Corrosion Protection and Dissimilar Material Joining for Next-Generation Lightweight Vehicles

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Arconic Technology Center

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Project ID: MAT133

ARCONIC
Innovation, engineered.

THE OHIO STATE UNIVERSITY

HONDA
Honda R&D Americas, Inc.

Overview

Timeline:

- Start Date: October 1, 2016
- End Date: June 30, 2020
- 70% complete

Barriers:

- Combinations of dissimilar materials with fasteners can cause galvanic corrosion.
- Joining of multi-material systems requires new technologies that may require billions in capital.
- Many existing fasteners are incompatible with UHSS/AHSS or require additional process steps.*

Budget:

- Total project funding: $2,395,295
  - Govt. share: $1,764,330
  - Partner share: $630,965
- Funding in FY2017: $742,878
- Funding for FY2018: $1,017,972

Partners:

- Arconic Inc. – Lead
- Honda R&D Americas Inc.
- The Ohio State University

* 2017 U.S. DRIVE MTT Roadmap Report, section 4.

Relevance

Project Objectives:

- Develop weld process parameters and produce joints between Al, AHSS, and CFRP to establish confidence in RSR process robustness.
- Evaluate extent of galvanic corrosion and identify corrosion mitigation strategies.
- Demonstrate RSR implementation on a robotic system exploring process boundaries such as joint gaps, angularity, adhesives, and flange width variations.

Impact:

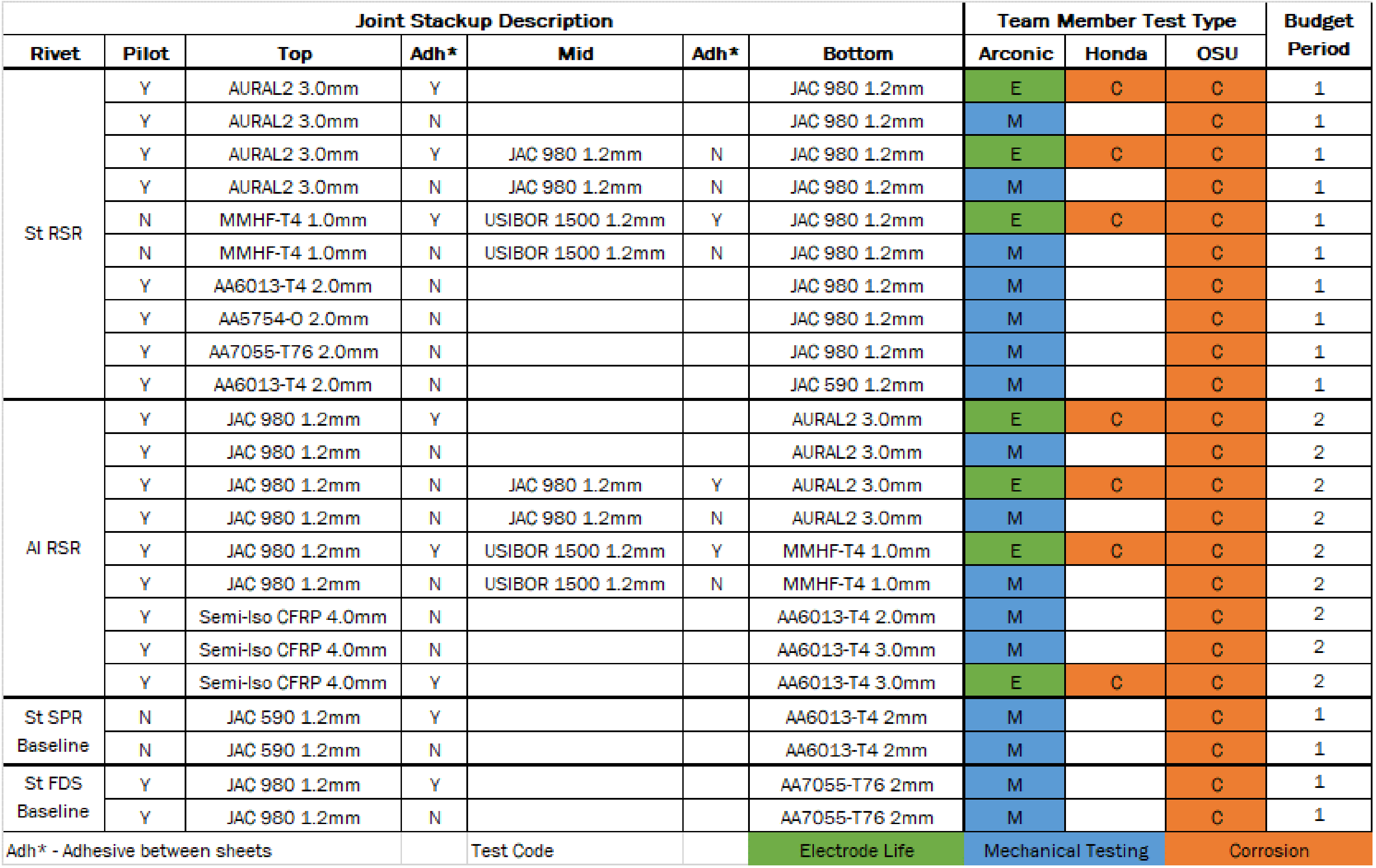
- Provide high performance multi-material joining (Al to Steel and Al to CFRP) with the existing resistance spot welding infrastructure and knowledge base, offsetting billions in capital other technologies would require.
- Increase the flexibility of the existing infrastructure by allowing spot welding of like materials in sequence along with dissimilar material joining by simply not feeding a rivet to the tips.
- Enable an additional 10-20% weight reduction over high strength steel-only designs, providing a 1.5 - 3% total improvement in fuel efficiency for vehicles that incorporate RSR for multi-material joining.

Milestones

	BP1					BP2				BP3					
	2016	2017				2018				2019				2020	
Milestones and Go / No-Go points	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2
Define preliminary material & part and testing requirement	100%	🟩													
Steel RSR piloted & self-piloted weld process developed		100%	🟩												
Al RSR piloted weld process developed		100%	🟩												
Rivet mat'l/coating assement for Al to St & CFRP		100%	🟩												
Mechanical property assessment for Steel RSR				100%	🟩										
Corrosion assessment for Baseline SPR and FDS joints				100%	🟩										
Go/No Go: Steel RSR Joints meet targets					100%										
Al to Steel RSR piloted weld process developed						100%	🟩								
Al to CFRP RSR piloted weld process developed							100%	🟩							
Corrosion Testing Completed for All RSR Configurations						80%	▨	▨	▨						
Steel & Al RSR production process condition limits								75%	▨		🟨				
Go/No Go: Establish production condition limits									▨	→	🟨				
RSR feed system repeatability established								75%	▨		🟨				
Go/No Go: Establish feed system repeatability									▨		🟨				
Determine prod galvanic corrosion mitigation strategies										25%	▨	→	🟨		
RSR pilot cell complete											75%				
Manufacture demonstrator parts and assemblies											10%	▨	🟨		
Test demonstrator assemblies												▨	▨	🟨	
Final Reporting													▨		🟨

