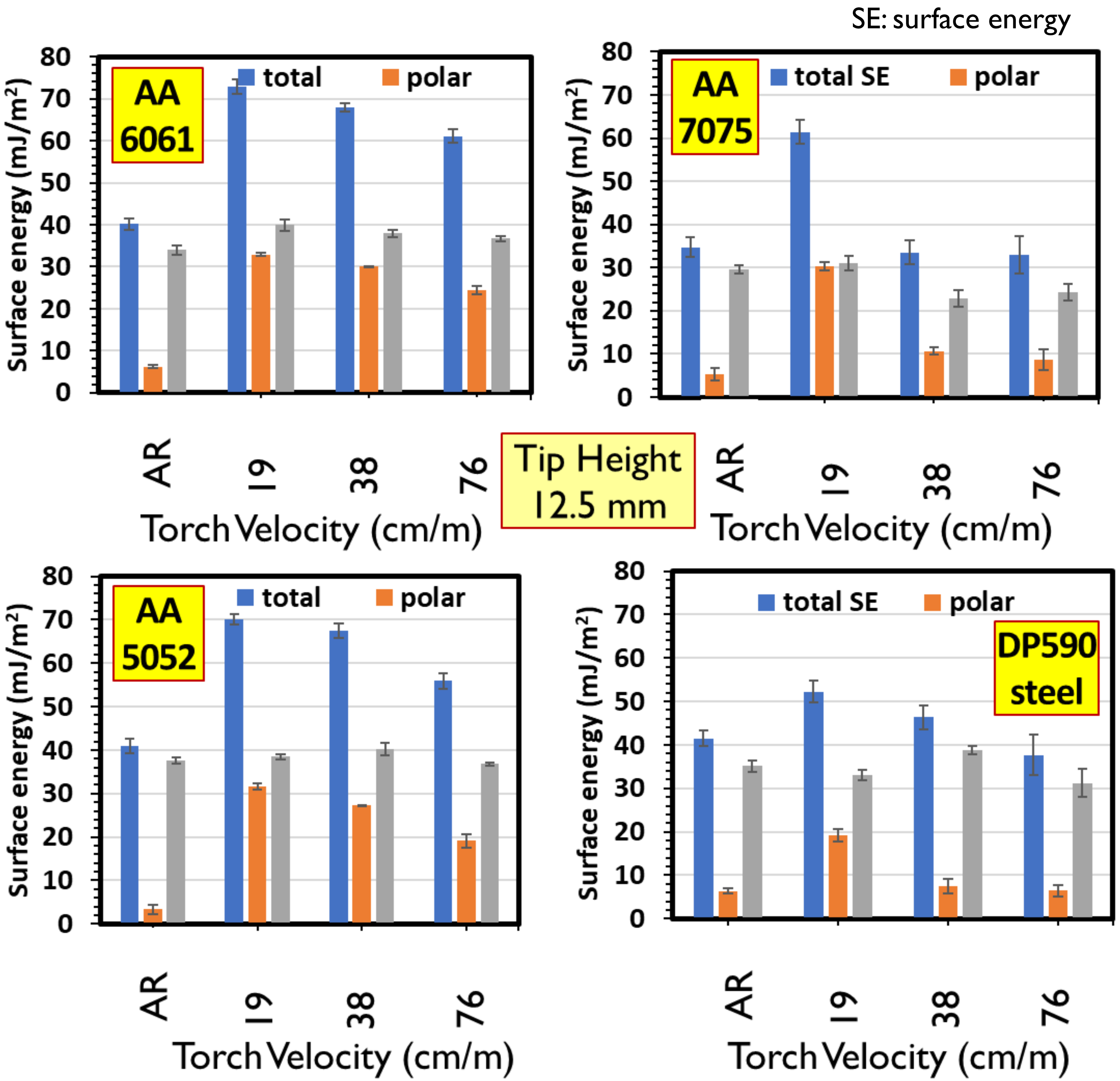
MILESTONES

Quarter	Milestone/Deliverable Name/Description	End Date
Q1	Complete baseline evaluation of general corrosion properties for monolithic (not joined) as-received materials (Al, steel, and/or CFRP) electrochemical testing	Month 3
Q2	• Develop a method for characterization of adhesive-CFRP and adhesive-Al (or galvanized steel) interfaces and interphase formation by microscopy • Utilize the corrosion model to provide a baseline corrosion potential without the surface treatment techniques in dissimilar joints	Month 6
Q3	Evaluate and characterize electrochemical properties before and after laser and atmosphere plasma treatment at least one Al alloy type at the flat coupon level	Month 9
Q4	• Complete electrochemical resistance and corrosion properties assessment for laser and/or AP treated oxide surfaces of at least one Al alloy type • Demonstrate at the coupon level the surface energy and bonding improvements after the air plasma treatment on CFRP composite	Month 12
