FIAT CHRYSLER AUTOMOBILES

Upset Protrusion Joining Techniques for Joining Dissimilar Metals

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FCA US LLC
June 12, 2015

Project ID #LM100

NAFTA
REGION

Overview

Timeline

- Start date: September 30, 2013
- End date: December 31, 2016
- Percent complete: ~40%

Budget

- Total project funding
  - DOE share: $587,248
  - Contractor share: $251,678
- Funding received in FY14:
  - $81,591
- Funding for FY15:
  - $361,437

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*

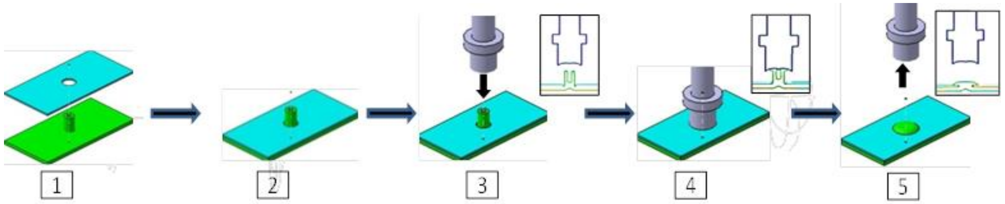
Partners

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

Relevance

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.



UPJ Conceptual Process Schematic

Objectives (September 2013 to March 2015):

- Characterize thermo-mechanical behavior of Mg alloys to support computer process modeling to assist in optimizing UPJ joining process.
- Optimize UPJ protrusion and electrode geometries, and process parameters, to provide robust, repeatable joining performance for each configuration being considered.
- For benchmark self pierce riveting (SPR), and round boss and oval joint UPJ, produce test coupons to support mechanical and corrosion performance evaluations.
- Conduct pre-corrosion mechanical testing for SPR and round boss UPJ assemblies.

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".***

Milestones

Date	Milestones and Go/No-Go Decisions	Status
September, 2013	Milestone Project kick-off	Complete
January, 2015	Milestone Complete process development preparation	Complete
January, 2015	Go/No-Go Decision SPR and round boss UPJ joints assembled and coated	Complete
December, 2015	Milestone Evaluate first set of UPJ and UCR Joints for pre-corrosion mechanical/structural performance	On track
December, 2015	Go/No-Go Decision Complete initial (pre-corrosion) mechanical/structural evaluations for all joints	On track

Approach

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- 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 Gleeble® 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.

Technical Accomplishments and Progress

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- Established ***benchmark*** performance of magnesium to aluminum joints produced through SPR:
  - Optimized joining process to produce high quality 2.0 mm Mg AM60B to 2.2 mm Al6013-T4 dissimilar metal joints by down-selecting the most promising (best rivet engagement, least cracking, etc.) from17 different rivet and die combinations.
  - Produced over 200 shear and cross tension assemblies to support evaluation of mechanical/structural and corrosion performance.
  - Evaluated ***pre-corrosion*** structural/mechanical performance of 105 samples and ***post corrosion*** performance of 122 joints subjected to ASTM G85-A2 accelerated corrosion procedure.

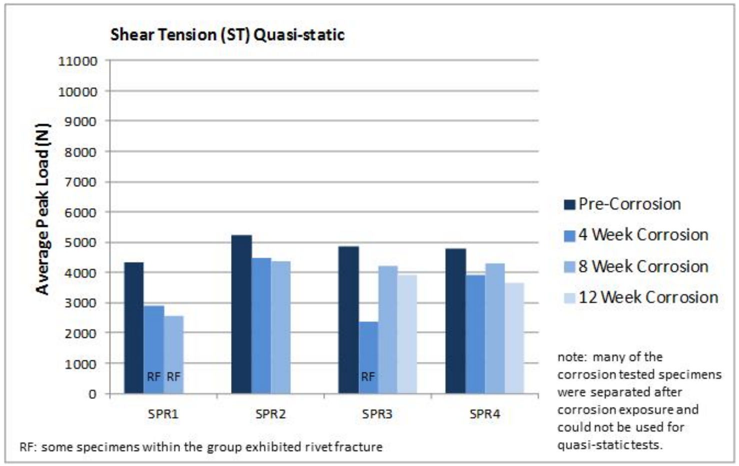
Self-Pierce Riveting - Round Rivet AM60B 2t

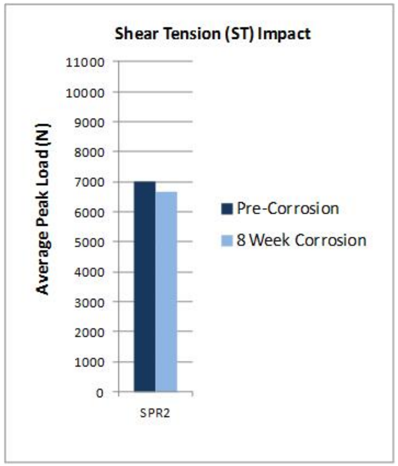
Base Plate Configuration			Joining Plate			Coated Assem-bly?	Preliminary Evaluations (Prior to Corrosion Exposure)							On-Going Accelerated Corrosion Exposure Evaluation									
														4 wks		8 wks		12 wks					
Material	Test Type Configu-ration	Surface Condition	Material	Thick-ness (mm)	Surface Condition		Micro-structure Charac-terization and Defect Evaluation	Quasi-Static		Fatigue		Impact		Quasi-Static		Quasi-Static		Quasi-Static		Fatigue		Impact	
								ST	CT	ST	CT	ST	CT	ST	CT	ST	CT	ST	CT	ST	CT	ST	CT
Mg AM60B	Shear Tension	Bare	Al 6013 T4	2.2	Bare	No	5	5						3		3		3					
		Pre-Treat	Al 6013 T4	2.2	Pre-treat	Yes		5		20		5		3		3		3		20		5	
					Coated	No		5						3		3		3					
					Coated	Yes		5						3		3		3					
	Cross Tension	Bare	Al 6013 T4	2.2	Bare	No			5						3		3		3				
		Pre-Treat	Al 6013 T4	2.2	Pre-treat	Yes	5		5		20		5		3		3		3		20		5
					Coated	No			5						3		3		3				
					Coated	Yes	5		5						3		3		3				

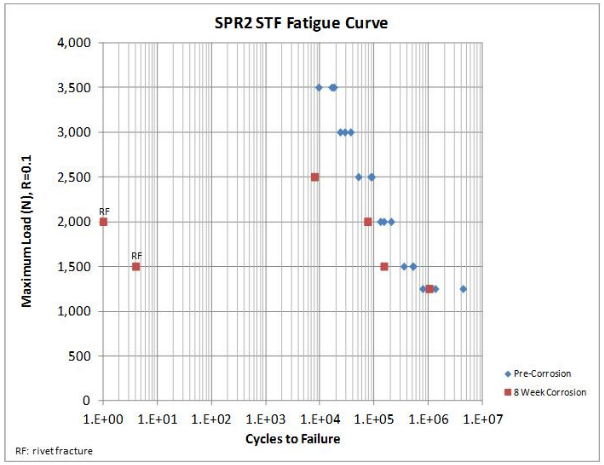
Full SPR test matrix – Green squares indicate testing completed, red squares indicate parts had to be removed early (after 8 wks) from testing due to numerous premature failures