Technical Accomplishments and Progress

Test Plan Matrix for Preliminary EL, Mechanical, and Corrosion Test

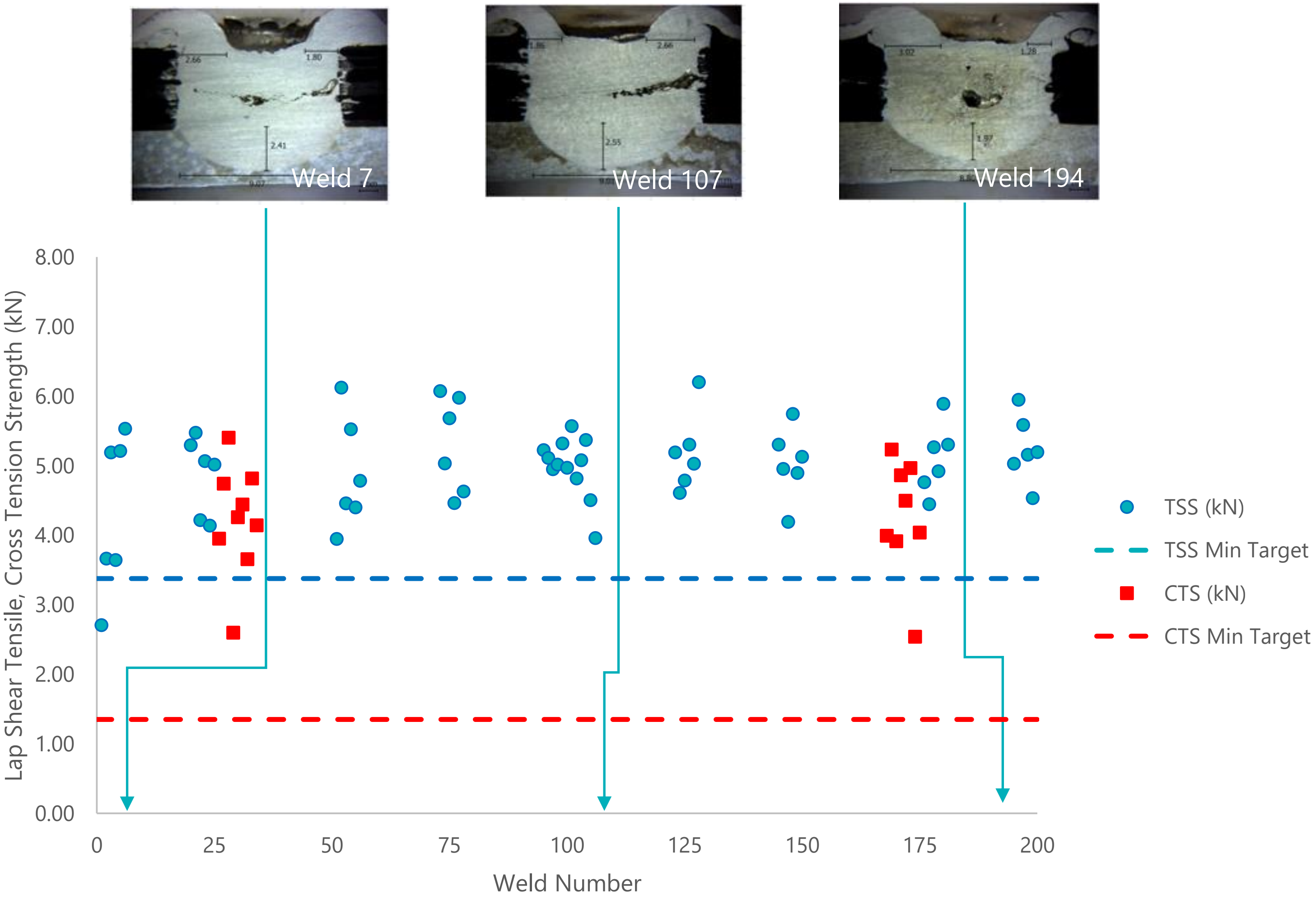


Joint Stackup Description							Team Member Test Type			Budget Period
Rivet	Pilot	Top	Adh*	Mid	Adh*	Bottom	Arconic	Honda	OSU	
St RSR	Y	AURAL2 3.0mm	Y			JAC 980 1.2mm	E	C	C	1
	Y	AURAL2 3.0mm	N			JAC 980 1.2mm	M		C	1
	Y	AURAL2 3.0mm	Y	JAC 980 1.2mm	N	JAC 980 1.2mm	E	C	C	1
	Y	AURAL2 3.0mm	N	JAC 980 1.2mm	N	JAC 980 1.2mm	M		C	1
	N	MMHF-T4 1.0mm	Y	USIBOR 1500 1.2mm	Y	JAC 980 1.2mm	E	C	C	1
	N	MMHF-T4 1.0mm	N	USIBOR 1500 1.2mm	N	JAC 980 1.2mm	M		C	1
	Y	AA6013-T4 2.0mm	N			JAC 980 1.2mm	M		C	1
	Y	AA5754-O 2.0mm	N			JAC 980 1.2mm	M		C	1
	Y	AA7055-T76 2.0mm	N			JAC 980 1.2mm	M		C	1
	Y	AA6013-T4 2.0mm	N			JAC 590 1.2mm	M		C	1
Al RSR	Y	JAC 980 1.2mm	Y			AURAL2 3.0mm	E	C	C	2
	Y	JAC 980 1.2mm	N			AURAL2 3.0mm	M		C	2
	Y	JAC 980 1.2mm	N	JAC 980 1.2mm	Y	AURAL2 3.0mm	E	C	C	2
	Y	JAC 980 1.2mm	N	JAC 980 1.2mm	N	AURAL2 3.0mm	M		C	2
	Y	JAC 980 1.2mm	Y	USIBOR 1500 1.2mm	Y	MMHF-T4 1.0mm	E	C	C	2
	Y	JAC 980 1.2mm	N	USIBOR 1500 1.2mm	N	MMHF-T4 1.0mm	M		C	2
	Y	Semi-Iso CFRP 4.0mm	N			AA6013-T4 2.0mm	M		C	2
	Y	Semi-Iso CFRP 4.0mm	N			AA6013-T4 3.0mm	M		C	2
	Y	Semi-Iso CFRP 4.0mm	Y			AA6013-T4 3.0mm	E	C	C	2
St SPR Baseline	N	JAC 590 1.2mm	Y			AA6013-T4 2mm	M		C	1
	N	JAC 590 1.2mm	N			AA6013-T4 2mm	M		C	1
St FDS Baseline	Y	JAC 980 1.2mm	Y			AA7055-T76 2mm	M		C	1
	Y	JAC 980 1.2mm	N			AA7055-T76 2mm	M		C	1
Adh* - Adhesive between sheets				Test Code		Electrode Life	Mechanical Testing		Corrosion	

Technical Accomplishments and Progress

AL RSR EL Results: 4mm CFRP to 3mm Aural2-T7 through Dow 5055-C with F7-7 Rivet

- AL Rivet strength less than ST Rivet Materials
- TSS fracture along faying surface/CTS button pull in AL casting
- Porosity in rivet contributed to more scatter in strength data
- Porosity function of pilot hole and pin length



Technical Accomplishments and Progress

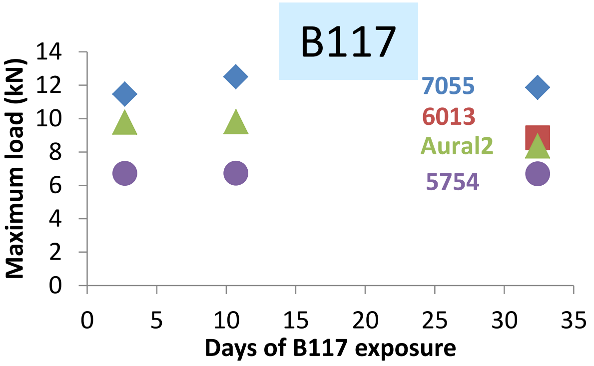
RSR and Baseline Technologies Undergoing 4 Different Types of Corrosion Testing

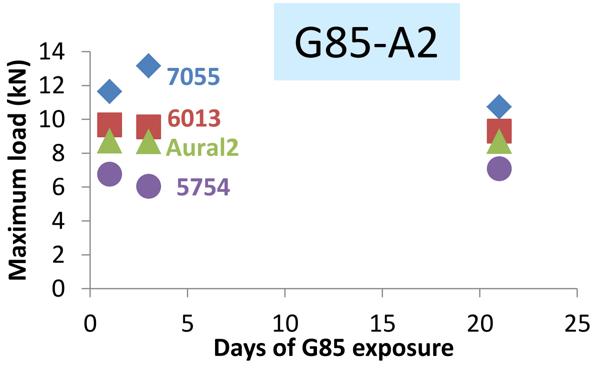
Test Code	Adhesive	Top Plate Material	Middle Plate Material	Bottom Plate Material	B117 (continuous neutral salt spray)	ASTM G85 (acidified salt spray with wet and dry cycles)	Nissan Underbody (wet and dry cycles with ?pH salt spray)	Received Prepared In Progress Standard 3 Exposures Complete All Exposures Complete	
								Micro. cell	Serial polishing
AL to SP									
B51-0-191.131-	Y	AURAL2 3.0mm	-	JAC 980 1.2mm	15	15	15	3	2
A51-0-191.131-	N	AURAL2 3.0mm	-	JAC 980 1.2mm	10*	10*	10	3	2
B51-0-191.191.131-	Y	AURAL2 3.0mm	JAC 980 1.2mm	JAC 980 1.2mm	15	15	15	3	2
A51-0-191.191.131-	N	AURAL2 3.0mm	JAC 980 1.2mm	JAC 980 1.2mm	10*	10*	10	3	2
B52-0-191.230.150-	Y	MMHF-T4EX 0.9mm	USIBOR 1500 1.0mm	JAC 980 1.2mm	15	15	15	3	2
A52-0-191.230.150-	N	MMHF-T4EX 0.9mm	USIBOR 1500 1.0mm	JAC 980 1.2mm	10*	10*	10	3	2
A51-0-191.40-	N	6013-T4 2.0mm	-	JAC 980 1.2mm	10	10*	10	3	2
A52-0-191.40-	N	6013-T4 2.0mm	-	JAC 980 1.2mm	10	10	10	3	2
A51-0-191.140-	N	5754-O 2.0mm	-	JAC 980 1.2mm	10*	10*	10	3	2
A51-0-191.160-	N	7055-T76 2.0mm	-	JAC 980 1.2mm	10*	10*	10	3	2
A51-0-171.40-	N	6013-T4 2.0mm	-	JAC 590 1.2mm	10*	10*	10	3	2
SP to AL									
B53-0-131.191-	Y	JAC 980 1.2mm	-	AURAL2 3.0mm	15	15	15	3	2
A53-0-131.191-	N	JAC 980 1.2mm	-	AURAL2 3.0mm	10*	10*	10	3	2
B53-0-131.191.191-	Y	JAC 980 1.2mm	JAC 980 1.2mm	AURAL2 3.0mm	15	15	15	3	2
A53-0-131.191.191-	N	JAC 980 1.2mm	JAC 980 1.2mm	AURAL2 3.0mm	10	10	10	3	2
B53-0-150.230.191-	Y	JAC 980 1.2mm	USIBOR 1500 1.0mm	MMHF-T4EX 1.0mm	15	15	15	3	2
A53-0-150.230.191-	N	JAC 980 1.2mm	USIBOR 1500 1.0mm	MMHF-T4EX 1.0mm	10	10	10	3	2
CFRP to AL									
B53-0-40.300-	Y	Semi-Iso CFRP 4.0mm	-	6013-T4 2.0mm	15	15	15	3	2
A53-0-40.300-	N	Semi-Iso CFRP 4.0mm	-	6013-T4 2.0mm	10	10	10	3	2
B53-0-41.300-	Y	Semi-Iso CFRP 4.0mm	-	6013-T4 3.0mm	15	15	15	3	2
SPR									
B54-0-40.171-	Y	JAC 590 1.2mm	-	6013-T4 2mm	15*	15*	15	3	2
A54-0-40.171-	N	JAC 590 1.2mm	-	6013-T4 2mm	10*	10*	10	3	2
EJOT FDS									
B55-0-160.191-	Y	JAC 980 1.2mm	-	7055-T76 2mm	15*	15*	15	3	2
A55-0-160.191-	N	JAC 980 1.2mm	-	7055-T76 2mm	10*	10*	10	3	2