Go/No-Go decision	• Document determination of targeted achievement of electrochemical resistance and/or corrosion properties at least 3x better than the baseline untreated Al surface • Perform lap shear tests to demonstrate a 20% increase in surface energy and an 10% increase in lap shear strength on CFRP composite with surface modification	9/30/2021

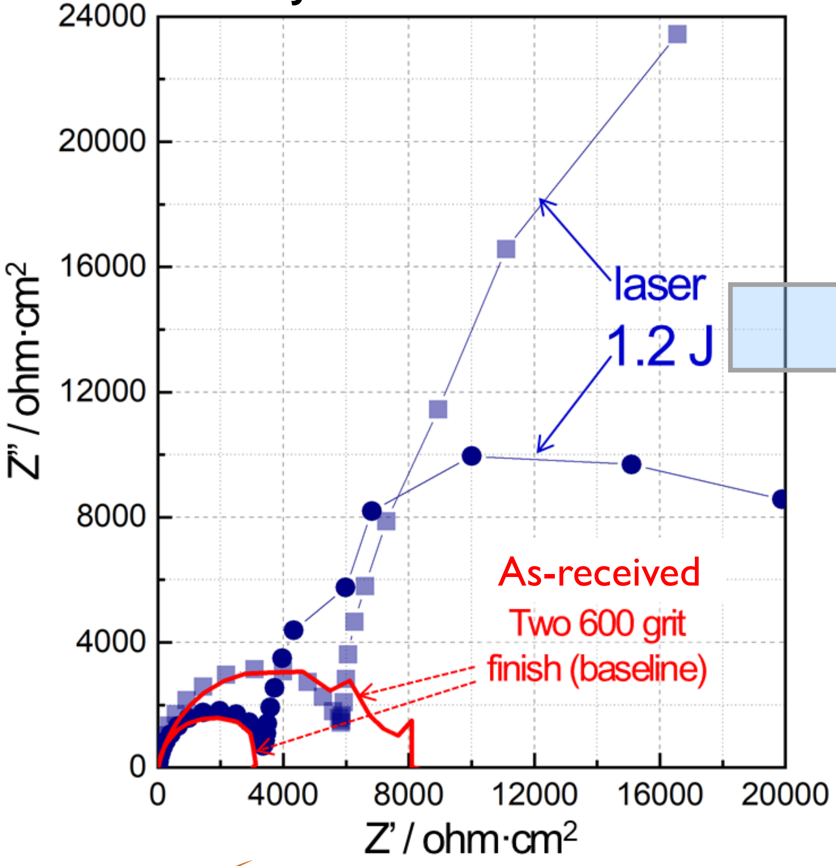
ACCOMPLISHMENTS: ATMOS. PLASMA TREATMENT OF AL ALLOYS (AA) AND DUAL PHASE (DP) 590 TO ENHANCE ADHESIVE BONDING

- 150W air plasma torch: all four metal substrates increase in surface energy with the slowest speed
- Increases in surface energy from exposed surfaces may be attributed to increased amounts of hydrated components (characterization in progress)
- Most of the epoxies are rich in hydroxyl groups and can provide better bonding characteristics with a hydroxyl-rich surface
- Higher traversing speeds reduce surface energy indicated by lower polar component