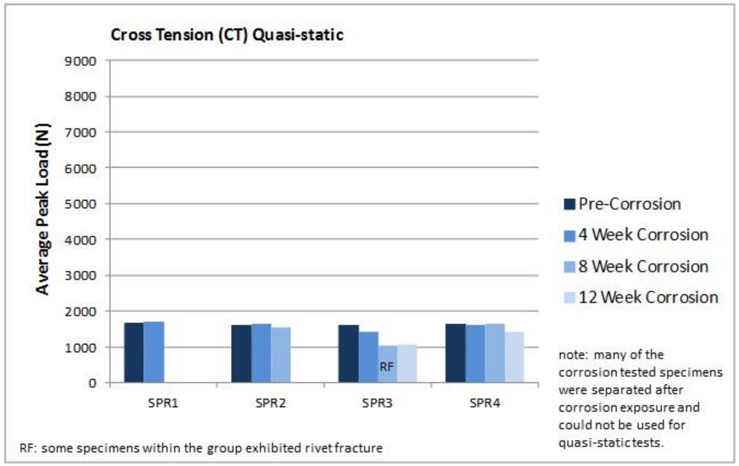
Technical Accomplishments and Progress

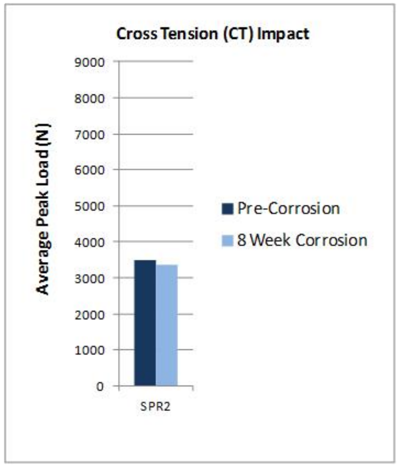
- Established ***benchmark*** performance of magnesium to aluminum joints produced through SPR.
  - Conducted structural/mechanical testing/evaluation throughout accelerated corrosion testing and fatigue and impact testing at the end of accelerated corrosion testing.