*Mechanical testing performed on samples

Technical Accomplishments and Progress

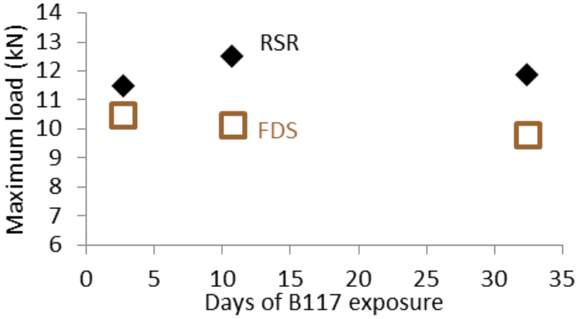
RSR for Various Aluminum Alloys

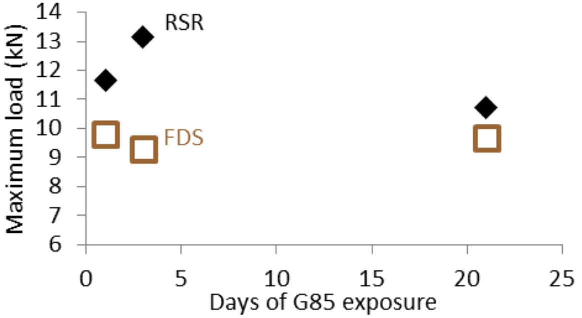




RSR vs FDS

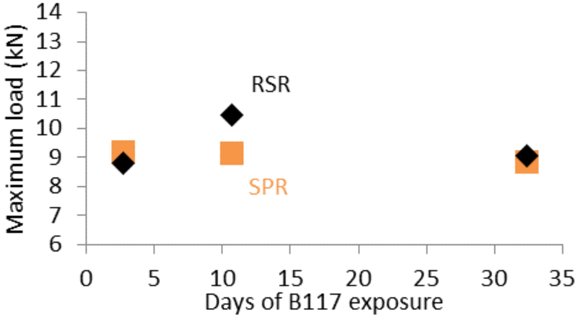
7055-T76 to 980MPa

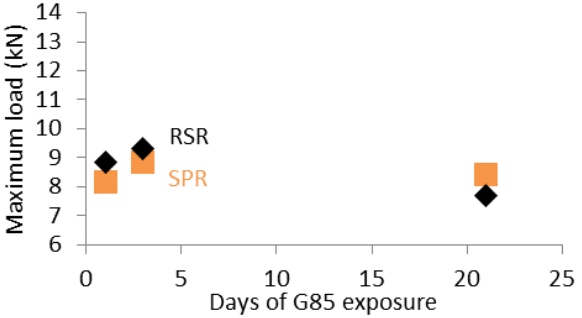




RSR vs SPR

6013-T4 to 590MPa



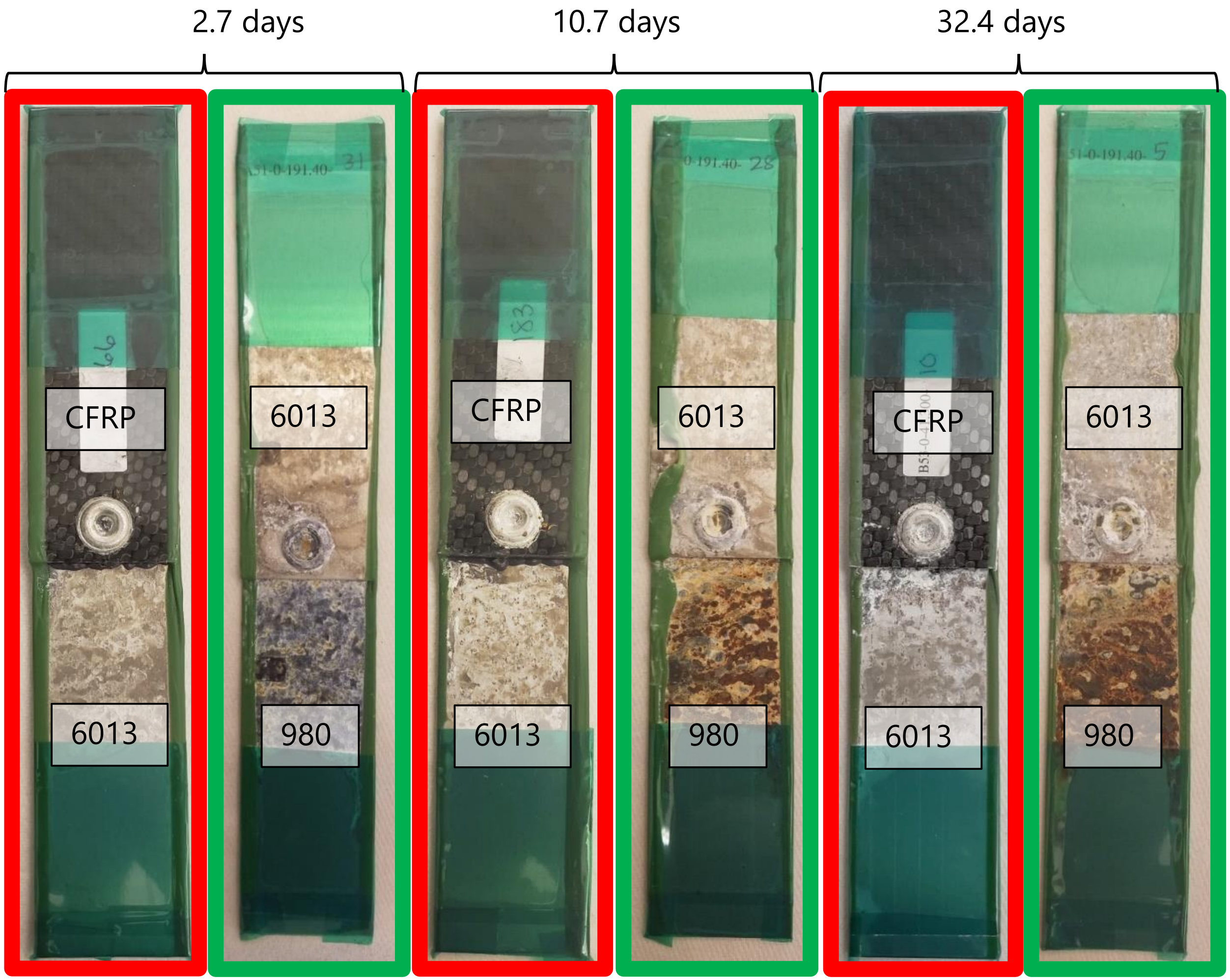


Technical Accomplishments and Progress

6013-T4 Macro Corrosion Similar Between CFRP (AL RSR) and 980MPa Steel (ST RSR) for ASTM B117

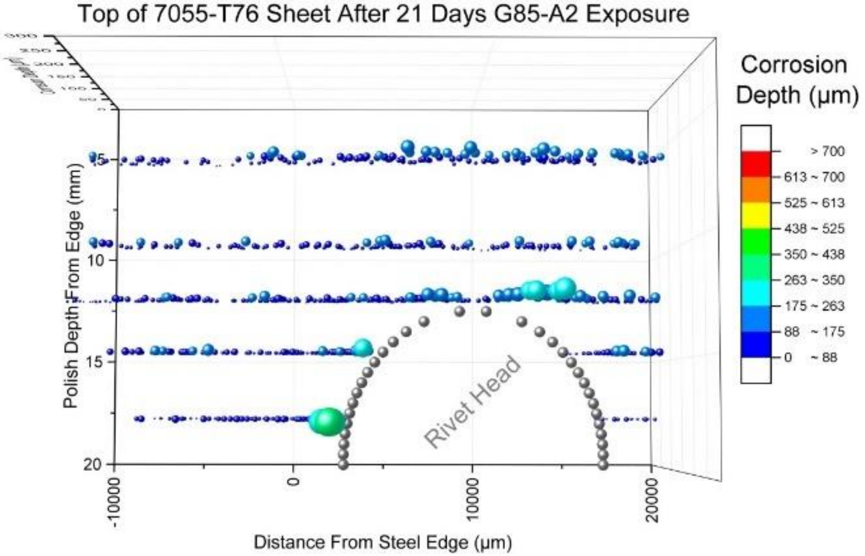
🟥 **RSR, adhesive**
Top: CFRP
Btm: 6013-T4
Rivet: F7-5

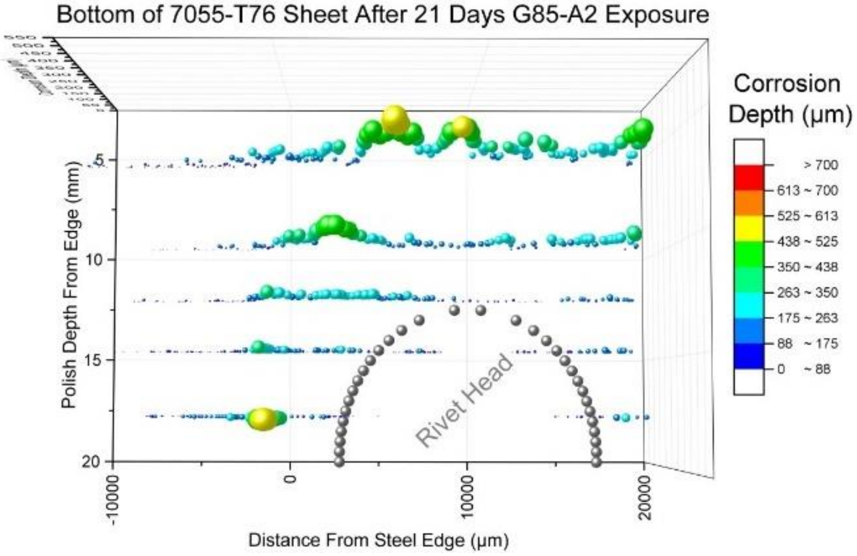
🟩 **RSR, no adhesive**
Top: 6013-T4
Btm: 980MPa
Rivet: R4-5

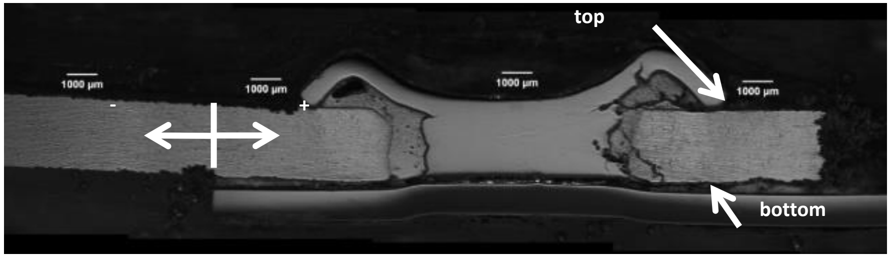


Technical Accomplishments and Progress

Corrosion Depth Map At Top/Faying Surface for 7055-T76 to 980MPa After 21 Days of G85-A2 Exposure


