

# Upset Protrusion Joining Techniques for Joining Dissimilar Metals

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Project ID #LM100

This presentation does not contain any proprietary, confidential, or otherwise restricted information

## Timeline

- Start date: September 30, 2013
- End date: December 31, 2016
- Percent complete: ~80%

## Budget

- Total project funding
  - DOE share: \$587,248
  - Contractor share: \$251,678
- Funding received in FY15:
  - \$321,465
- Funding for FY16:
  - \$184,192

## Barriers

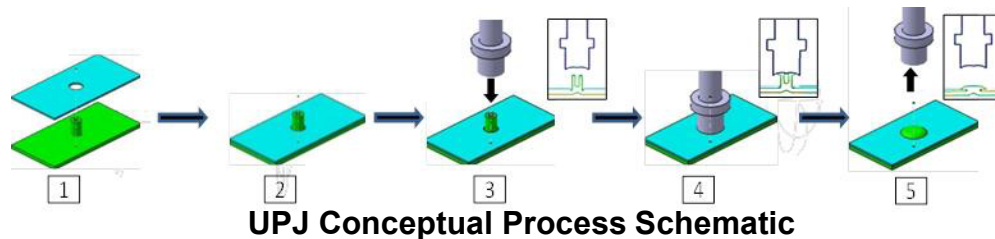
- F- “High-volume, high-yield joining technologies for lightweight and dissimilar materials needs further development”
  - *Develop and demonstrate robust, cost effective, and versatile process to join Mg die castings to Al and steel sheet*

## Partners

- FCA US LLC – Project Lead
- AET Integration, Inc.
- Meridian Lightweight Technologies

## Overall Objectives

- Develop and demonstrate a robust, cost effective, and versatile joining technique, known as Upset Protrusion Joining (UPJ), for joining challenging dissimilar metal combinations, especially those where one of the metals is a die cast magnesium (Mg) component, and develop variations for unique requirements, such as oval boss UPJ for narrow flanges and upset cast riveting (UCR) for dissimilar metal joints where neither metal is a casting.



## Objectives (March 2015 to March 2016):

- Optimize oval boss UPJ and round boss UCR process parameters, to provide robust, repeatable joining performance for each configuration being considered.
- Produce oval boss UPJ and round boss UCR test coupons to support mechanical and corrosion performance evaluations.
- Complete pre-corrosion mechanical testing all UPJ and UCR assemblies.
- Subject round boss UPJ joint configurations to an aggressive 12 week accelerated corrosion test for comparison to SPR results reported last year

## Impact on barriers

- All objectives are aimed at addressing the VTO barrier ***“High-volume, high-yield joining technologies for lightweight and dissimilar materials needs further development”***.

Date	Milestones and Go/No-Go Decisions	Status
January, 2015	<u>Milestone</u> Complete process development preparation	Complete
January, 2015	<u>Go/No-Go Decision</u> SPR and round boss UPJ joints assembled and coated	Complete
December, 2015	<u>Milestone</u> Evaluate first set of UPJ and UCR Joints for pre-corrosion mechanical/structural performance	Complete
December, 2015	<u>Go/No-Go Decision</u> Complete Initial pre-corrosion mechanical/structural evaluations of all joints	Complete
December, 2016	<u>Milestone</u> Evaluate all benchmark joints for accelerated corrosion performance completed. Accelerated corrosion testing initiated for all UPJ and UCR joints.	Complete
December, 2016	<u>Go/No-Go Decision</u> Corrosion testing and evaluations for all joint configurations completed.	On track

- Establish **benchmark** performance of Mg to Al joints produced through Self Pierce Riveting (SPR) **for comparison purposes only** using the following “evaluation procedure”:
  - *Subject all joints to mechanical tests including microstructure / defect evaluation, shear tension and cross tension quasi-static, impact, and fatigue testing.*
  - *Subject all joints to accelerated corrosion tests, reviewing visually every two weeks and removing three samples of each configuration at four week intervals for quasi-static testing.*
  - *Subject select configurations to post-corrosion fatigue and impact testing for comparison to pre-corrosion performance.*
- Characterize thermo-mechanical behavior of Mg alloys through testing being conducted in Canada at no cost to the U.S. Department of Energy (DOE).
- Optimize protrusion and electrode geometries and process parameters to reduce electrical current requirements and provide robust, repeatable forming performance for each of the joint configurations being considered.
- For each joint type/material/coating configuration, produce tensile shear and cross tension test coupons to support mechanical/structural and corrosion evaluations using the “evaluation procedure” described above for SPR.