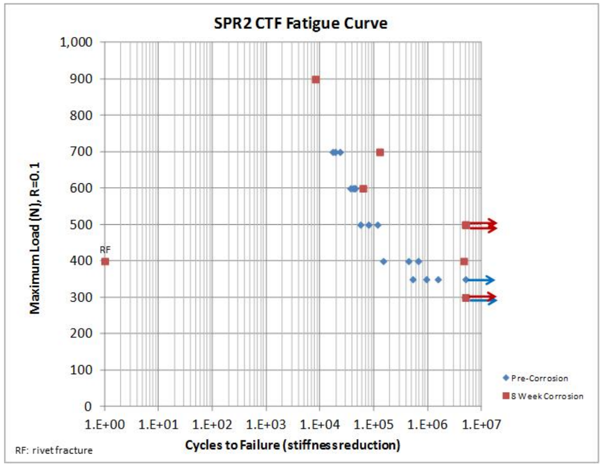




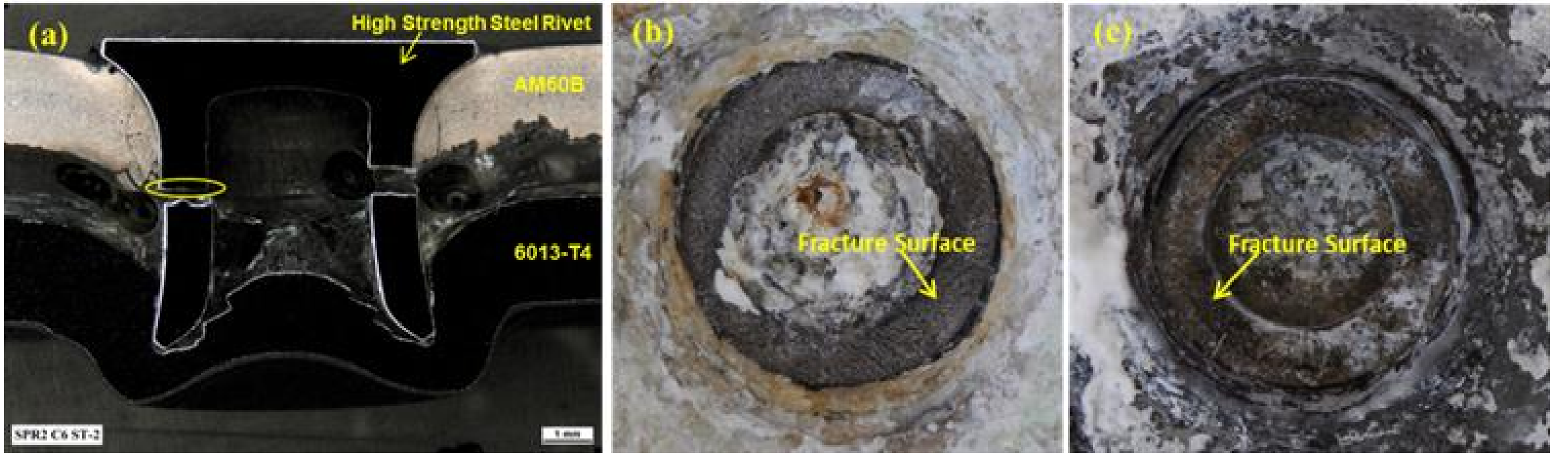


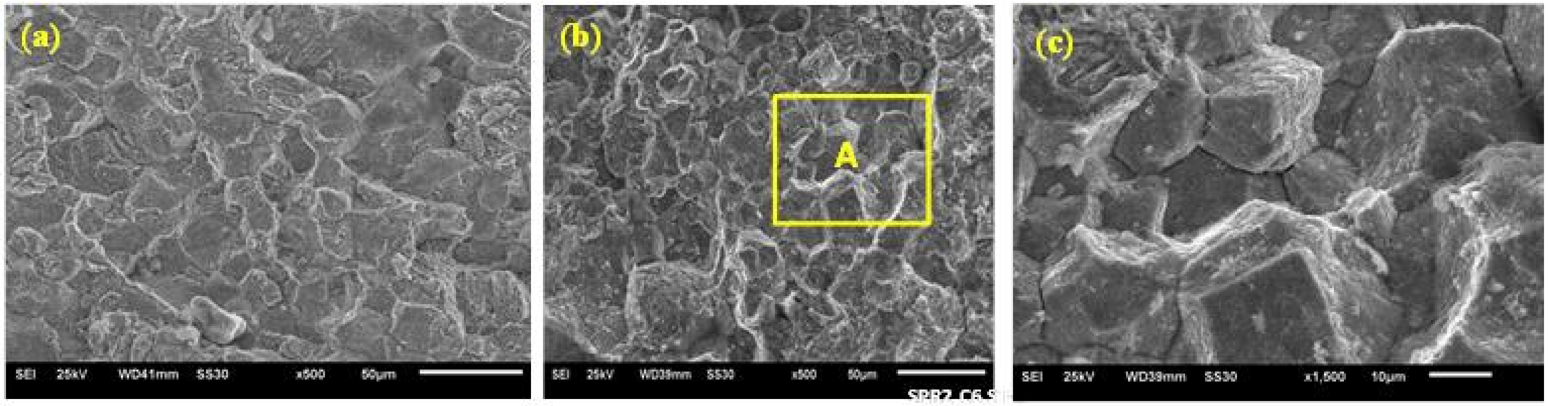






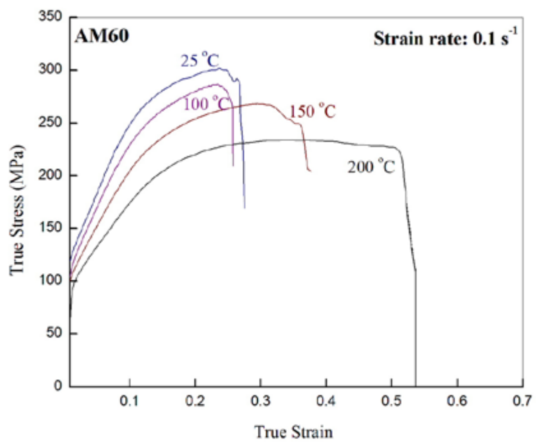
- Established ***benchmark*** performance of magnesium to aluminum joints produced through SPR.
  - Evaluated reason for premature joint failures of numerous samples during corrosion exposure to be hydrogen embrittlement of the steel rivet.

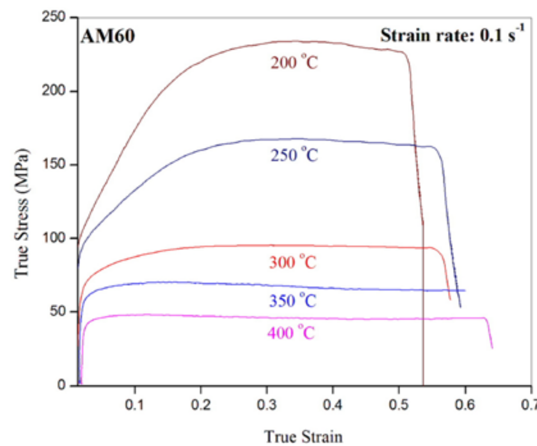


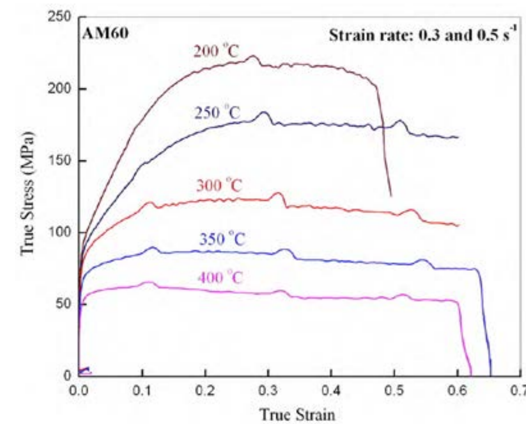


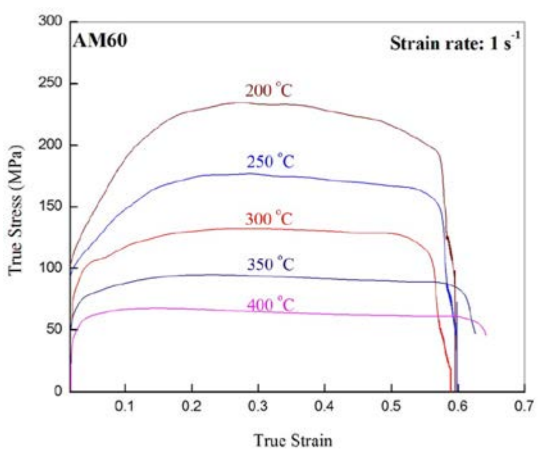
Technical Accomplishments and Progress

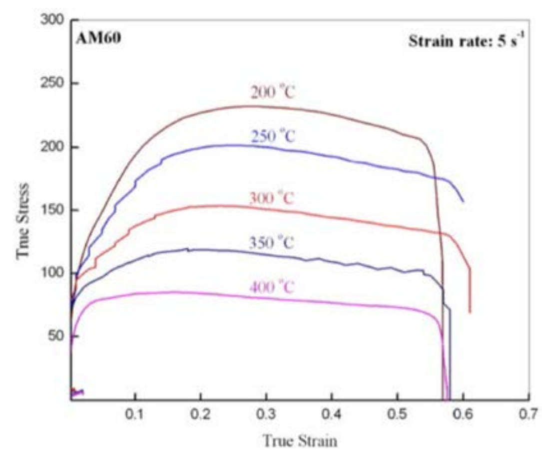
- Characterized thermo-mechanical behavior for Mg AM60B at several strain rates between 0.1 and 5.0 s^{-1} and temperatures from 25°C to 400°C, through a Canadian Government Automotive Partnership Canada (APC) funded project with McMaster University, to support modeling predictions of UPJ process. Examples are shown below:

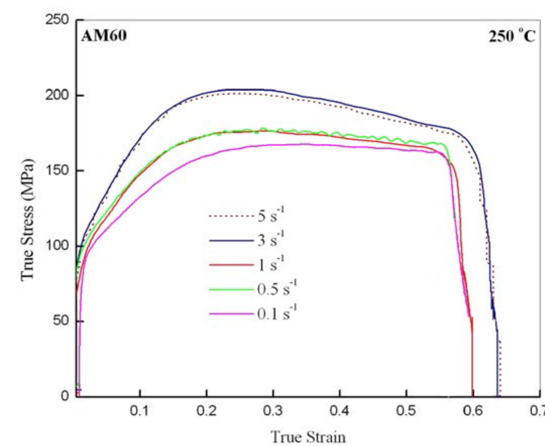






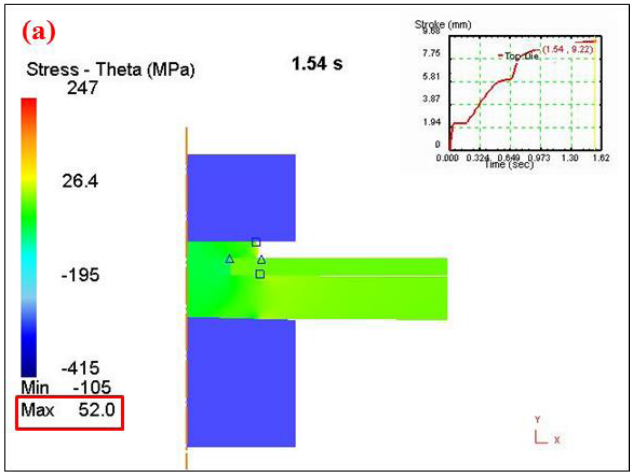


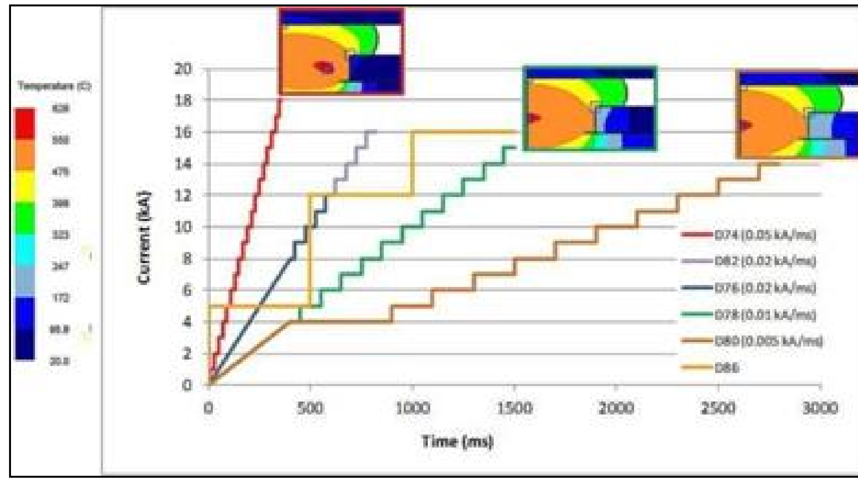


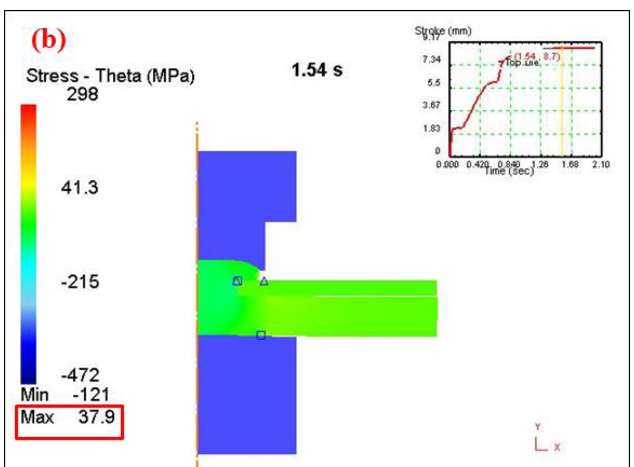


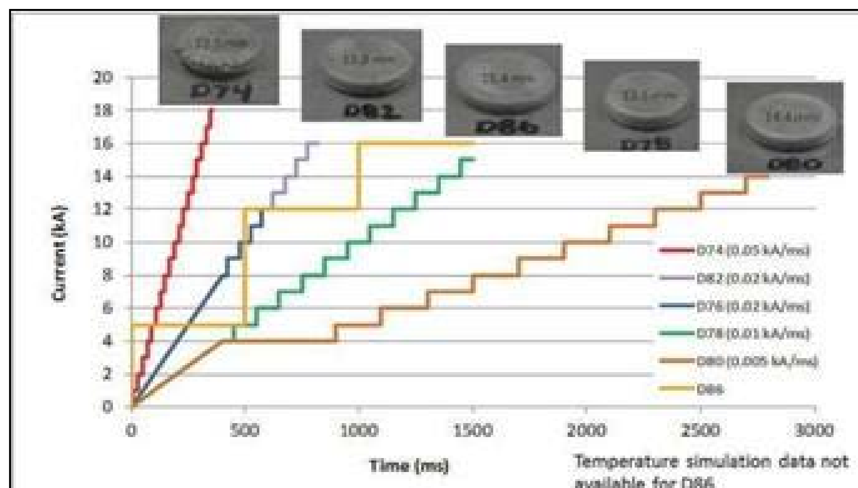
Technical Accomplishments and Progress

- Conducted extensive process modeling and simulation development work as well as additional experimental work to support production of robust, repeatable joints for 11 unique round boss UPJ material / coating configurations.









Technical Accomplishments and Progress

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- Produced over 650 round boss UPJ joints from 11 unique material/coating configurations and conducted pre-corrosion mechanical tests of over 300 joints from those same configurations. Evaluations included microstructure evaluations, joining induced defect characterization, and quasi-static, impact, and fatigue tests of shear and cross tension joint configurations.

Upset Protrusion Joining - Round Boss AM60B 2t																									
Base Plate Configuration					Joining Plate			Coated Assem-bly? *	Preliminary Evaluations (Prior to Corrosion Exposure)							On-Going Accelerated Corrosion Exposure Evaluation									
Material	Rivet Configuration		Test Type Configu-ration	Surface Condition	Material	Thick-ness	Surface Condition		Microstructure Characterization and Defect Evaluation	Quasi-Static		Fatigue		Impact		4 wks		8 wks		12 wks					
																Quasi-Static		Quasi-Static		Quasi-Static		Fatigue		Impact	
	Shape	Size								ST	CT	ST	CT	ST	CT	ST	CT	ST	CT	ST	CT	ST	CT	ST	CT
Mg AM60B	Round	7 mm Diam	Shear Tension	Bare	Al 6016	1.0 mm	Bare	No		5				5		3		3		3				5	
				Alodine 5200	Al 6016	1.0 mm	Pre-treat	Yes	5	5						3		3		3					
					Al 6016	1.0 mm	Powder-coated	No		5						3		3		3					
								Yes		5						3		3		3				5	
			Cross Tension	Bare	Al 6016	1.0 mm	Bare	No	5		5				5		3		3		3				5
				Alodine 5200	Al 6016	1.0 mm	Pre-treat	Yes			5						3		3		3				
					Al 6016	1.0 mm	Powder-coated	No	5		5						3		3		3				
								Yes			5						3		3		3				5
Mg AM60B	Round	8 mm Diam	Shear Tension	Bare	AM60B	2.0 mm	Bare	No		5		20		5											
					Al 6013	2.2 mm	Bare	No		5						3		3		3		20		5	
				Alodine 5200	Al 6013	2.2 mm	Pre-treat	Yes	5	5						3		3		3					
							Powder-coated	No		5						3		3		3					
								Yes		5		20		5		3		3		3		20		5	
					HSS DP-590	2.0 mm	Armorgalv, zinc-phosphate, Tritop, Universal	No		5						3		3		3					
					HSS DP-590	2.0 mm	Armorgalv, zinc-phosphate, E-Coat w/ sealed edges	Yes	5	5		20		5		3		3		3		20		5	
			Cross Tension	Bare	AM60B	2.0 mm	Bare	No	3		5	20		5											
					Al 6013	2.2 mm	Bare	No	5		5						3		3		3		20		5
				Alodine 5200	Al 6013	2.2 mm	Pre-treat	No			5						3		3		3				
							Powder-coated	No			5		20		5		3		3		3		20		5
								Yes			5						3		3		3				
					HSS DP-590	2.0 mm	Armorgalv, zinc-phosphate, Tritop, Universal	No	5		5						3		3		3				
					HSS DP-590	2.0 mm	Armorgalv, zinc-phosphate, E-Coat w/ sealed edges	Yes			5		20		5		3		3		3		20		5

Full test matrix for round boss UPJ joints – green squares indicate that work has been completed

Technical Accomplishments and Progress

- Produced "good" joints (i.e., good head formation, no visible cracks, no observable damage to coatings on joined materials, etc.) from 11 unique material/coating configurations to support mechanical and corrosion performance evaluations. Six examples are shown below:

UPJ8-1
2.0 mm (Armorgalv) DP590
(Bare) AM60

UPJ8-4
2.2 mm (Pre-treated) Al 6013-T4
(Pre-treated) AM60
Powdercoated Assembly

UPJ8-6
2.2 mm (Powdercoated) Al 6013-T4
(Pre-treated) AM60
Powdercoated Assembly

UPJ8-2
2.2 mm (Bare) Al 6013-T4
(Bare) AM60

UPJ8-5
2.2 mm (Powdercoated) Al 6013-T4
(Pre-treated) AM60

UPJ8-7
2.0 mm (Bare) AM60
(Bare) AM60

Technical Accomplishments and Progress

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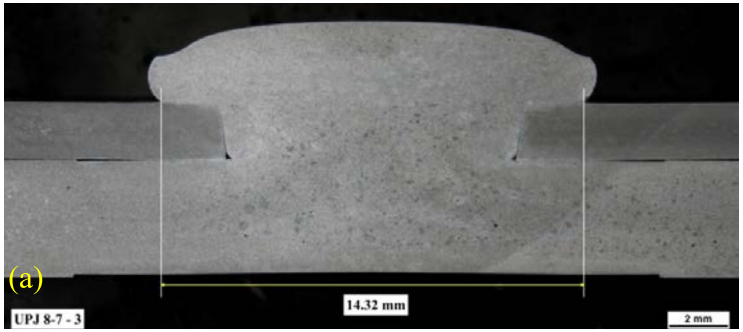
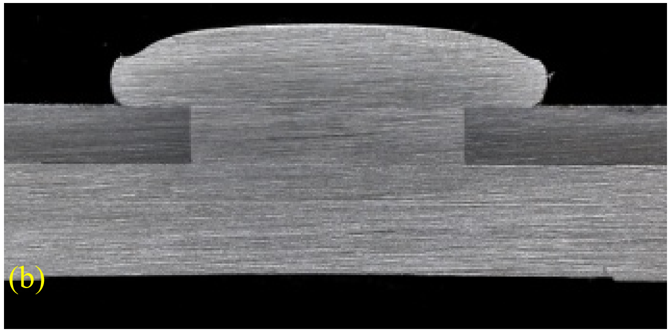
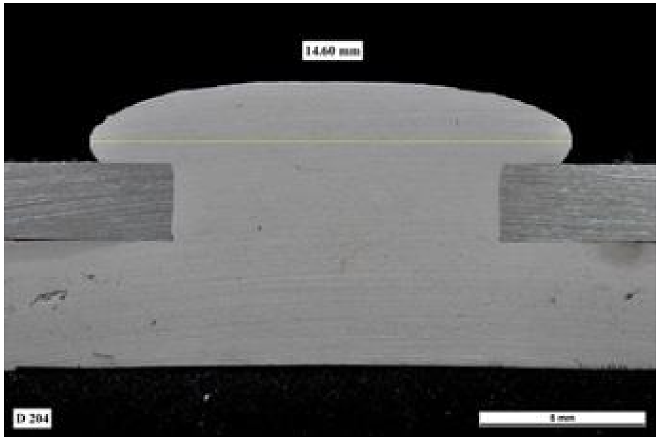
- Evaluated microstructures of round boss UPJ samples.



Magnesium Upper Sheet



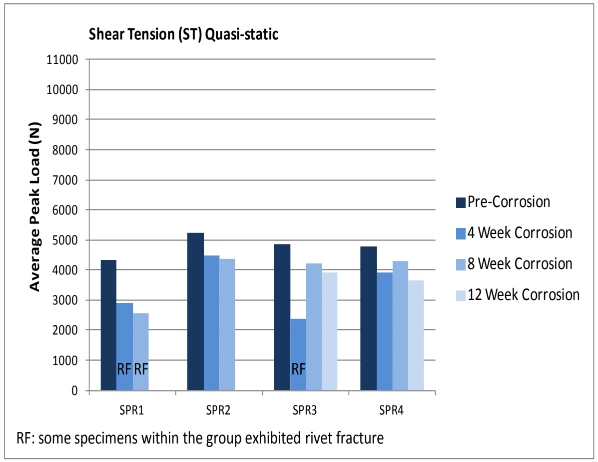
Steel Upper Sheet

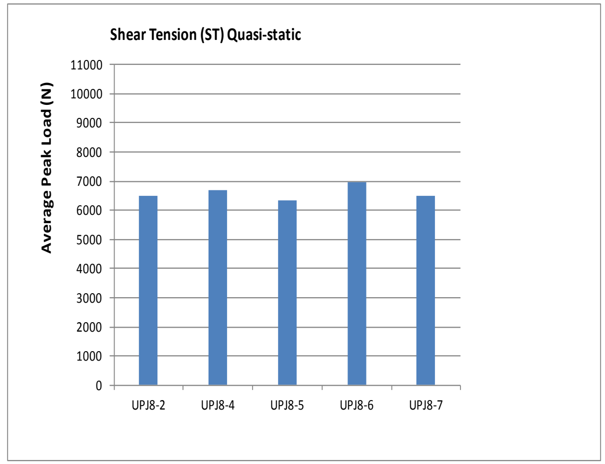


Aluminum Al6013 Upper Sheet

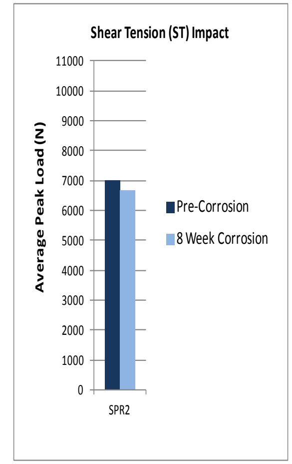
Technical Accomplishments and Progress

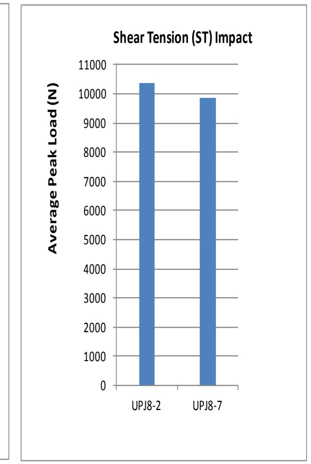
- Evaluated pre-corrosion ***quasi-static*** structural / mechanical performance of round boss UPJ joints and compared to similar performance of SPR joints.