Top of 7055-T76 Sheet After 21 Days G85-A2 Exposure

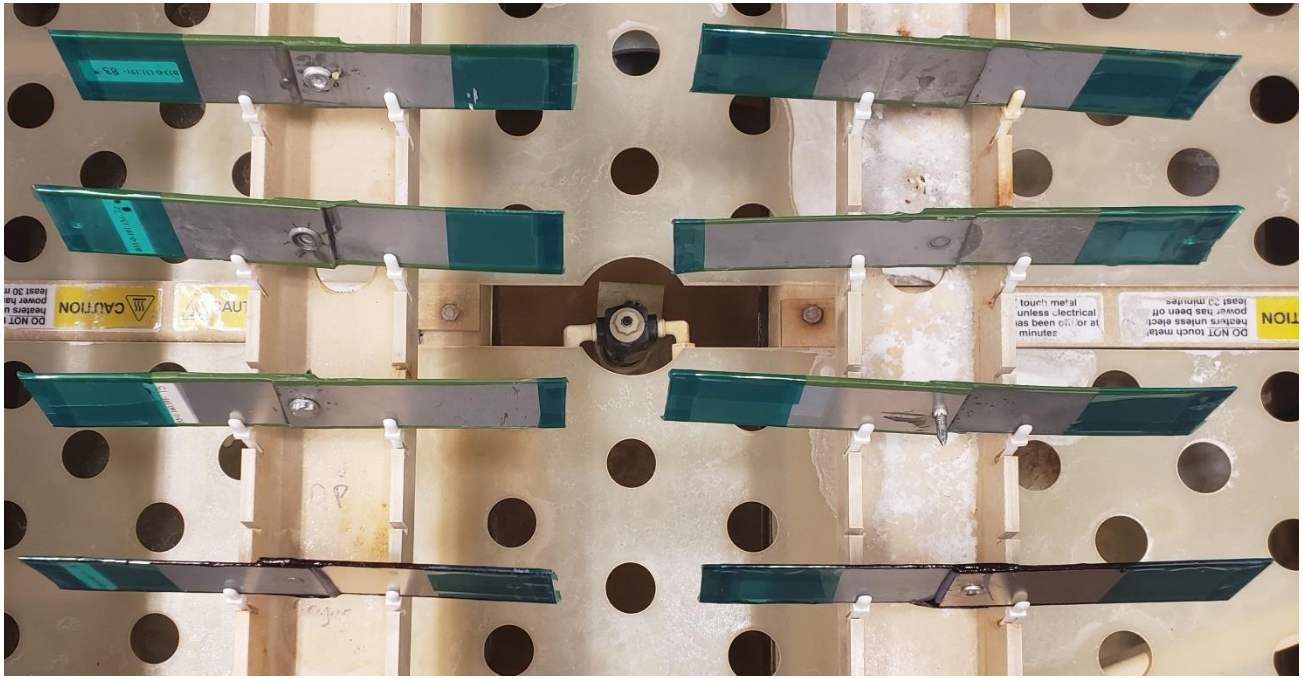

Bottom of 7055-T76 Sheet After 21 Days G85-A2 Exposure



Technical Accomplishments and Progress

Does sample orientation effect location of most severe corrosion and severity

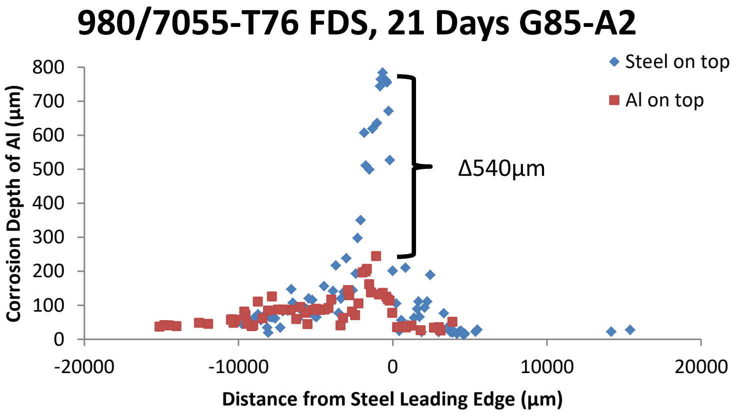
- RSR and FDS joints observed most severe corrosion at the steel sheet leading edge
- Sample orientation in corrosion test chamber could impact the results

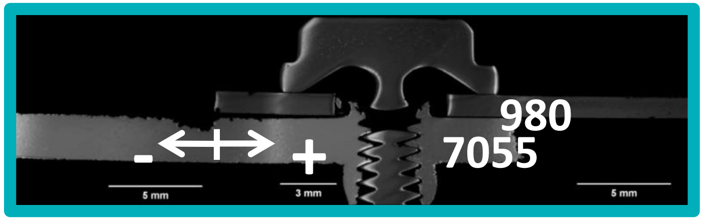


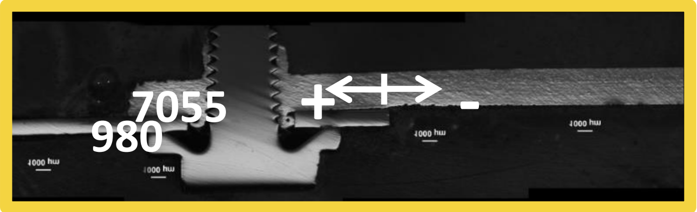
RSR – Resistance Spot Rivet FDS – Flow Drill Screw SPR – Self-Pierce Rivet

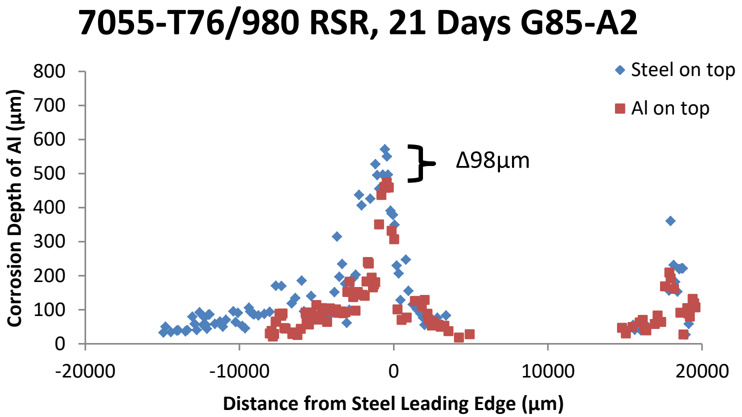
Technical Accomplishments and Progress

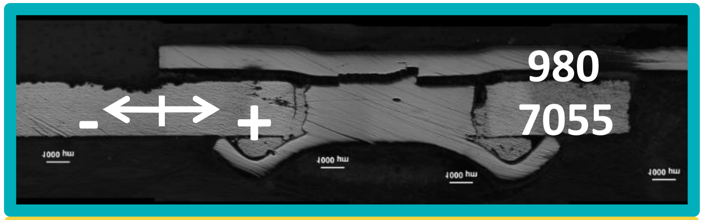
Depth of Corrosion Attack Can Be Influenced by Orientation of Sample in Test Chamber

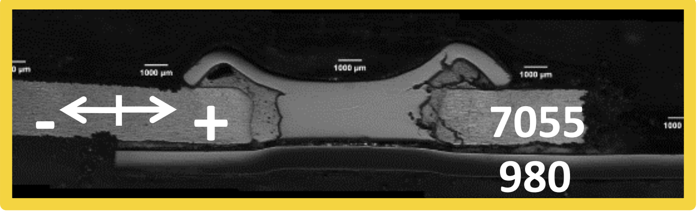

980/7055-T76 FDS, 21 Days G85-A2





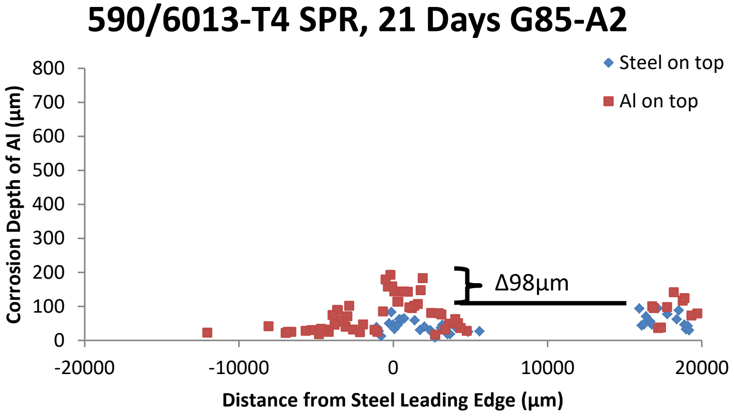

7055-T76/980 RSR, 21 Days G85-A2

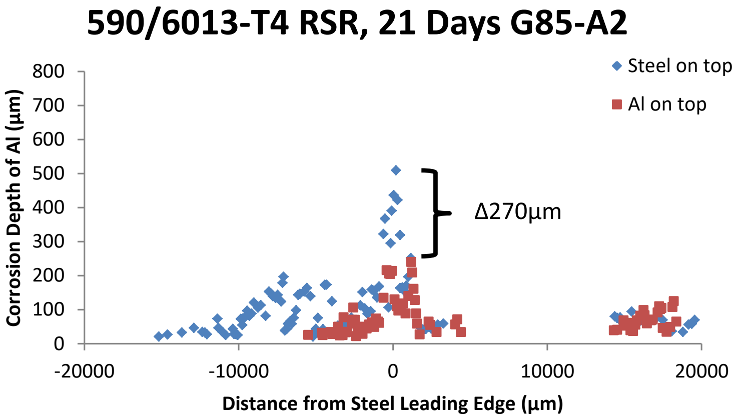


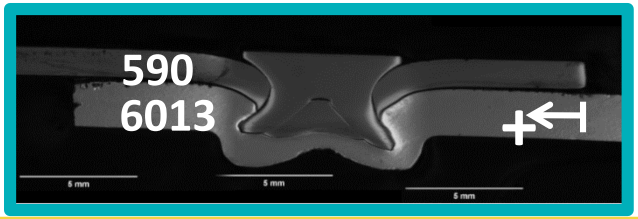


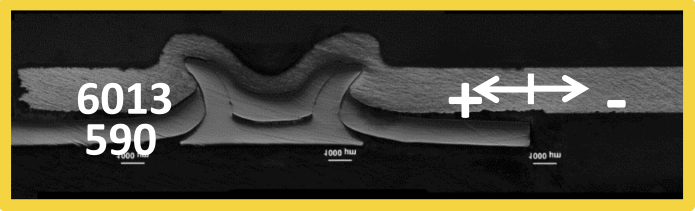
Technical Accomplishments and Progress

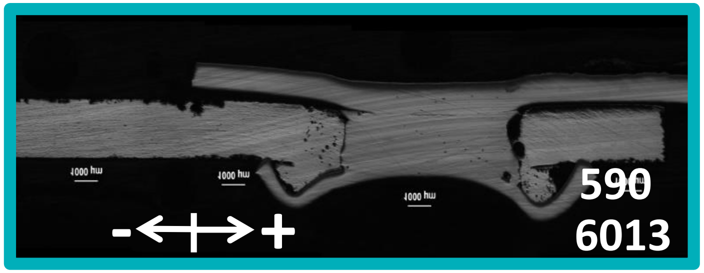
Depth of Attack Different for Various Aluminum Alloys – Reduced Severity for Room Temperature Joining

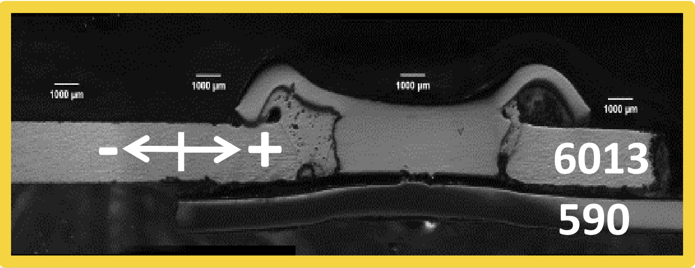










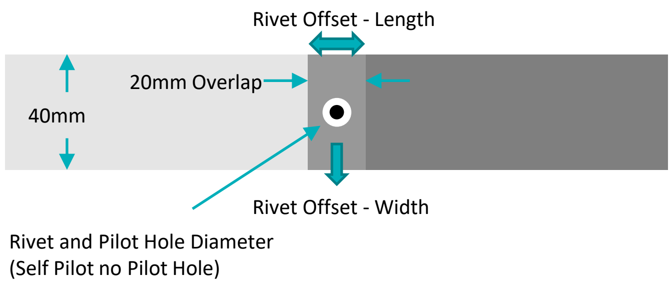


Production Condition Testing

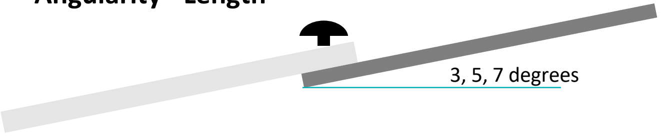
Rivet Offset, Workpiece Angularity and Part Gap for Various Stackup Conditions