- Completed accelerated corrosion evaluation of all 350 round boss UPJ joints. Full UPJ corrosion test matrix shown below:

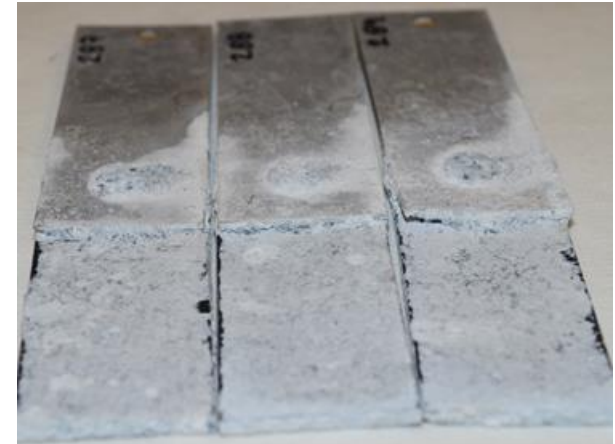
Upset Protrusion Joining - Round Boss AM60B 2t																				
Base Plate Configuration					Joining Plate			Coated Assem- bly? *	On-Going Accelerated Corrosion Exposure Evaluation											
Material	Configu- ration ID #	Boss Configuration		Test Type Configu- ration	Surface Condition	Material	Thick- ness		Surface Condition	4 wks		8 wks		12 wks						
		Shape	Size							Quasi- Static		Quasi- Static		Quasi- Static		Fatigue		Impact		
										ST	CT	ST	CT	ST	CT	ST	CT	ST	CT	ST
Mg AM60B	UPJ 7-1	Round	7 mm Diam	Shear Tension	Bare	Al 6016	1.1 mm	Bare	No	3		3		3					5	
	UPJ 7-2				Al 6016	1.1 mm	Pre-treat	Yes	3		3		3							
	UPJ 7-3				Al 6016	1.1 mm	Powder-coated	No	3		3		3							
	UPJ 7-4				Al 6016	1.1 mm	Powder-coated	Yes	3		3		3					5		
	UPJ 7-1	Round	7 mm Diam	Cross Tension	Bare	Al 6016	1.1 mm	Bare	No		3		3(2)		3				5	
	UPJ 7-2				Al 6016	1.1 mm	Pre-treat	Yes		3		3		3						
	UPJ 7-3				Al 6016	1.1 mm	Powder-coated	No		3		3		3						
	UPJ 7-4				Al 6016	1.1 mm	Powder-coated	Yes		3		3		3				5		
Mg AM60B	UPJ 8-2	Round	8 mm Diam	Shear Tension	Bare	Al 6013	2.2 mm	Bare	No	3		3		3(2)		20		5		
	UPJ 8-4				Alodine 5200	Al 6013	2.2 mm	Pre-treat	Yes	3		3		3		20 (10)		5		
	UPJ 8-5							Powder-coated	No	3		3		3						
	UPJ 8-6							Powder-coated	Yes	3		3		3						
	UPJ 8-1					HSS DP-590	2.0 mm	Armorgalv, zinc-phosphate, Tritop, Universal	No	3(2)		3		3						
	UPJ 8-3					HSS DP-590	2.0 mm	Armorgalv, zinc-phosphate, E-Coat w/ sealed edges	Yes	3		3(2)		3		20		5		
	UPJ 8-2	Round	8 mm Diam	Cross Tension	Bare	Al 6013	2.2 mm	Bare	No		3		3		3		20		5	
	UPJ 8-4				Alodine 5200	Al 6013	2.2 mm	Pre-treat	Yes		3		3		3(1)					
	UPJ 8-5							Powder-coated	No		3		3		3		20		5	
	UPJ 8-6							Powder-coated	Yes		3		3		3					
	UPJ 8-1					HSS DP-590	2.0 mm	Armorgalv, zinc-phosphate, Tritop, Universal	No		3		3		3					
	UPJ 8-3					HSS DP-590	2.0 mm	Armorgalv, zinc-phosphate, E-Coat w/ sealed edges	Yes		3		3		3		20		5(2)	

- Green squares indicate that all samples were intact when removed from the corrosion chamber.
- Yellow squares indicate that some samples remained intact when removed from the corrosion chamber.
- Red squares indicate that no samples were intact when removed from the corrosion chamber.

- Completed accelerated corrosion evaluation of all 350 round boss UPJ joints. Some worst case samples are shown below:



**Bare Mg - Bare Al 6013 joints after 12-wks exposure**



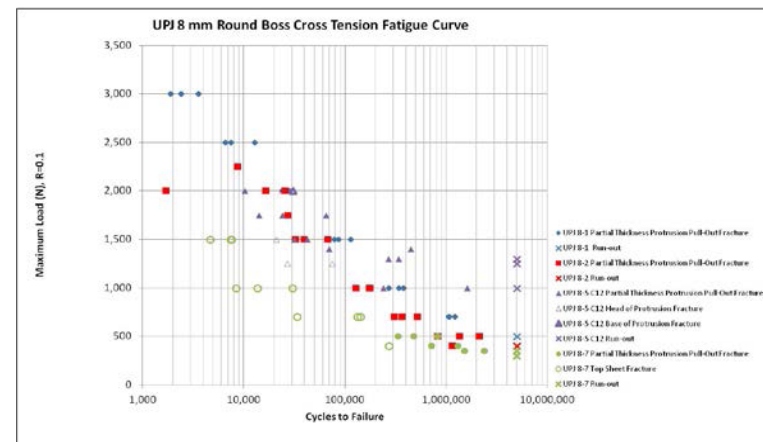
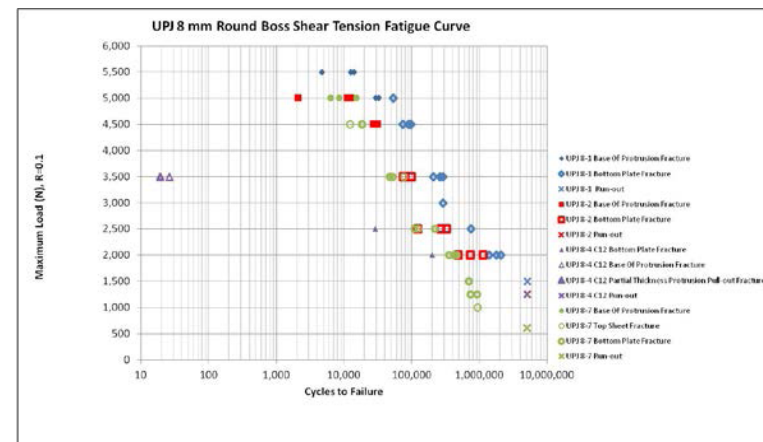
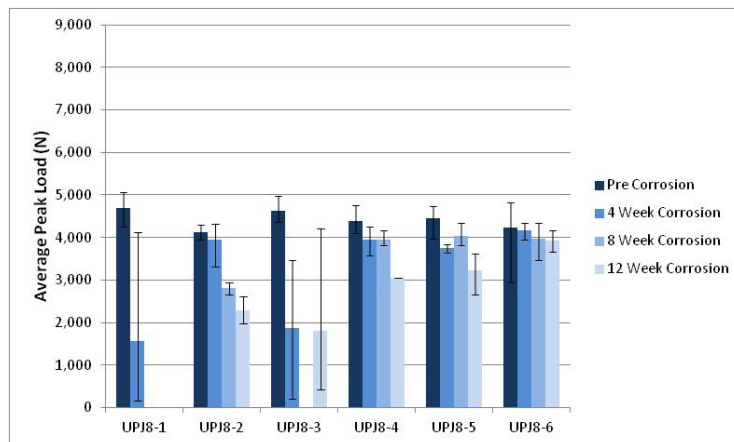
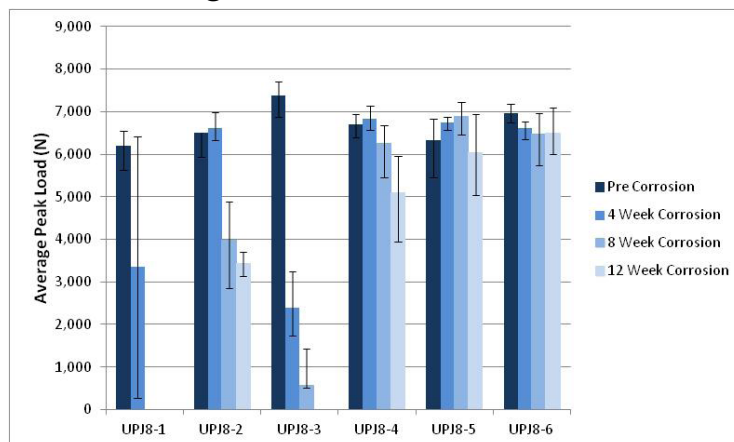
**Bare Mg – Bare Al 6016 joints after 12-wks exposure**



**Pretreated Mg – Pretreated (Armorgalv, zinc-phosphate, Tritop, Universal) DP590 steel joints after 6-wks exposure**

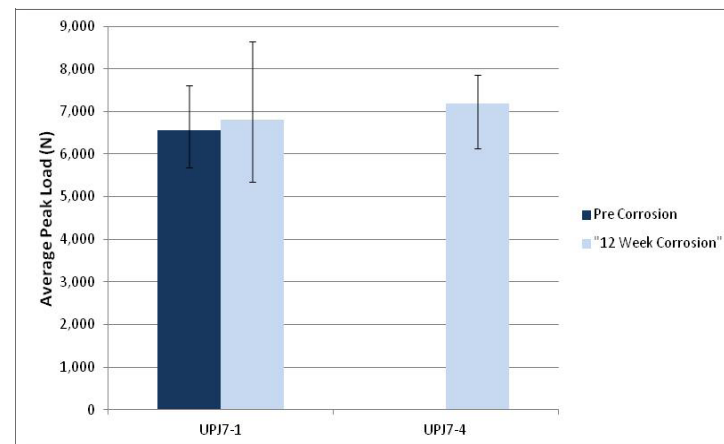
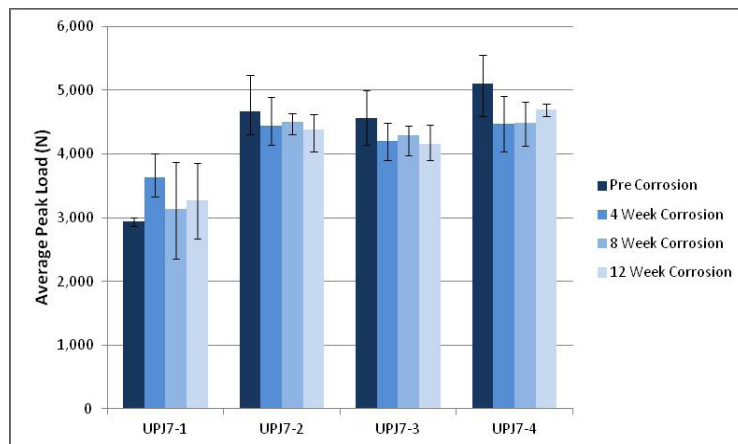


- Completed post-corrosion performance evaluation of all Mg to Al and Mg to steel joints produced through UPJ.
  - Conducted quasi-static structural/mechanical testing/evaluation throughout accelerated corrosion testing and fatigue and impact testing at the end of accelerated corrosion testing.