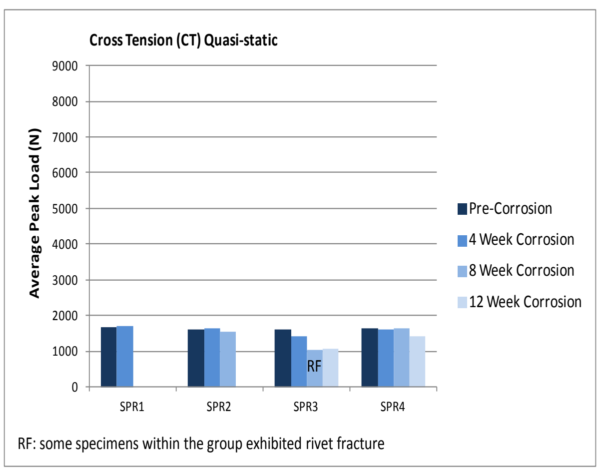


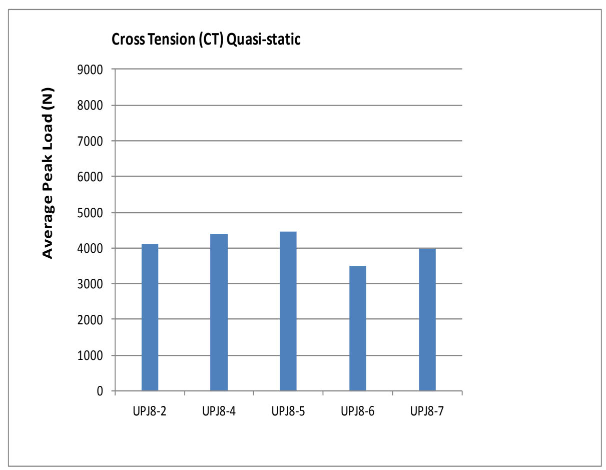
Quasi-Static Shear Tension Test Results of SPR (before, during, and after corrosion) and UPJ (pre-corrosion only)



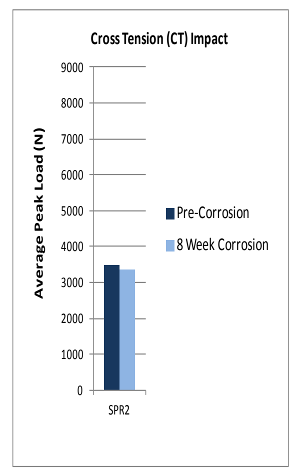


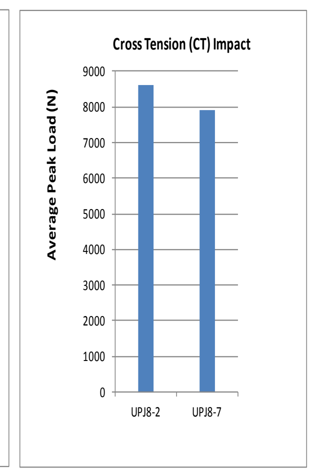
Impact Shear Tension Test Results of SPR and UPJ





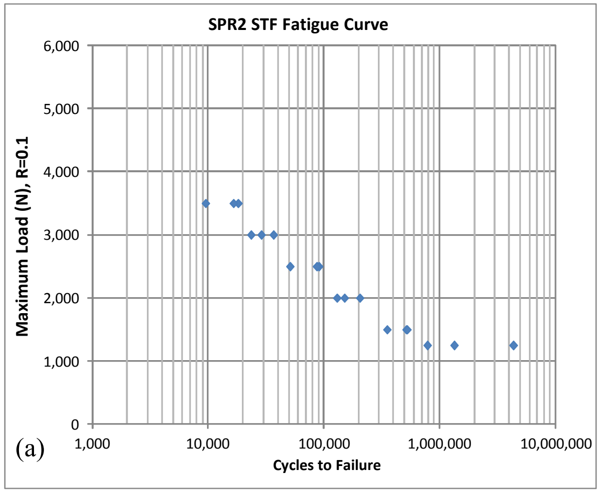
Quasi-Static Cross Tension Test Results of SPR (before, during, and after corrosion) and UPJ (pre-corrosion only)

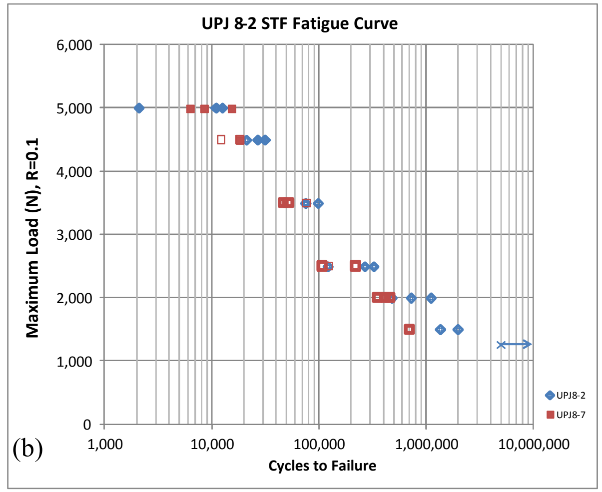


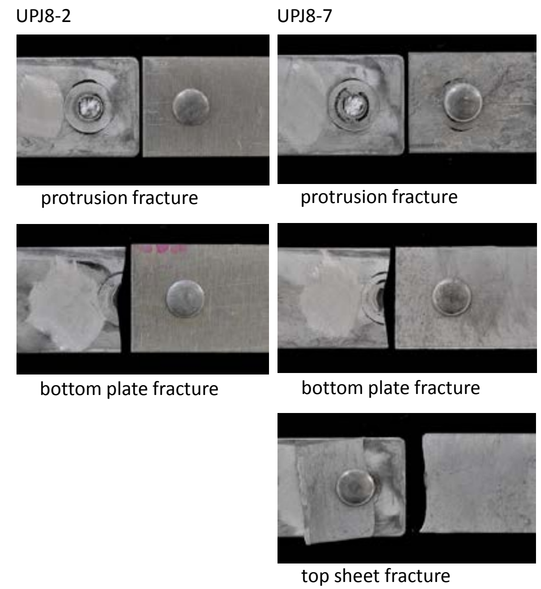


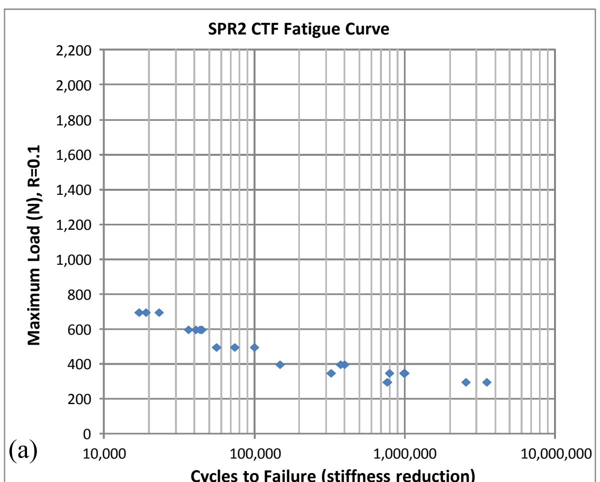
Impact Cross Tension Test Results of SPR and UPJ

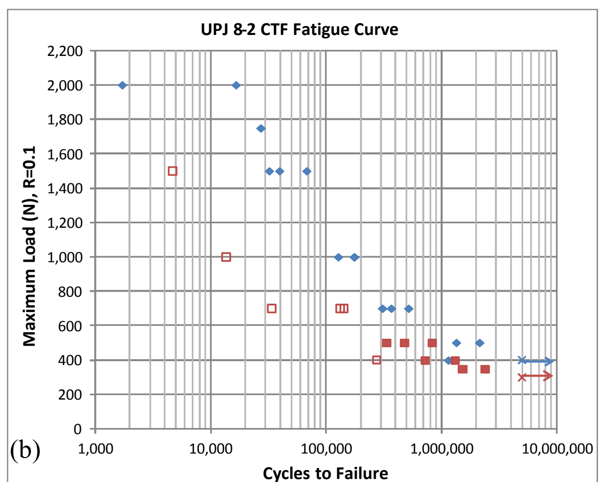
- Evaluated ***fatigue*** performance of round boss UPJ joints and compared to performance of benchmark SPR joints.