	Piloted (2mm AL) - 3 Pilot Hole Diameters	**Self-Piloted (1, 3mm AL)**
Rivet Offset - Width	$\frac{1}{2}(Pilot - Pin\ Diameter) \pm 0.5mm$	Not Applicable
Rivet Offset - Length	$\pm\left(\frac{1}{2}(Pilot - Pin\ Diameter) + 0.5mm\right)$	$\pm 1.0mm, \pm 2.0mm$
Angularity - Width	3°, 5°, 7° Across TSS width	
Angularity - Length	3°, 5°, 7° Along TSS length	
Gap	0.5, 1.0, 1.5, 2.0mm	
Flange Width	Minimum 20, 2mm increments until no edge bulge or expulsion	

Offset

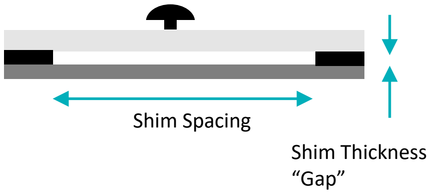


Angularity - Length



Angularity - Width

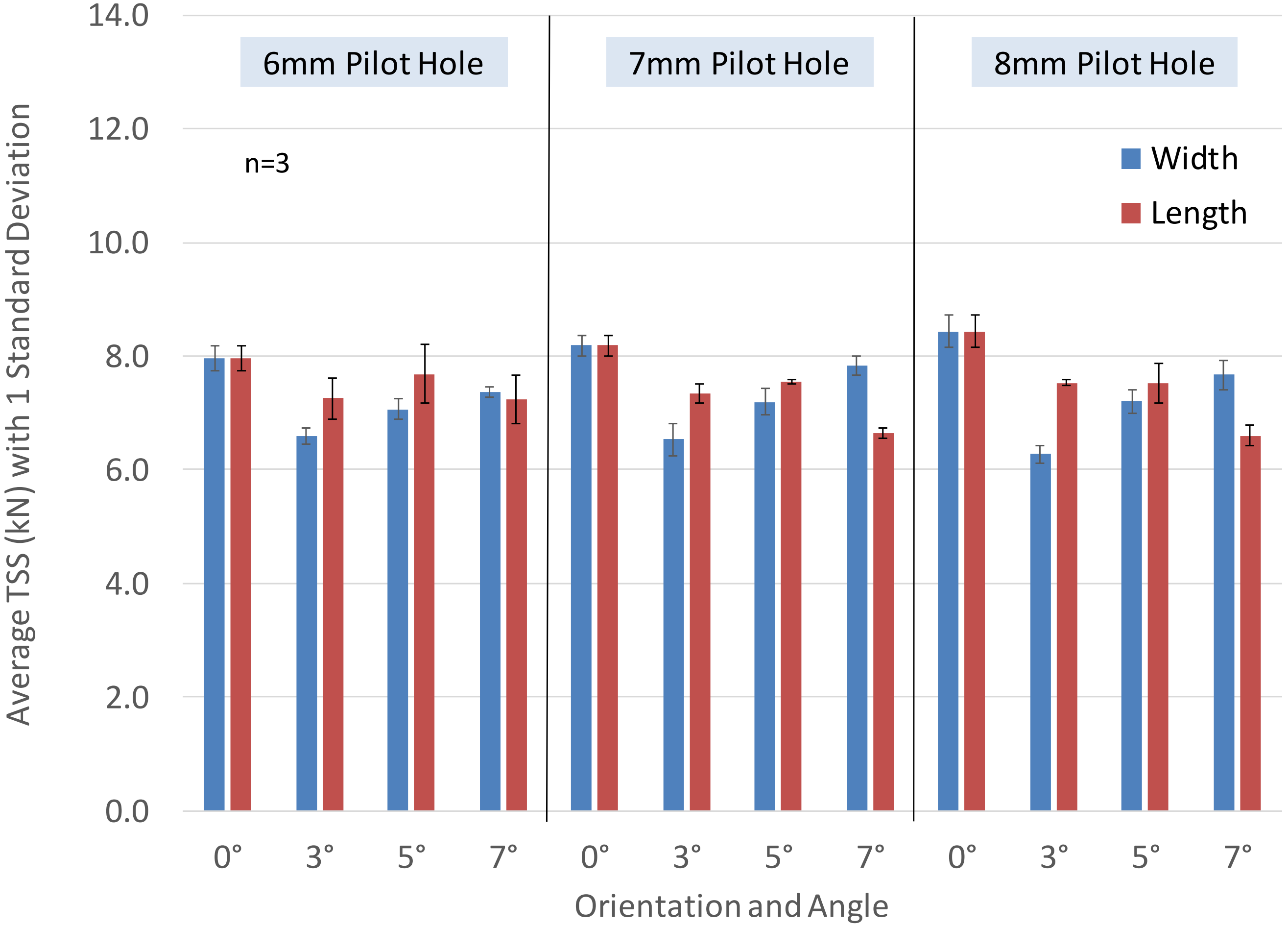
Gap

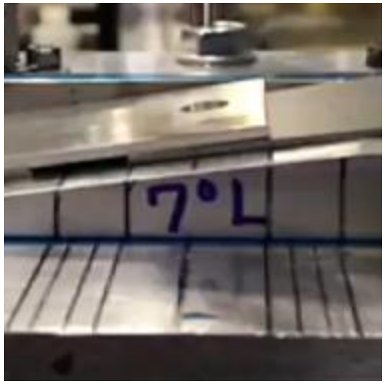


TSS, Weld Sectioning and CT Scans Performed for All Production Conditions

Angularity Testing – 2mm 6013-T4 to 1.2mm 980MPa Piloted

Similar Trends Across All Pilot Hole Diameters, Strength Reductions less Than 25% of Normal