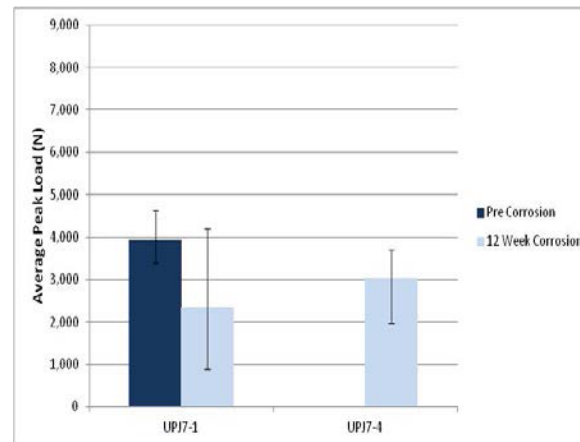
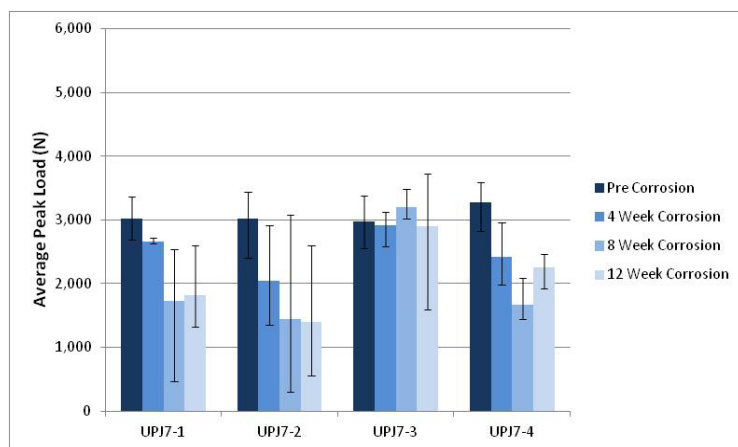




- Evaluated structural/mechanical performance of Mg to Al 6016 UPJ joints prior to and throughout accelerated corrosion testing, and evaluated fatigue and impact performance prior to and at the end of accelerated corrosion testing.