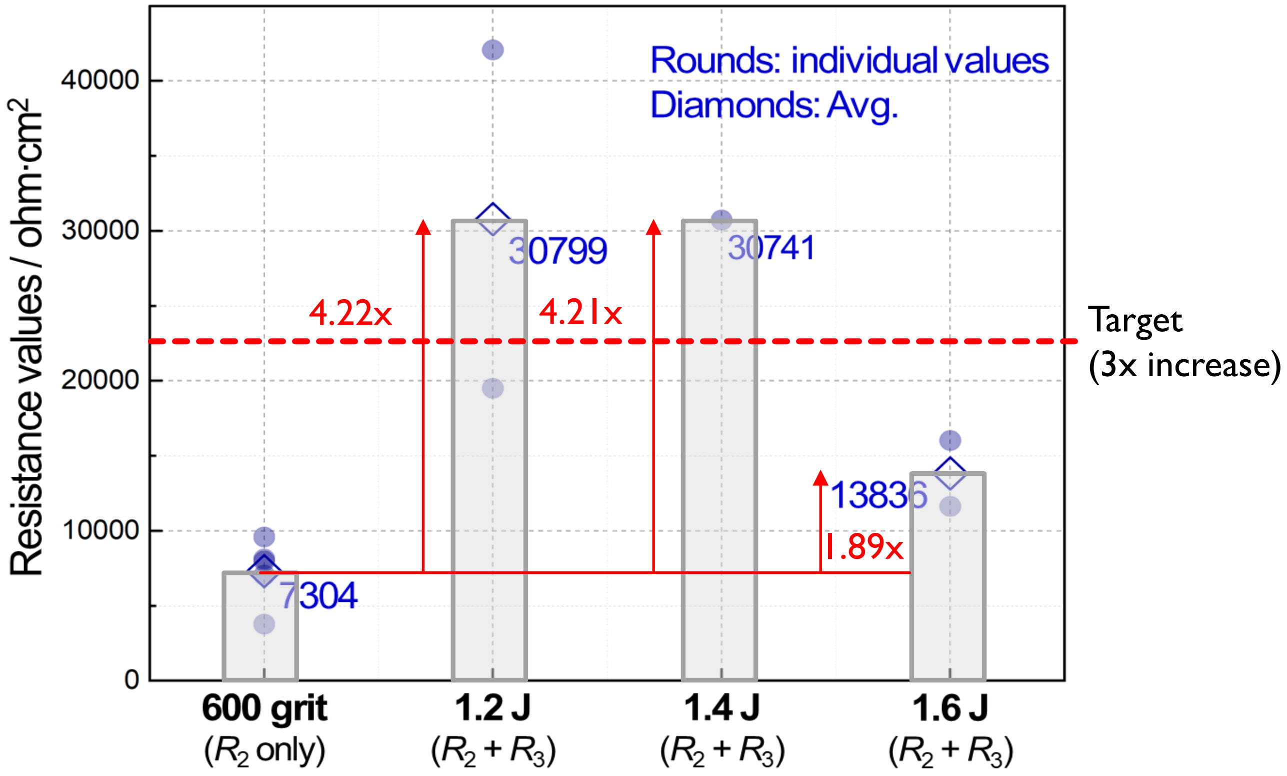


ACCOMPLISHMENTS: INITIAL LASER SURFACE PROCESSING OF 7075 AL SHOWED ENHANCED CORROSION RESISTANCE IN 3.5 WT.% NACL

Impedance Data for As-Received vs 1.2 J Laser Treated 7075 Al



Electrochemical Resistance Data



Corrosion Resistance: 600 grit < 1.6 J < 1.2 J ≃ 1.4 J

- The impedance values were greater in laser-treated A7075 than untreated material
- Surface characterization in progress