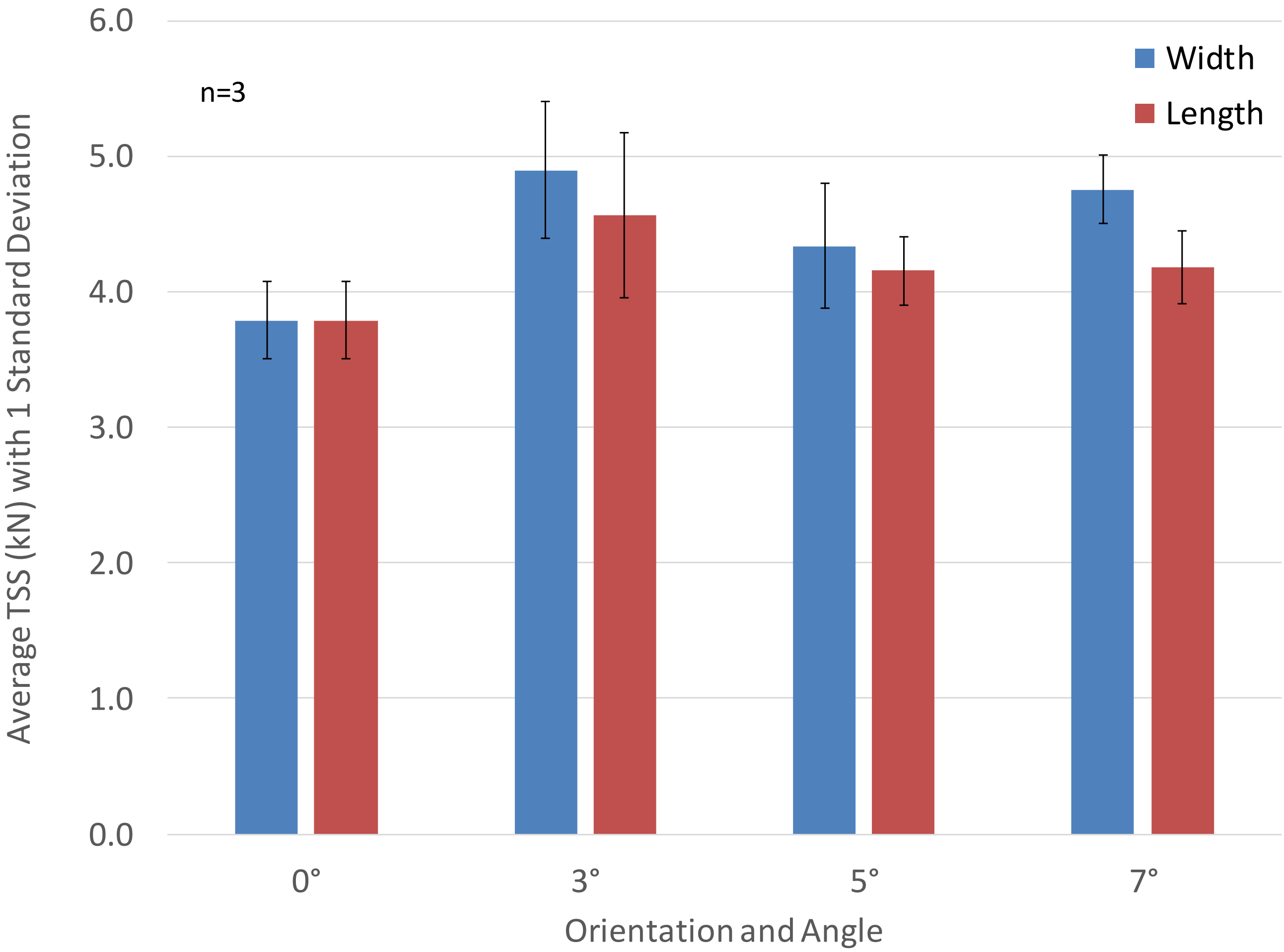


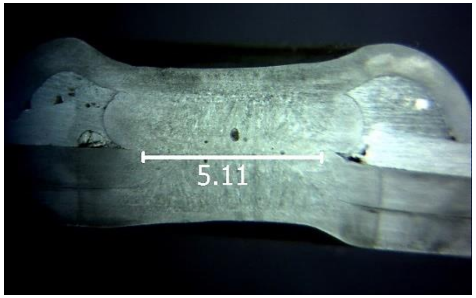


7° Length Fixture

Angularity Testing – 1.0mm 6xxx-T4 to 1.2mm 980MPa (2 Sheets) Self-Piloted

Strengths for Angled Conditions Exceeded Baseline ~10 to 25%

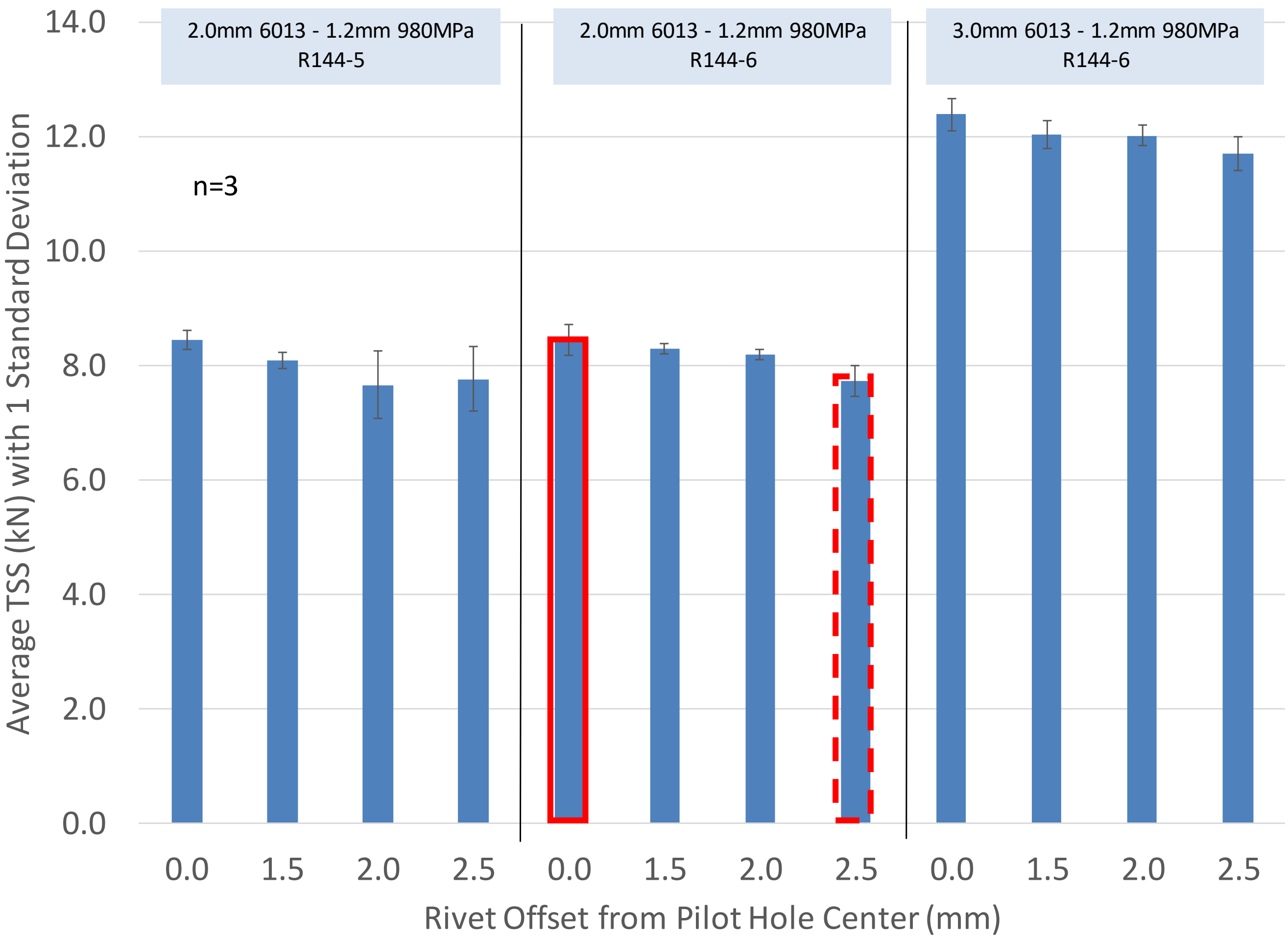




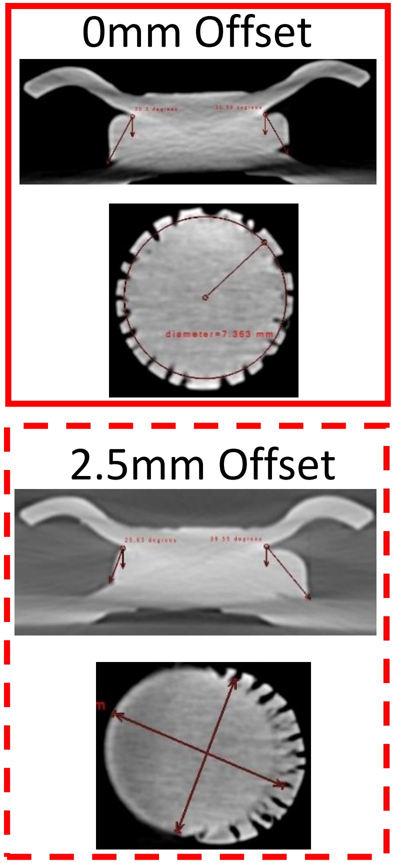
7^O Along Coupon Width

Rivet Offset Testing – 2mm 6013-T4 to 1.2mm 980MPa (8mm Pilot Hole in Aluminum Sheet)

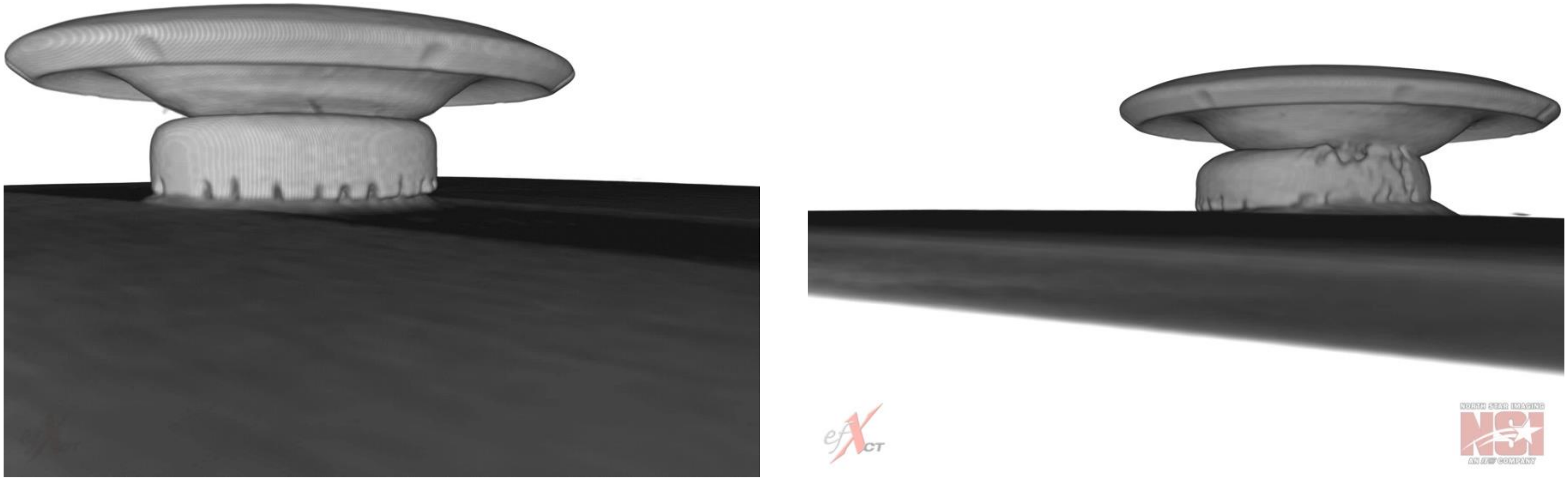
Slight Downward Strength/Variability with Increasing Rivet Offsets for Various Stackup Conditions and Rivet Lengths



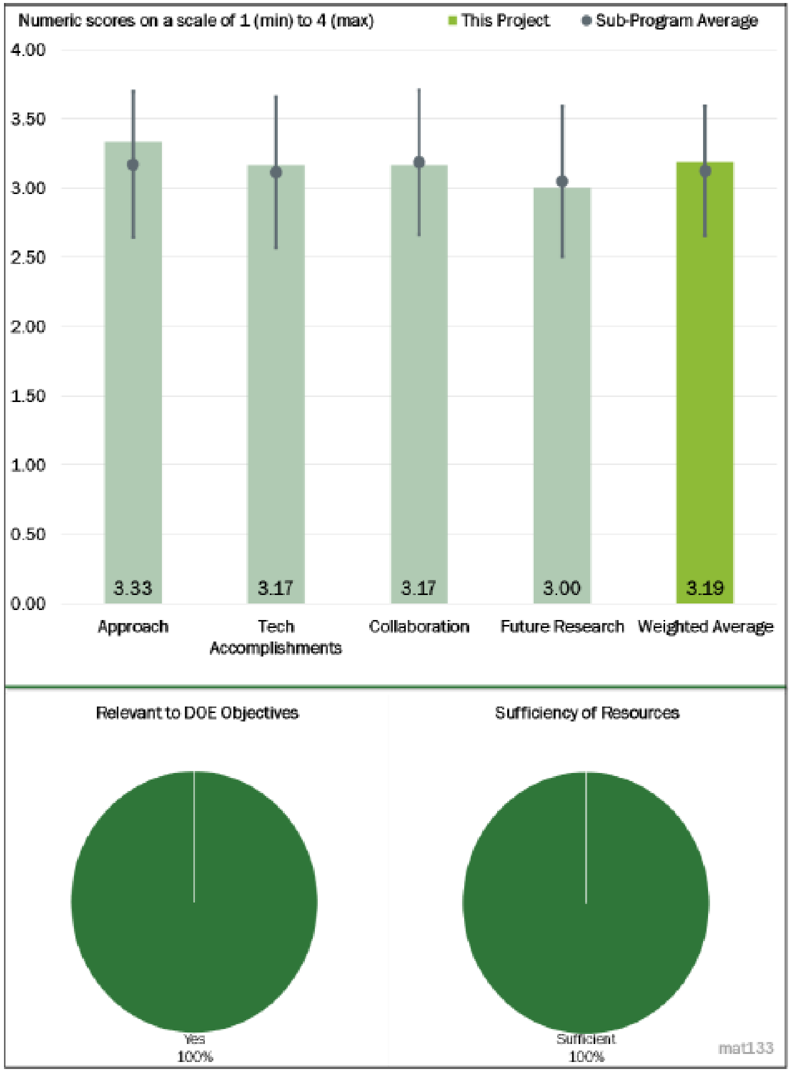
CT Scan Sections



Rivet Offset CT Rotational Views – 2mm 6013-T4 to 1.2mm 980MPa Piloted



Responses to Prior-Year Comments



- <u>Comment</u>: Challenging to use RSR method to join long-fiber CFC because difficult to cut by riveting or machining). <u>Response:</u> RSR process requires pilot hole in composites prior to installation. Water jet cutting and conventional hole drilling used for creating pilot holes, issues with hole quality and ply delamination were observed.
- <u>Comment</u>: Qualitative corrosion test results need to be included. <u>Response:</u> Corrosion depth and morphology assessments across and within the RSR and baseline reference joining technologies were added.
- <u>Comment</u>: Better interpretation of the process physics and metallurgy would be beneficial. <u>Response:</u> Additional emphasis was placed on the fundamental mechanisms for various aluminum alloys. New RSR coatings will be evaluated and compared against baseline technologies.