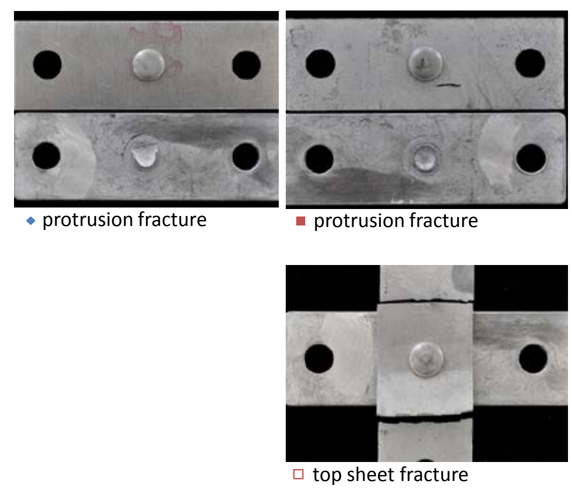












Comparisons of SPR and UPJ Fatigue Performance and Associated UPJ Failure Modes (Shown on the Right)

Responses to Previous Year Reviewers' Comments

This project was not reviewed last year.

Collaboration and Coordination

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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.

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

- Corrosion performance of UPJ joints for joining dissimilar metals must be validated.
  - Even when coating the cathode before joining, this is ***not*** a trivial issue, especially when joining Mg to steel.
- Unique oval boss UPJ joint geometry must be developed to support use of UPJ process on narrow flanges.
- Neither round boss or oval boss UPJ is amenable to joining surfaces where the casting die direction is not perpendicular to the material surface.
- Neither round boss or oval boss UPJ is feasible in joint combinations where neither metal is a casting.

Proposed Future Work

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FY2015

- Conduct accelerated corrosion evaluation and post-corrosion evaluation of round boss UPJ joints.
- Finish optimizing oval boss UPJ joining processes, produce oval boss UPJ joints, and conduct structural / mechanical evaluation of these joints.
  - These joints will not be exposed to accelerated corrosion aging as there is no reason to expect them to perform differently from the round boss UPJ samples.
- Finish optimizing round boss UCR process for joints that do not include a casting or where the joint surface is not perpendicular to die direction; produce joint evaluation samples, and conduct structural / mechanical evaluation of these joints.

FY2016

- Conduct accelerated corrosion evaluation, and conduct post corrosion evaluation of round boss UCR joints.

Summary

- During the past fiscal year, over 200 Mg to Al SPR joints were produced and evaluated for mechanical and corrosion performance to serve as a benchmark for UPJ performance evaluations.
  - Many benchmark SPR joints were unable to pass the full test exposure prescribed by FCA US Corrosion Engineering without losing joint integrity.
  - Several joints failed as a result of hydrogen embrittlement of the steel rivet.
- Extensive thermo-mechanical material characterization, computer modeling and physical experimentation were used to optimize round boss UPJ process parameters to support production of over 650 assemblies in 11 unique configurations, over 300 of which have been subjected to pre-corrosion mechanical evaluation, and compared to SPR performance.
  - Quasi-static and impact performance substantially improved over SPR.
  - Low cycle fatigue performance substantially improved over SPR while high cycle fatigue performance is similar to SPR.
  - Corrosion performance of round boss UPJ joints yet to be evaluated in FY2015.
- Process simulation and optimization were conducted on oval boss UPJ and round boss UCR to support joining and evaluation work in FY2015.

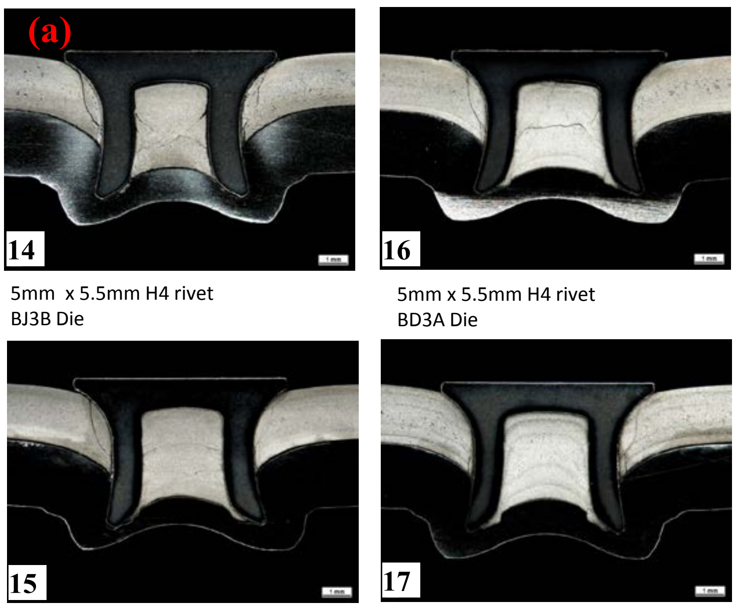
Acknowledgement of Federal support and Disclaimer

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

Technical Back-Up Slides

Technical Accomplishments and Progress

- Established ***benchmark*** performance of magnesium to aluminum joints produced through SPR.
  - Optimized SPR joining process to produce high quality 2.0 mm Mg AM60B to 2.2 mm Al6013-T4 dissimilar metal joints by evaluating 17 different rivet and die combinations, and down-selecting four that looked most promising (best rivet engagement, least cracking, etc.).