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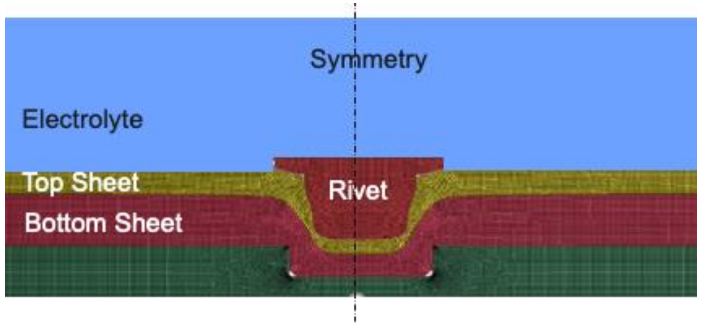
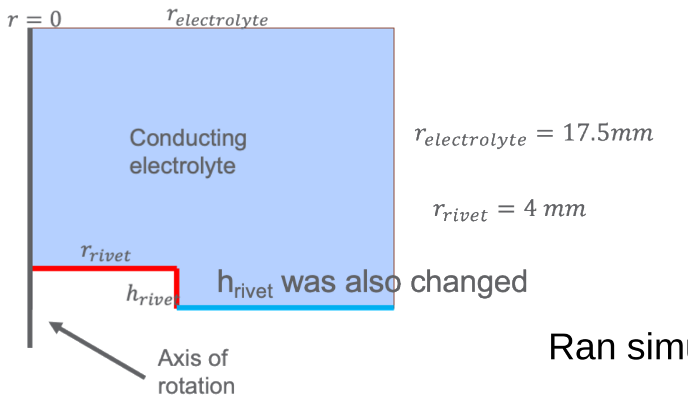
ACCOMPLISHMENTS: ESTABLISHING BASELINE TO UNDERSTAND THE RIVET-SHEET GALVANIC INTERACTIONS VIA COMSOL MODELING

Model Setup- High Velocity Riveting



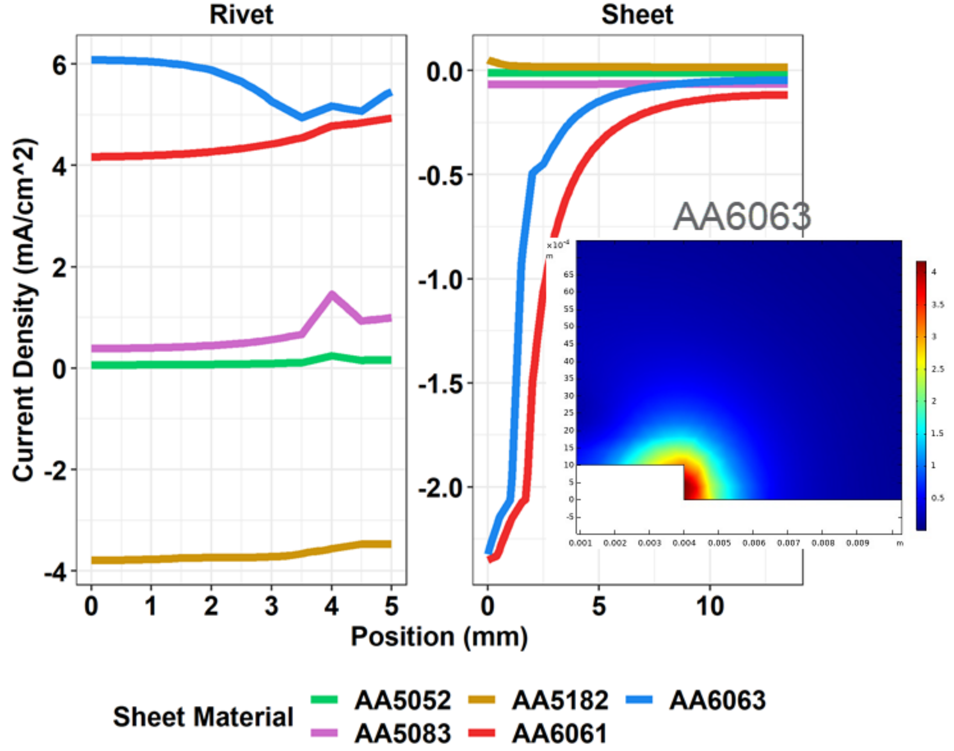
Material	Eq Potential (V)	Electrode
AA5083	-0.44	Cathode
AA5052	-0.59	Cathode
AA6063	-0.68	Cathode
AA6061	-0.72	Cathode
AA7075 (Rivet Material)	-0.76	-
AA5182	-1.05	Anode