Collaboration and Coordination with Other Institutions

ARCONIC

Arconic will oversee project management. Arconic will produce the RSR samples for mechanical and corrosion testing and later produce the demonstration assemblies. Arconic will integrate the rivet delivery system to a robotic pilot cell to demonstrate production capability. Arconic will explore production variations such as joint gaps, angularity, flange length variations and stack thickness variations.

HONDA

Honda R&D Americas, Inc.

Honda will develop specification requirements for related coupon testing that will be conducted by Honda, industry, and the Ohio State University. Honda will also provide support with specification development for the joining process and equipment requirements. Honda will judge the functional performance of the component in comparison to the baseline hot stamped UHSS application.

THE OHIO STATE UNIVERSITY

The Ohio State University will characterize and quantify the galvanic corrosion resistance of RSR joints of aluminum to steel and aluminum to CFRP and the ability of adhesives, pre joining surface coatings, and e-coat/paint/sealant packages to protect the RSR joint against galvanic corrosion.

Remaining Challenges and Barriers

- Corrosion behavior of other multi-material joining technologies are well understood. These technologies are typically done at room temperature (i.e. mechanical fasteners) which do not alter the sensitivity of the base aluminum. RSR needs to have the baseline established, and if necessary, improve the corrosion performance to meet industry needs.
- Confidence in the RSR process robustness must be established for production applications. EL of the process must be in line with existing tip-dressing frequency to be viable.
- Confidence in the RSR process to meet target strengths with variations in the processing conditions (gap, angularity, offset, flange width) must be demonstrated to prove production feasibility.
- The ability to self-pilot through aluminum materials thicker than 2.0mm with acceptable insertion times will increase the applicability of the RSR process.
- Confidence in the RSR process for high-volume manufacturing. RSR has only been demonstrated on a stationary pilot station.

We will address these items in our future work

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

Proposed Future Research

FY19 – FY20 proposed Work will Include:

1. Corrosion Testing for All RSR Configurations at OSU and Honda
2. Develop and establish Steel & Al RSR production process condition limits
3. Go/No Go: Establish production condition limits
4. Develop and establish RSR feed system repeatability
5. Go/No Go: Establish feed system repeatability
6. Determine production galvanic corrosion mitigation strategies to improve corrosion performance
7. Manufacture demonstrator parts and assemblies
8. Test demonstrator assemblies
9. Final Reporting

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

Summary

1. OSU ASTM B117, G85-A2 and Nissan CCT-1 corrosion testing for Steel and Aluminum RSR completed and/or ongoing.
2. Honda corrosion fatigue testing on e-coated Steel to Aluminum joints (including both AL and ST RSR) and uncoated CFRP to Aluminum joints (AL RSR) ongoing.
3. Sample orientation in the corrosion test chamber study initiated by OSU and preliminary results are being analyzed.
4. Installed new rivet collet feeding system on ATC RSR station. Production condition testing being conducted with prototype feed system for production condition testing.
5. Ongoing integration planning of the production feed system being independently developed by Arconic Fastening System (AFS). The fully turnkey rivet delivery system is targeted for completion in Q2 2019.
6. Developed comprehensive production condition tests, completing rivet offset and angularity for piloted and self-piloted joint combinations. Three different angles (3, 5, and 7 degrees) were evaluated both along and across the joint.
7. Feasibility of CT scanning for the production condition tests has been evaluated. The scans provide valuable insight of the rivet flow during the installation process under system disturbances such an angularity and hole offset.
8. Evaluated the welding performance of new fastener size for self-piloting through 3mm aluminum that is targeted for the demonstrator assembly.
9. Preliminary design of the demonstrator assembly is complete. Demonstrator manufacturing, assembly and testing scheduled in BP3

Backup Slides

Project ID: MAT133

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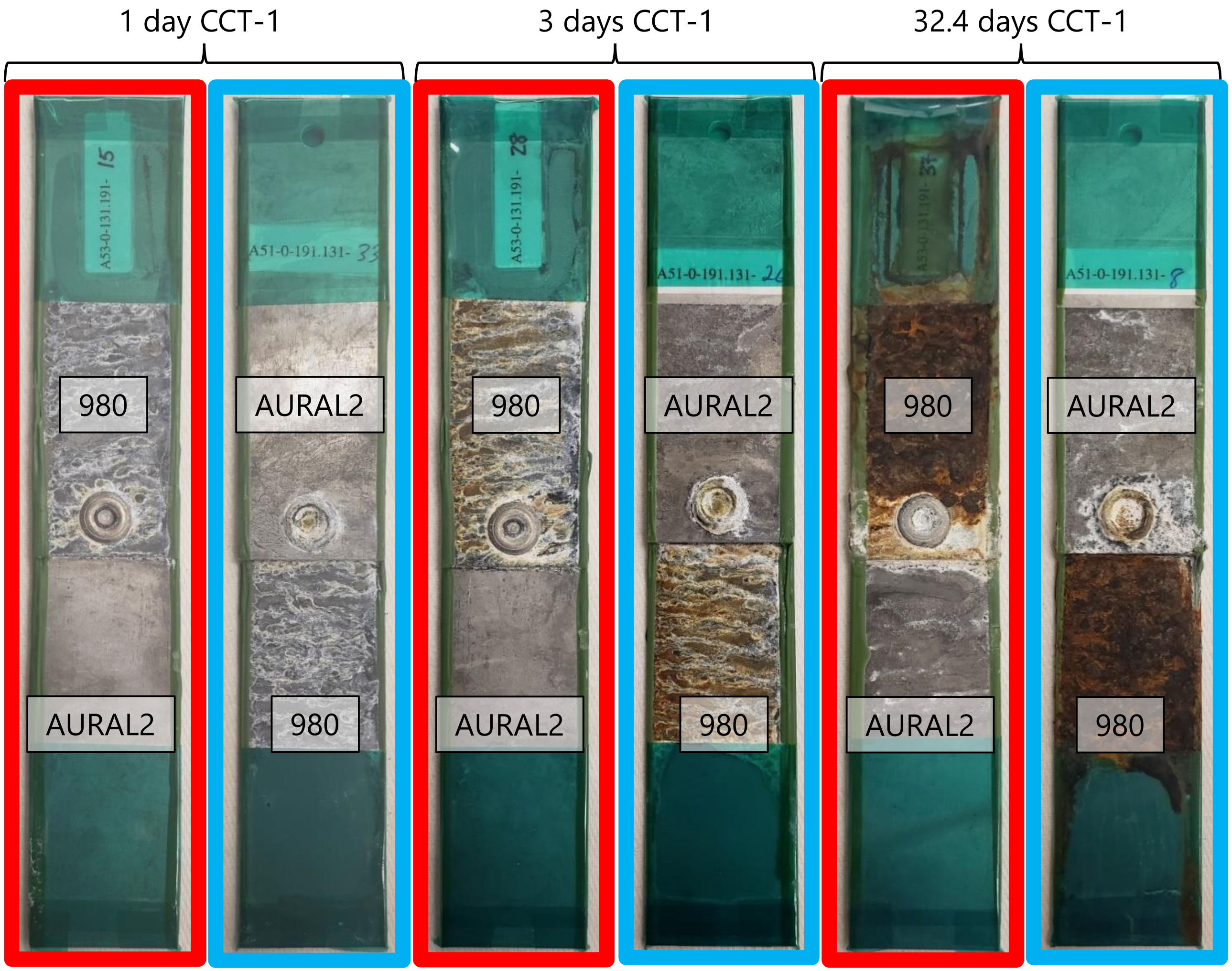
HONDA
Honda R&D Americas, Inc.

Technical Accomplishments and Progress

Aural2-T7 to 980MPa Macro Corrosion Similar Between AL and ST RSR for Nissan CCT-1

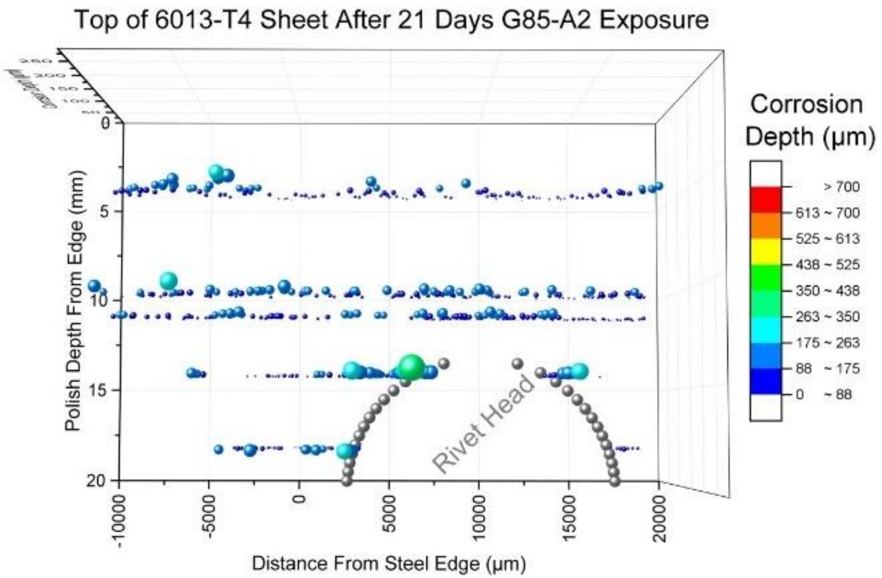
RSR, no adhesive
Top: 980MPa
Btm: AURAL 2
Rivet: F7-4