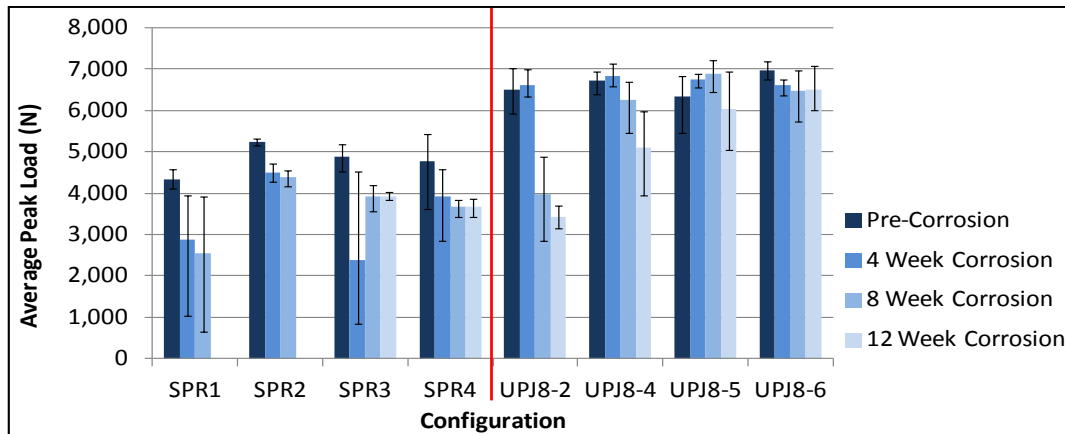


**Mg-Al 6016 UPJ Lap Shear Test Results**

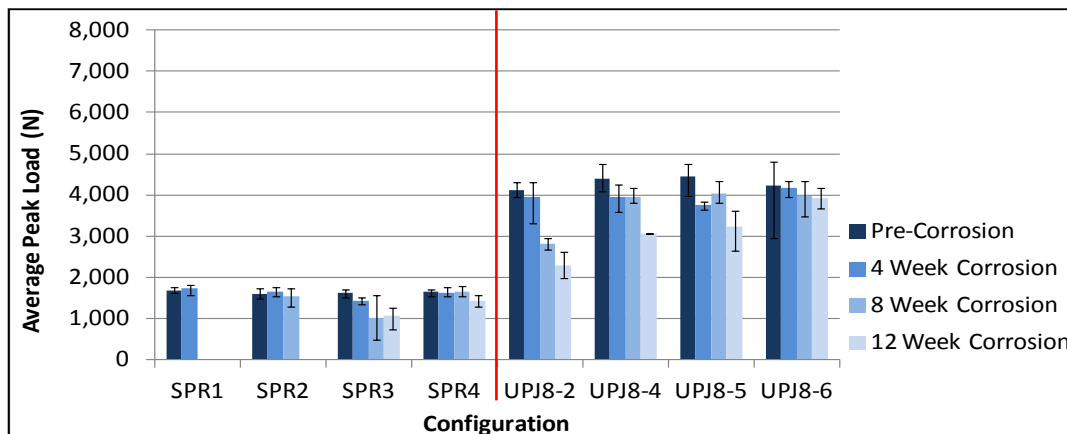


**Mg-Al 6016 UPJ Cross Tension Test Results**

- Compared **quasi-static** structural/mechanical performance of round boss Mg-Al 6013 UPJ joints to similar performance of SPR joints for four coating configurations prior to corrosion and at 4-wks, 8-wks, and 12-wks of accelerated corrosion exposure, as well as impact and fatigue prior to corrosion and after 12-wks of exposure. Due to geometrical differences between SPR and UPJ, the focus of this comparison is on joint strength **retention**, not initial joint strength. Quasi-static results are shown here:



**Quasi-Static Shear Tension Test Results of SPR and UPJ joints (before, during, and after accelerated corrosion testing)**

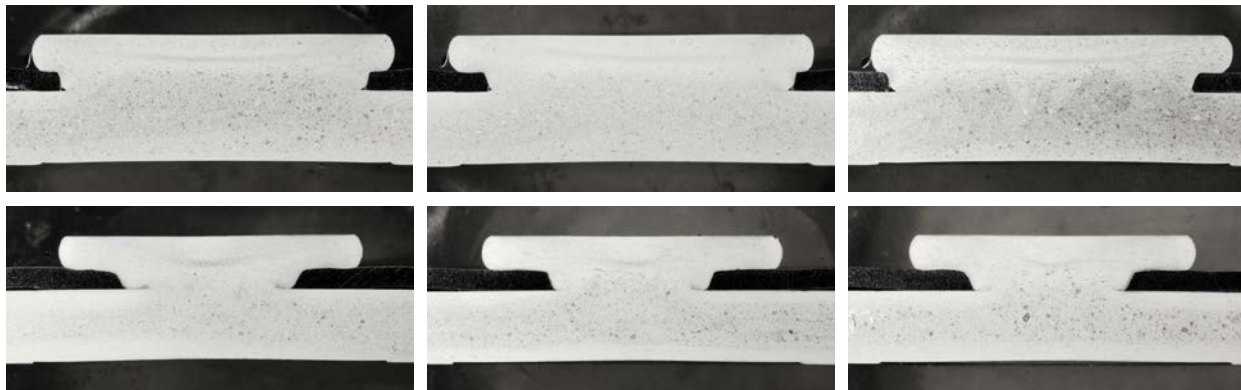


**Quasi-Static Cross Tension Test Results of SPR and UPJ joints (before, during, and after accelerated corrosion testing)**

- Produced over 400 oval boss UPJ joints and evaluated 220 for use on narrow flanges. Evaluation did not include corrosion testing.
  - Oval boss head formations did not maintain the same oval shape proportions of the original boss. This situation was magnified with increasing force and temperature.