Ran simulations for $h_{rivet} = 1mm, 0.5\ \text{mm and flushed}$

7075 Rivet material with different top sheet aluminum alloys were modeled

Results



- AA6063 as a top sheet has greatest corrosion current when coupled with 7075 rivet and will lead to the corrosion of the rivet

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COLLABORATION AND COORDINATION

- Teams meet and virtually present monthly
- The exact same batches of materials are being used by all teams at each lab across the JCP
- Oak Ridge National Laboratory Team:
  - Materials Joining, Deposition Science & Technology, Corrosion Science & Technology, and Carbon & Composites Groups
- Pacific Northwest National Laboratory:
  - Solid Phase Processing- Joining, Materials Performance, Electrochemical Sciences Groups
- Argonne National Laboratory: X-ray, synchrotron beam characterization of surfaces
- Tri-national lab team formed to support joining, characterization, corrosion, and modeling tasks
- Periodic interactions with other thrusts within JCP with close coordination/ ties to automotive industry
- L&L Products: provide adhesives

PROPOSED FUTURE WORK

- Evaluate laser and atmosphere plasma processes to controllably form insulating submicron oxide/ceramic surfaces on Al to increase corrosion resistance and reduce Al-steel joint galvanic coupling
  - Can such surfaces still be joined? Do they appreciably impact corrosion resistance?
- Evaluate atmosphere plasma processes to enhance adhesive bonding
  - Al-CFRP: joint quality and reduced galvanic coupling
  - Al-steel: joint quality and reduced galvanic coupling
- Collaboration with other thrusts in Joining Core Program Phase 2 to explore multiple joining processes
- Characterization
  - Surface/cross-section (x-ray photoelectron spectroscopy, electron microscopy, x-ray diffraction, radiography, tomography)
  - Extensive bulk and local electrochemical evaluation of bulk and joined materials
- Model and validate the effect of deformation, gaps, adhesives, surface treatment and crevice on the corrosion behavior of multi-material joints

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

SUMMARY

- Identified and procured selected materials (Al alloys, CFRP, and steel) in collaboration with other thrusts in the joining core program phase 2 to ensure consistent, comparable findings
- Atmosphere plasma surface treatment on Al and steel metal surface increased surface energy compared with the untreated material to enhance adhesive bonding performance
- Initial laser surface treatment on AA7075 improved the corrosion resistance and electrochemical resistance compared with the untreated material
- COMSOL modeling of sheet/rivet interaction impacts on galvanic coupling initiated to guide materials surface modification and joining strategies