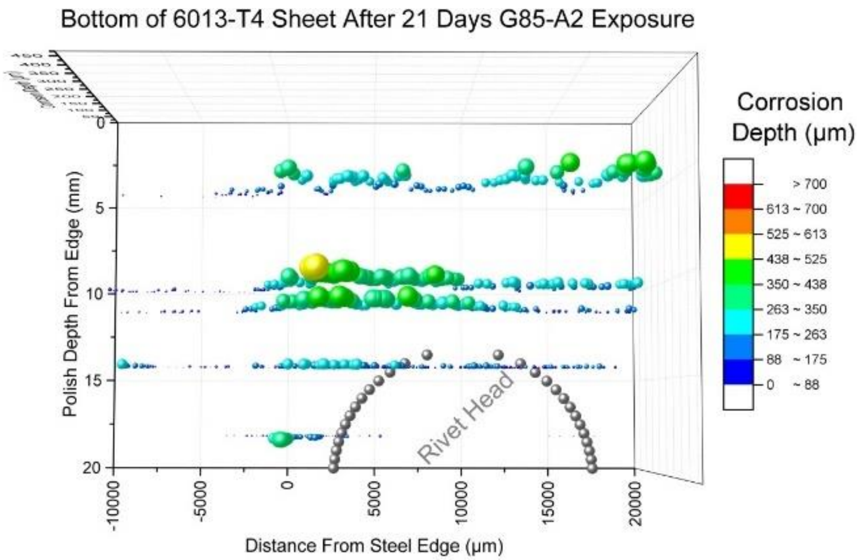
RSR, no adhesive
Top: AURAL2
Btm: 980
Rivet: R4-5/6

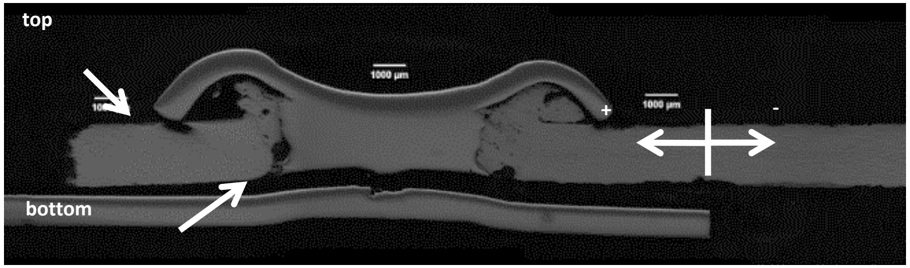


Technical Accomplishments and Progress

Corrosion Depth Map At Top/Faying Surface for 6013-T4 to 590MPa After 21 Days of G85-A2 Exposure

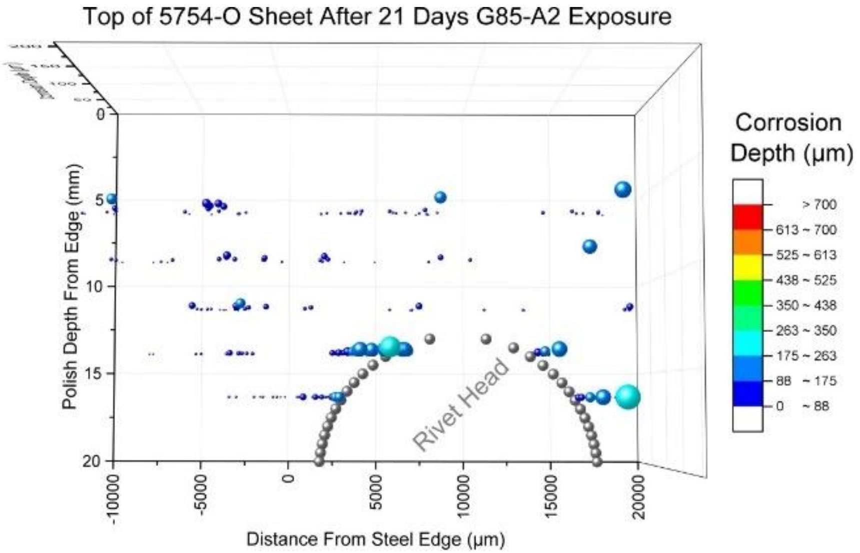


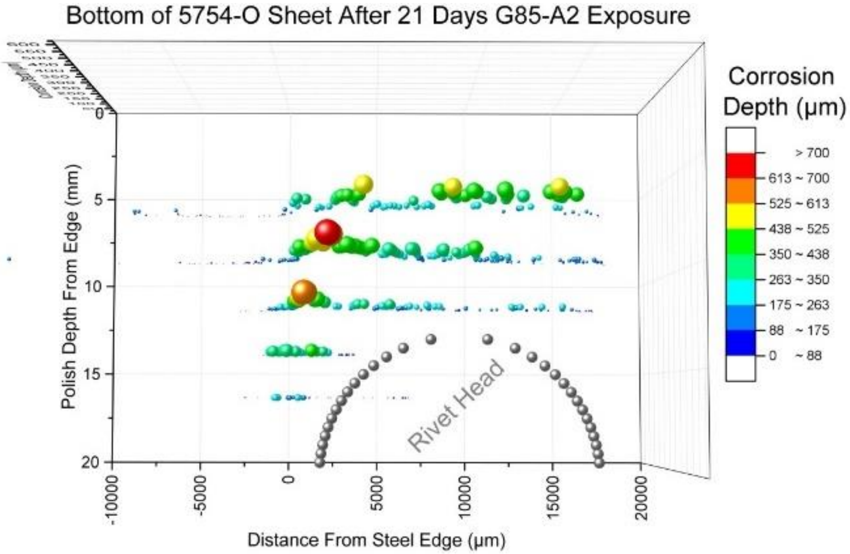


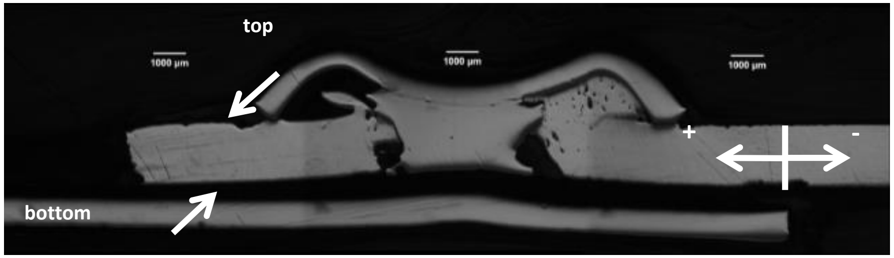


Technical Accomplishments and Progress

Corrosion Depth Map At Top/Faying Surface for 5754-O to 590MPa After 21 Days of G85-A2 Exposure





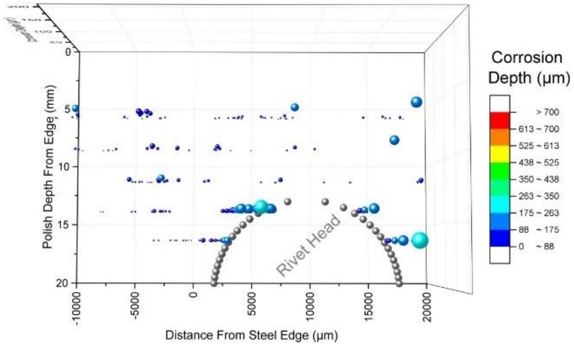


Technical Accomplishments and Progress

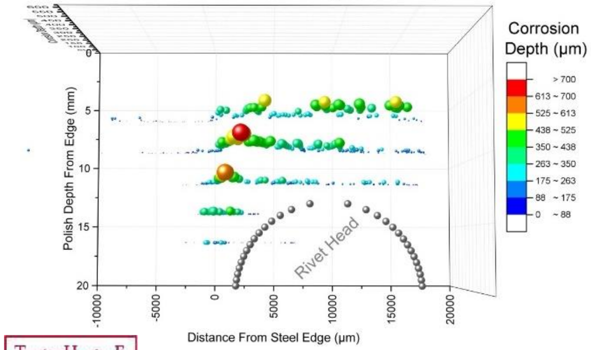
Mapping of Corrosion Depth At Top/Faying Surface for Various AL Alloys After 21 Days of G85-A2 Exposure

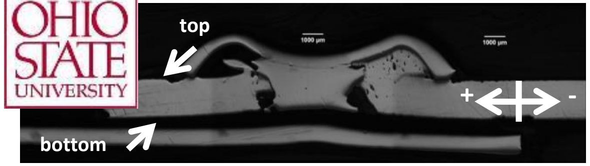
5754-O

Top of 5754-O Sheet After 21 Days G85-A2 Exposure



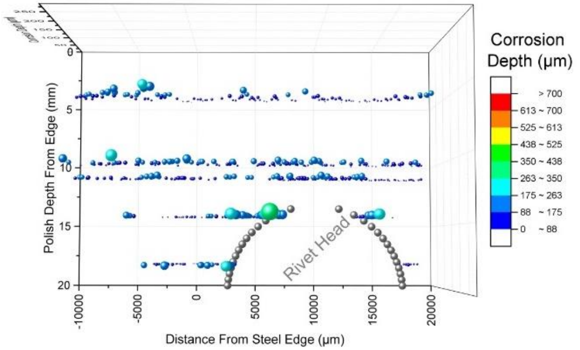
Bottom of 5754-O Sheet After 21 Days G85-A2 Exposure



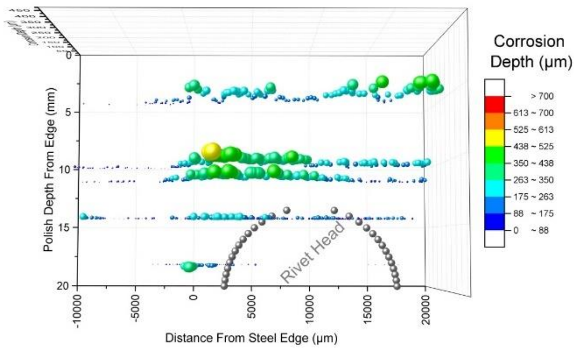


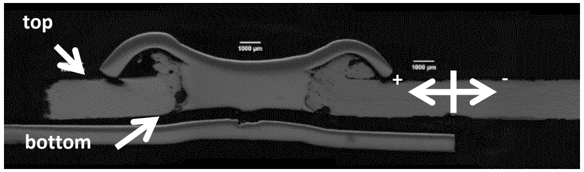
6013-T4

Top of 6013-T4 Sheet After 21 Days G85-A2 Exposure



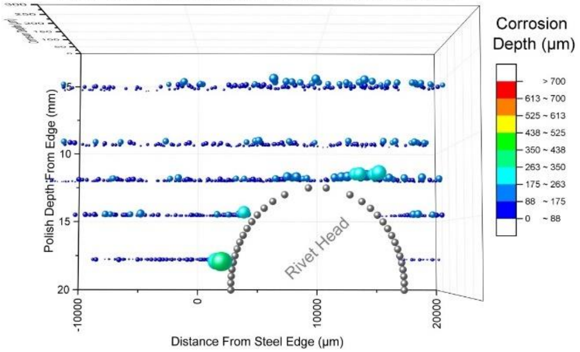
Bottom of 6013-T4 Sheet After 21 Days G85-A2 Exposure





7055-T76

Top of 7055-T76 Sheet After 21 Days G85-A2 Exposure



Bottom of 7055-T76 Sheet After 21 Days G85-A2 Exposure