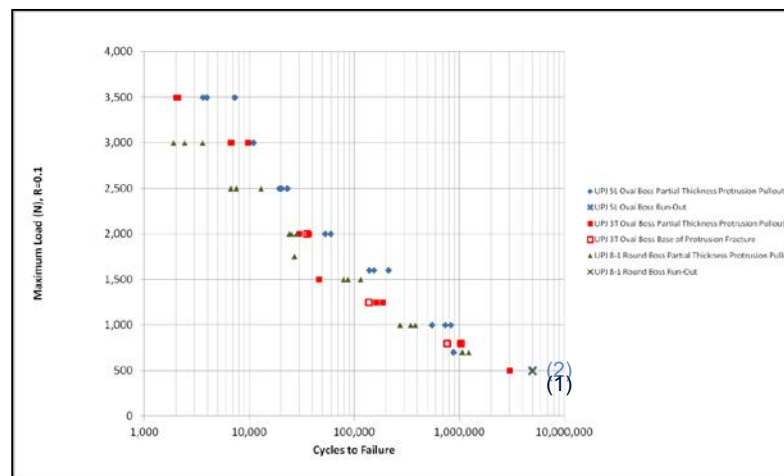
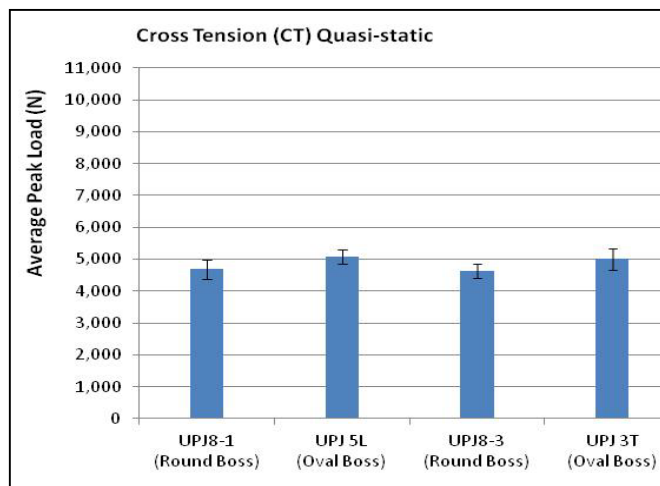
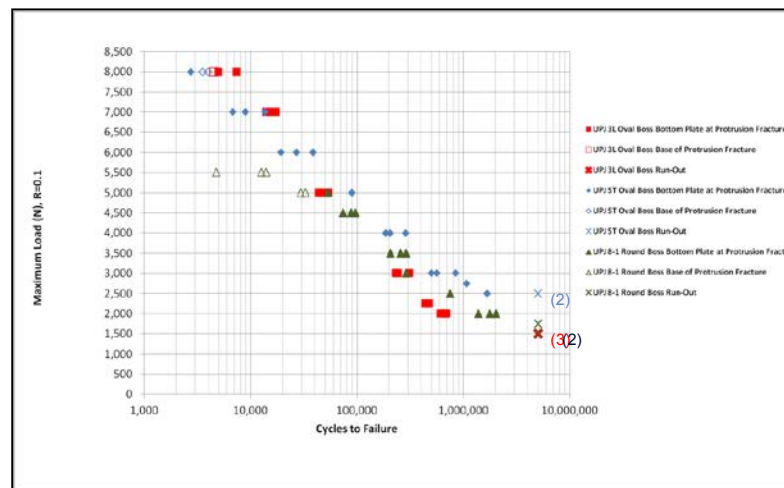
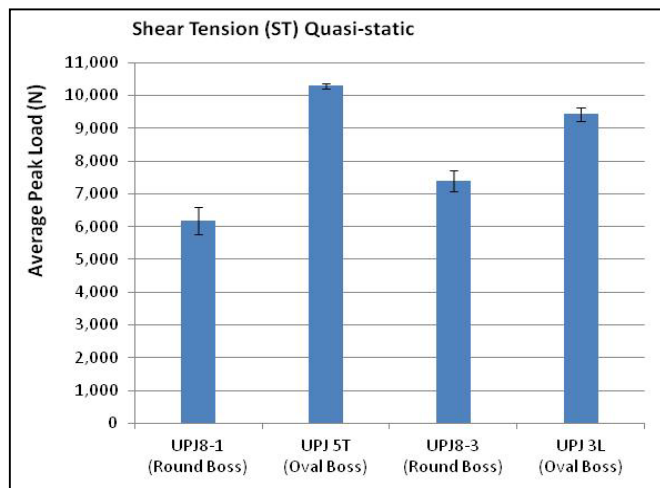


**Effect of increasing force and temperature on oval boss UPJ head shape and size**



**Metallurgical cross-sections of oval boss UPJ joints through the transverse axis (top) and the longitudinal axis (bottom )**

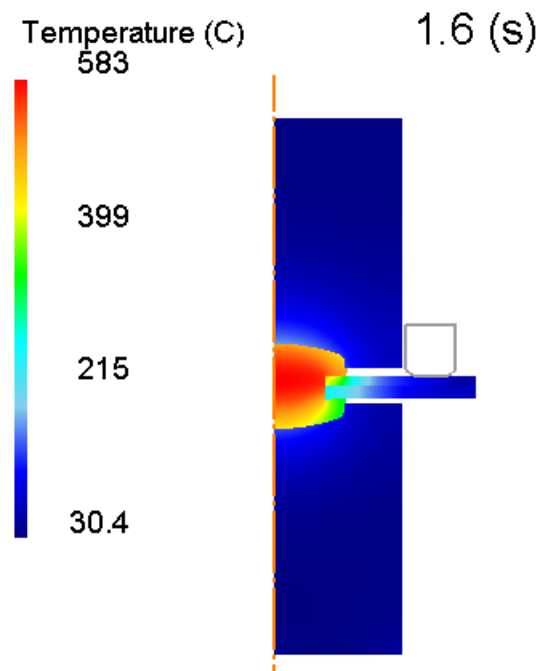
- Comparisons of oval boss UPJ joint performance to 8-mm round boss UPJ joints are shown below:



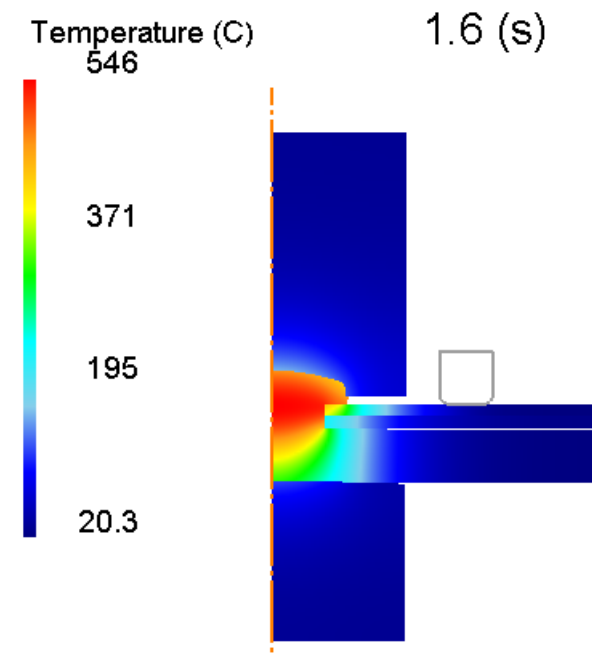
- Optimized geometry and process parameters to support UCR joining of dissimilar (Al to steel) metal joints where neither metal is a casting.
  - Optimum process parameters were very close to those of the 8-mm round boss UPJ process, although the maximum temperatures were slightly higher as a result of less material for heat conduction



**Mg UCR Rivet**



**UCR Simulation**



**UPJ Simulation**

- Produced over 500 UCR joints to optimize the process and evaluated pre-corrosion mechanical performance of 384 assemblies of dissimilar (Al to steel) metal joints where neither metal is a casting.
  - Head formation quality was improved over UPJ. Possible reason may lie in the improved casting quality of the rivets compared to the bosses (different vendor and different casting configuration). Note the lack of porosity in the metallographic sections.
  - Also note the ability of the rivet to fill the clearance holes in the mating panels even when the holes are misaligned.

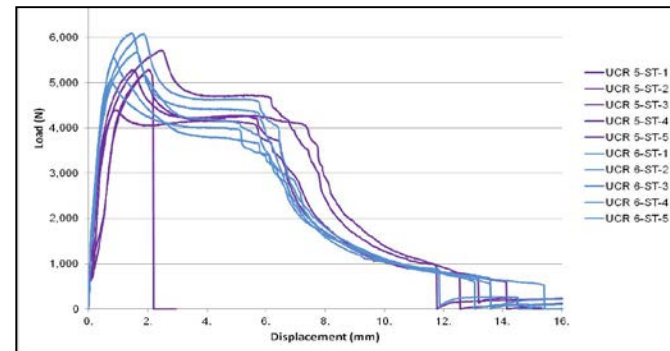
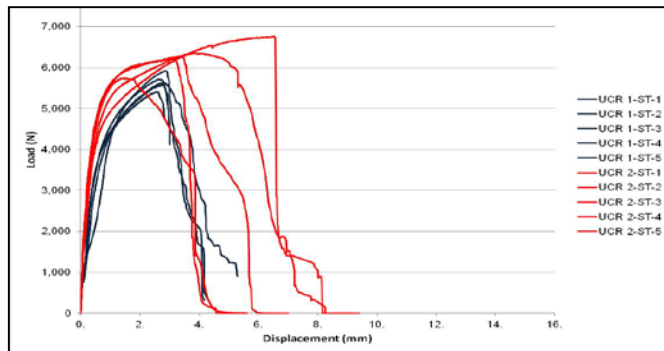
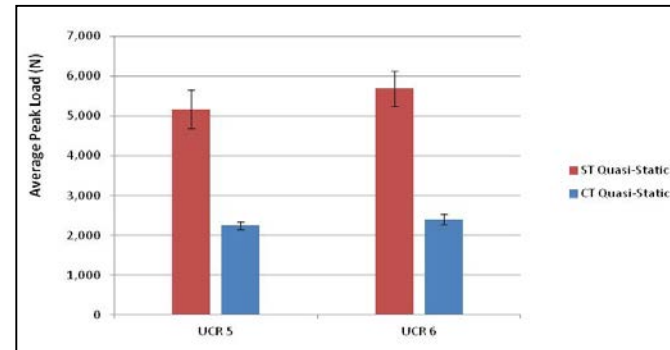
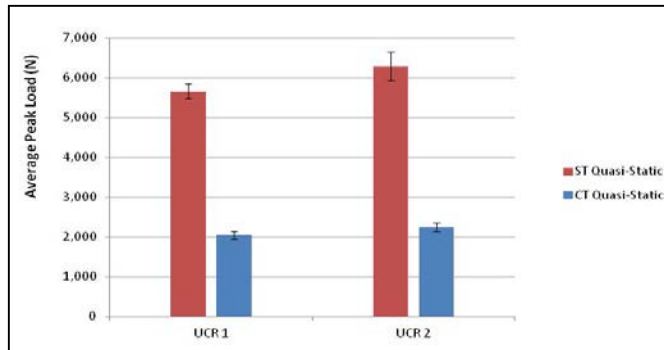


**UCR head formations for four unique material/coating configurations**

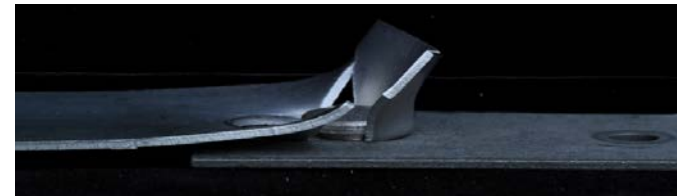


**Metallographic cross-sections for a typical UCR material/coating configuration**

- Completed pre-corrosion quasi-static structural/mechanical testing/evaluation performance evaluation of all Al to steel joints produced through UCR.