TECHNICAL BACKUP SLIDES

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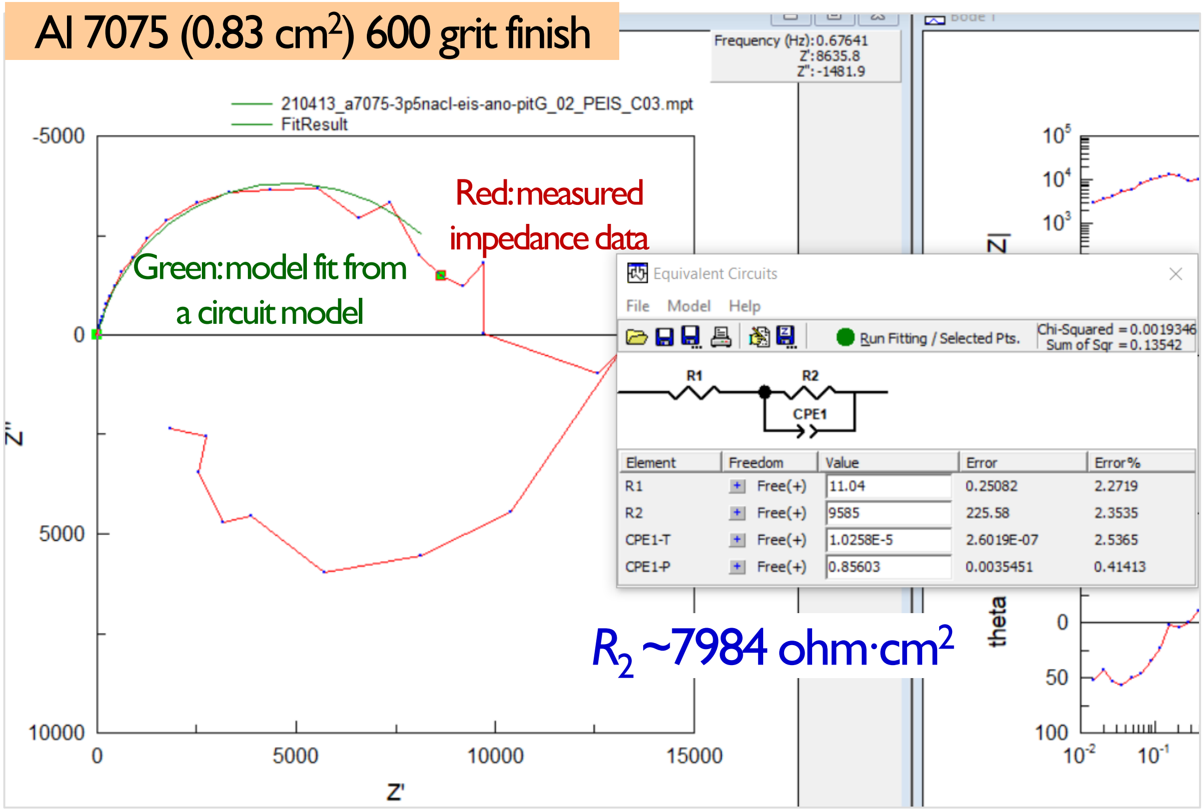
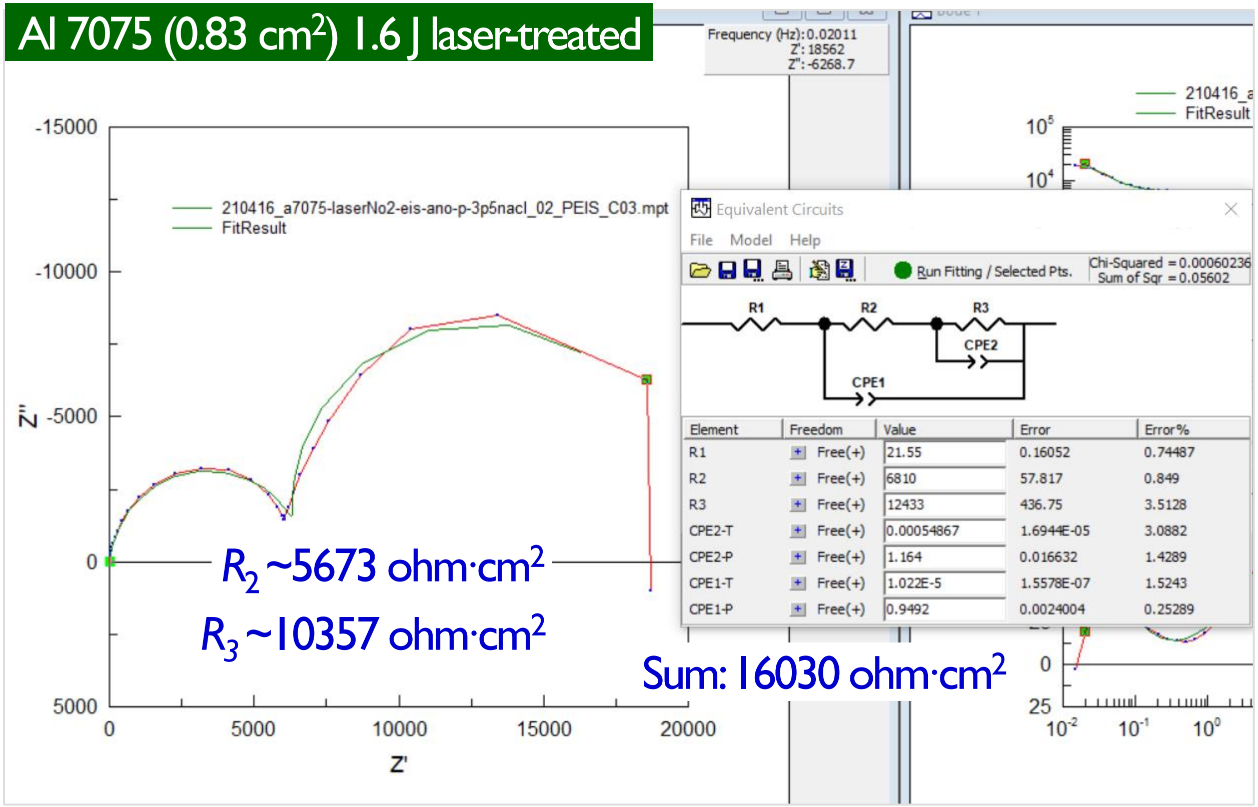
TECHNICAL BACK-UP: IMPEDANCE DATA FITTING EXAMPLES