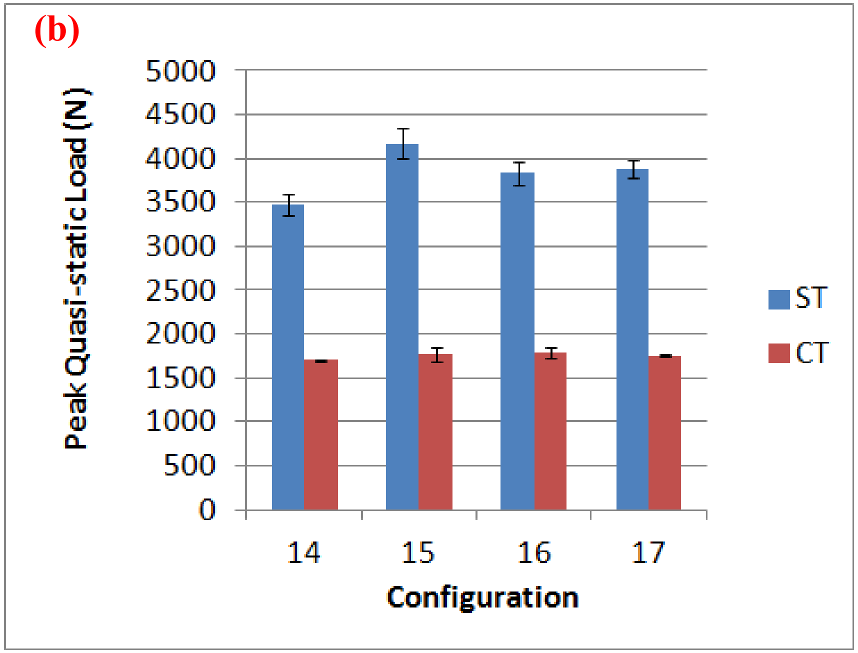


5mm x 5.5mm H4 rivet
BJ3B Die

5mm x 5.5mm H4 rivet
BD3A Die

5mm x 5.5mm H6 rivet
BD3A Die

5mm x 5.5mm H6 rivet
BJ3B Die

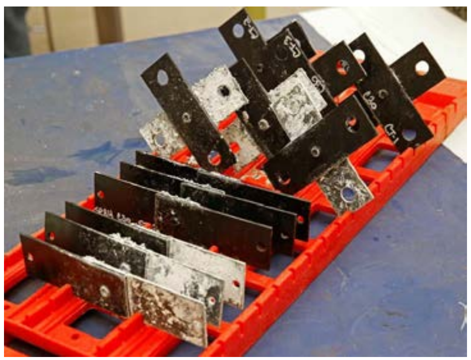
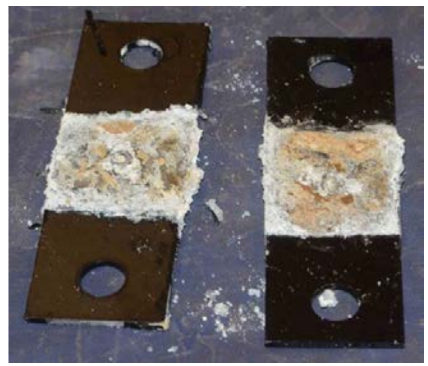
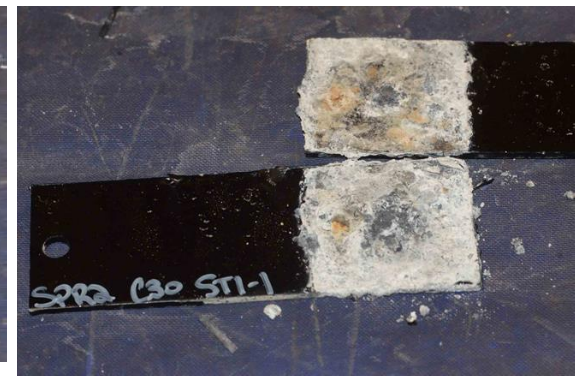


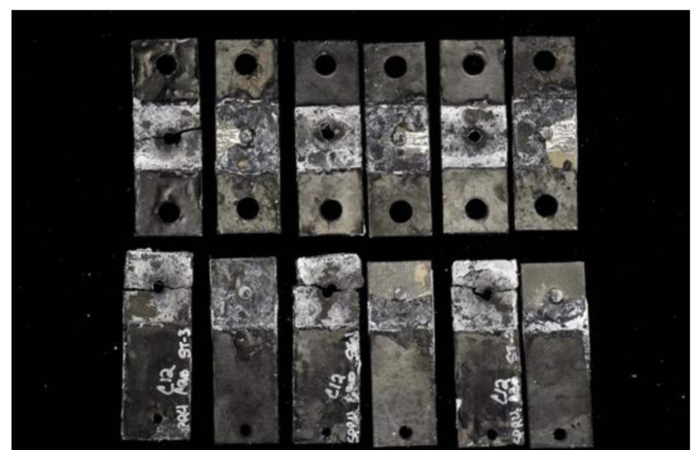
  - Configuration 17 was selected to continue development work due to least material cracking and most repeatable results.

Technical Accomplishments and Progress

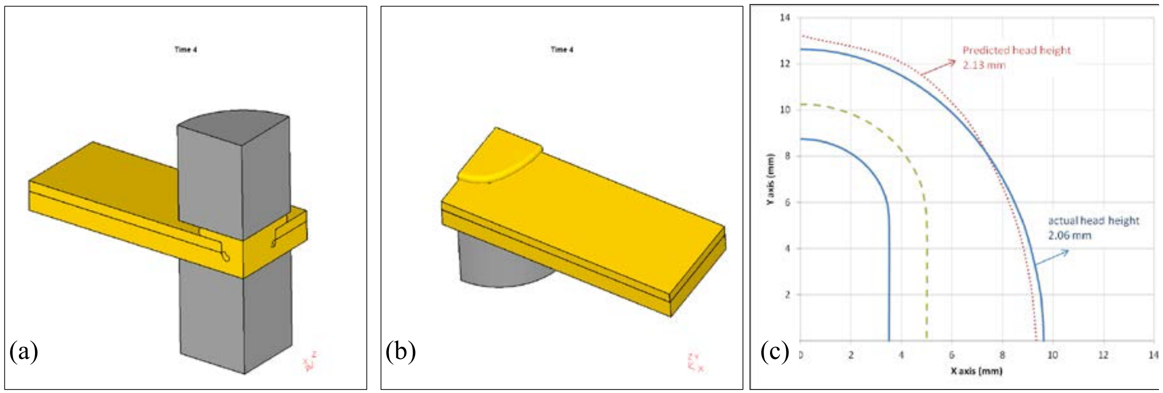
FIAT CHRYSLER AUTOMOBILES

- Established ***benchmark*** performance of magnesium to aluminum joints produced through SPR.
  - Subjected 122 shear and cross tension assemblies to ASTM G85-A2 accelerated corrosion procedure.

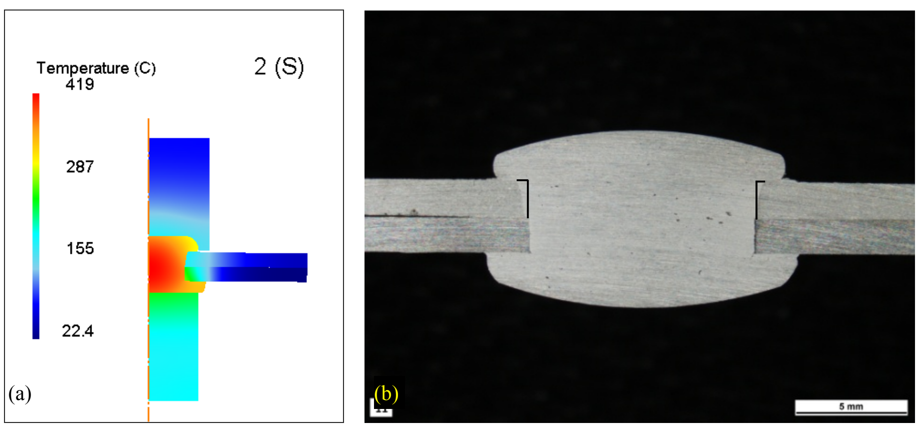



- Conducted initial simulation work and some physical experimentation to develop optimized electrode shapes for ***oval joint UPJ*** and ***round boss UCR*** joints for evaluation in the next fiscal year.



Oval Joint Forming Simulation and Head Shape Outline Comparison to Physical Experimental Part

Experimental Oval Boss Head Shape with Hole Shape Superimposed



Round Boss UCR Process Simulation and Section Through Actual Experimental Joint