**Quasi-static test results of 1.0 mm DP-590 steel to 1.3 Al 6016 (left) and 1.4 mm steel to 1.3 mm Al 6016 (right)**



**Failure modes of 1.0 mm DP-590 steel to 1.3 Al 6016 (left) and 1.4 mm steel to 1.3 mm Al 6016 (right)**



# Responses to Previous Year Reviewers' Comment

**Comment:** Reviewer suggested including a dimensional tolerance study to help increase the manufacturability of the process.

**Response:** The dimensional tolerance study has been conducted separately at FCA US to ensure that the process is compatible with automotive manufacturing and assembly processes for future applications.

**Comment:** This process cannot be used if the material is not cast.

**Response:** Development of a variation of UPJ referred to as Upset Cast Riveting (UCR), which can be used for joining dissimilar metals where neither material is a casting, is reported in this presentation.

**Comment:** Reviewer commented that it is all internal to FCA US and would have preferred if others had joined the project.

**Response:** Substantial preliminary process development work was conducted at FCA US prior to involvement with DOD/DOE. The partners included in this project were primarily those with whom FCA US was already working.

# Responses to Previous Year Reviewers' Comments

**Comment:** It may be interesting to see whether this technique can be extended to other cast alloys including Al.

**Response:** It would be interesting. However, this has not been part of this funded project due primarily to:

- 1) Initial focus on die-cast Mg to dissimilar metals because:
  - Mg is lighter than Al
  - There are fewer options for joining die-cast Mg to dissimilar metals than there are for Al
  - Galvanic corrosion challenges are greater for Mg than for Al
- 2) Tooling being used to produce the test coupons (purchased by FCA US prior to the project with DOD/DOE) resides at a company that only die casts Mg. Additional cost will be required to move the tooling to a supplier that die casts Al as well
- 3) Al die casting requires higher draft angles on protrusions, meaning the boss size must increase significantly compared Mg castings

Nevertheless, FCA US may still evaluate the process on Al outside of this DOD/DOE funded project at a later time once the work with Mg is completed

## Within the VT Program

- AET Integration, Inc. – Industry Primary subcontractor to FCA US
  - Provided weld process development, machining services, joint evaluations, and metallurgical services throughout the project as well as overseeing additional subcontractors, joining SPR coupons, overseeing process modeling simulation efforts, and providing testing and evaluation services for all testing except corrosion.
- Meridian Lightweight Technologies – Industry subcontractor to FCA US
  - Provided die cast UPJ test coupons.
- Almond Products – Industry subcontractor to AET
  - Provided pretreated and coated magnesium, aluminum, and steel test coupons.
- Dynacast – Industry subcontractor to AET
  - Provided die-cast UCR rivets

## Outside the VT Program

- McMaster University – University collaboration
  - Worked with Canmet to develop magnesium alloy thermo-mechanical compression and electrical resistivity data, and constitutive equations, to support process modeling efforts.
- Canmet Materials (CMAT) – Canadian federal laboratory collaboration
  - Provided use of their Gleeble® test machines as well as technical assistance to McMaster University researchers in order to obtain thermo-mechanical evaluation and characterization data from cylindrical compression test coupons.

# Remaining Challenges and Barriers and Proposed Future Work

- Corrosion performance of Al to steel UCR joints must be evaluated.
- **FY2016**
  - Conduct accelerated corrosion evaluation, and conduct post corrosion evaluation of round boss UCR joints.

- During the past year, 350 round boss Mg to Al and Mg to steel joints were evaluated for corrosion performance and compared to benchmark SPR performance evaluations conducted in FY14.
  - In general, UPJ showed better performance retention than SPR. Specifically;
    - In the bare Mg to bare Al 6013 configuration, neither SPR or UPJ were able to pass 12-wks test exposure without losing joint integrity
    - In the pretreated Mg to pretreated Al 6013 coated ass'y configuration, most of the UPJ joints passed 12-wks of corrosion exposure whereas none of the SPR joints passed the full test
    - In the configurations where the Al 6013 was fully coated prior to joining, most all of the UPJ and SPR joints passed the full 12-wks of testing
  - **None** of the Mg-steel UPJ joints passed more than 6-wks of exposure. No Mg-steel SPR joints were evaluated
  - **All** of the Mg-Al 6016 UPJ joints passed the full 12-wks of testing. No Mg-Al 6016 SPR joints were evaluated

- Over 400 oval boss Mg to Al joints were produced and 220 subjected to quasi-static and dynamic mechanical/structural testing
  - Oval boss configurations tended toward more rounded shapes when joints were formed
  - Quasi-static and dynamic test results in both lap shear and cross tension load cases showed significant improvements over round boss joints
- Over 500 Al to steel UCR joints were produced to support process optimization and performance evaluation efforts.
  - Head formation quality was improved over UPJ
  - 180 assemblies were evaluated for pre-corrosion mechanical performance
  - 204 assemblies were allocated for corrosion testing.

# Acknowledgement of Federal support and Disclaimer

Acknowledgment: "This material is based upon work supported by the Department of Energy under Award Number(s) DE-EE0006442."

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