Zview (Scribner INC.) was used for computer-assisted impedance spectra fitting of all electrochemical impedance spectroscopy (EIS) data. Some examples of impedance fitting (as snapshots) are shown below.





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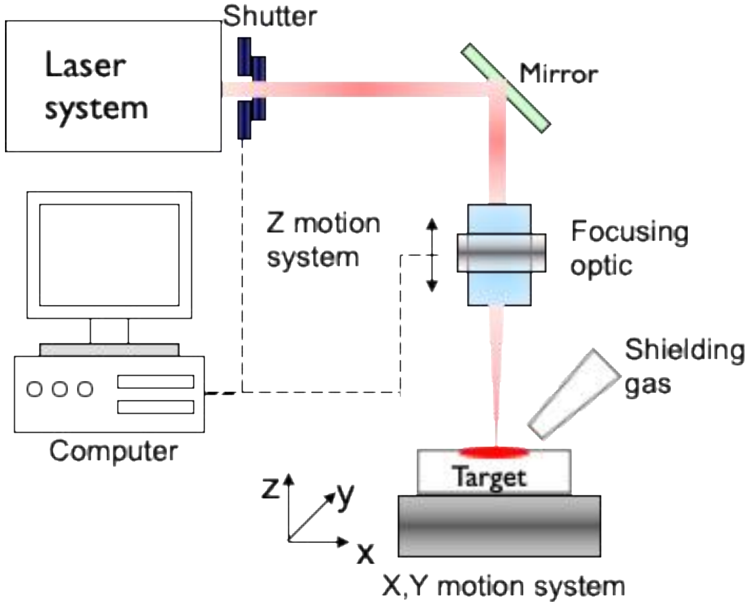
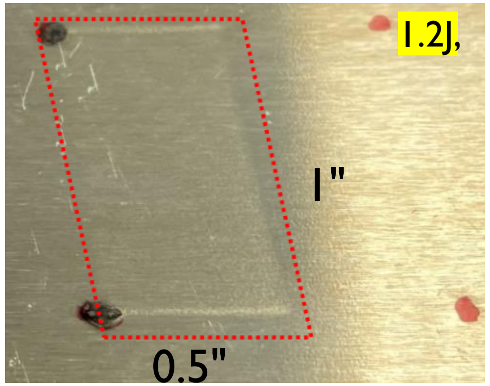
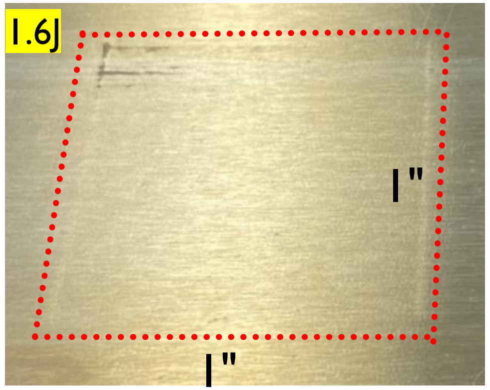
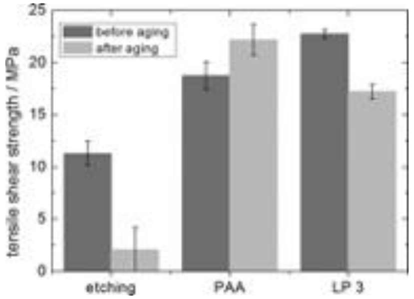
ACCOMPLISHMENT: LASER SURFACE PROCESSING ON AL ALLOYS

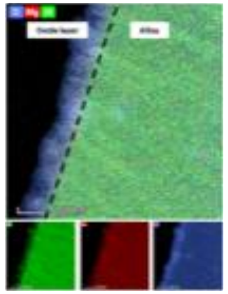








J. Laser Appl. **24**, 032002 (2012)



J. Laser Appl. **31**, 012001 (2019)

- Advantage of laser process
  - Non-contact
  - High precision, selective area, less distortion, environment friendly
  - Applicable to complex, three-dimensional geometry by robot or CNC motion stages
  - Amenable to Scale up
- Laser Process parameters
  - Laser power, pulse repletion rate, pulse duration, wavelength
  - Focusing optic/ beam shaping
  - Scan speed
  - Shielding gas (e.g., oxygen, nitrogen): forms Al_2O_3 or AlN
- **Improve adhesive bonding strength**
- **Improve corrosion resistance of material and joint**

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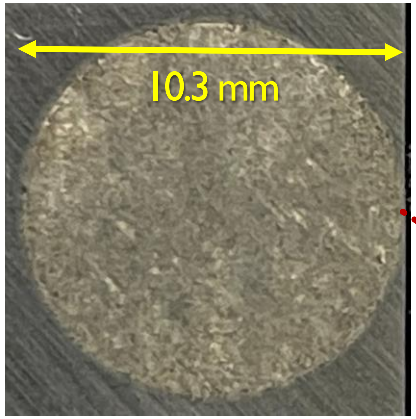
TECHNICAL BACK-UP: EIS DATA SUMMARY & POST-EXPOSURE SURFACE IMAGES



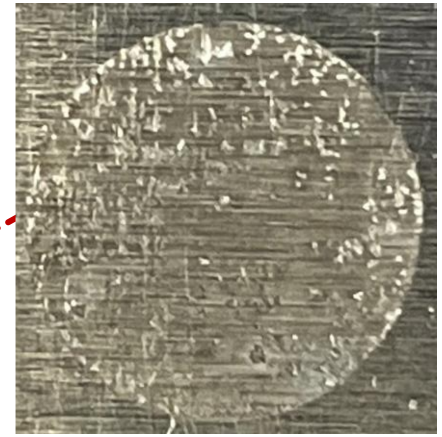
Post-corrosion surface of 7075 after EIS + anodic polarization + anodic constant potential

A7075 (2"x2" & 1"x1" coupons) EIS results

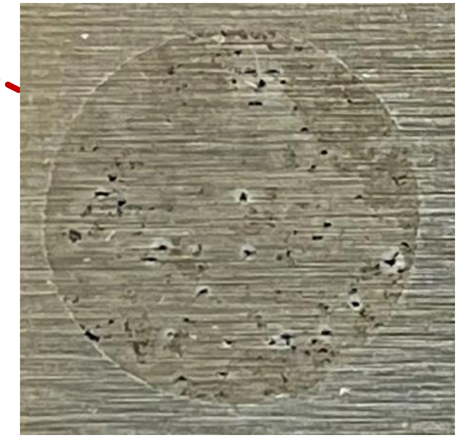
$Ohm \cdot cm^2$	600 grit (baseline)	Laser 1.6 J	Laser 1.4 J	Laser 1.2 J
Fitted *R* values	R_2 only	$R_2 + R_3$	$R_2 + R_3$	$R_2 + R_3$
Run 1	3777	16030	30741 (1"x1")	42082
Run 2	7043	11641 (1"x1")		19515 (1"x1")
Run 3	7984			
Run 4	8123			
Run 5	9591			
Avg.	7304	13836	30741	30799

Resistance rank (tentative)

Baseline < 1.6 J < 1.4J~1.2 J



Pitting but no visible substrate dissolution



Pitting but no visible substrate dissolution