SOLID-STATE JOINING OF MAGNESIUM SHEET TO HIGH-STRENGTH STEEL

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DOE- VTO Annual Merit Review Meeting, June 20 2018

Project ID # MAT-138

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OVERVIEW

Timeline

- Start: October 2017
- End: September 2020
- 22% Complete

Budget

- Project Funding $1.7M
- FY 2018: $525k
  - PNNL: $375k
  - ORNL: $150k
- FY 2019:$600k
- FY 2020: $600k

Barriers

- Broader scientific understanding of (Mg-Steel) joint interface needed.
- Ability to control interfacial chemistry in order to maximize joint performance between Mg-Steel needed.

Partners

- Pacific Northwest National Laboratory
- Oak Ridge National Laboratory

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

RELEVANCE

- Overall Objective
  - The goal of this project is to mature two types of solid phase joining techniques by developing an understanding of methods and processing conditions required to achieve robust joints between Magnesium and Steel, thus integrating lightweight materials for multi-material vehicles. (Addressing barrier listed in MTT Road Map, 2017, section 4)
- FY 18 Objectives
  - Establish methods of joint fabrication, joint characterization
  - Establish methods of joining process data acquisition.
  - Joint Fabrication in various conditions.
  - Characterization and analysis of joint interface.
- Impact
  - The knowledgebase on Mg-Steel joint interface in relation to strength, ductility and corrosion properties obtained in this project has the potential to enable widespread use of Mg-Steel joints.

SCHEDULE AND MILESTONE

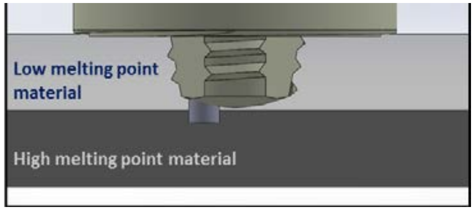
Tasks	2018								
	1	2	3	4	5	6	7	8	9
Task 1. Development of joints with & without geometric joint line feature									
1.1 Process development & mechanical property									
1.2 Interface characterization									
1.3 In-process control and feedback									
Task 2. Fundamental Study of Bond Formation & Mechanical Properties									
2.1 Interface characterization of the different joining methods and coatings									
2.1.1 Gleeble / In-Situ Neutron Analysis									
2.1. 2 Interface characterization by SEM, TEM									
Task 3. Interface Control & Tailoring for Improved Corrosion & Strength									
3.1 Create functionally graded microstructure									
3.2 Create different heat conditions at the interface (with modeling project)									
3.3 Other strategy to tailor interface for galvanic corrosion mitigation									

FY18 Milestone: Sept 2018:Complete characterization of type and extent of interface formed between Magnesium and steel and down-select to one or two joining methods for continued development in FY19.

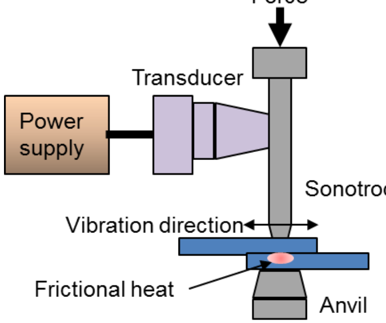
APPROACH

- Two solid phase joining techniques are utilized to produce Mg-Steel joints
  - Friction Stir Welding (FSW)
  - Ultra Sonic Welding (USW)
- By utilizing several advanced characterization techniques, we intend to correlate process parameters and variables to resulting interface chemistry and properties in order to tailor the joint interface that maximizes strength, ductility and corrosion resistance.
- **Magnesium Alloys**: AZ31 Sheet , AM50 Casting
- **Steel**: DP 590

Joining Methods	Interlayers	Parameters
Conventional FSW/USW [No joint line feature]	As received Zn Coating (HDG and EG), Bare Steel Other interlayers	Power Input
In Process Joint line feature		Scribe geometry Heat input
Pre-Machined joint line feature Eg: Friction Stir Interlocking	Zn Coatings, Bare Steel	Heat Input Joint line geometry



FSW



USW

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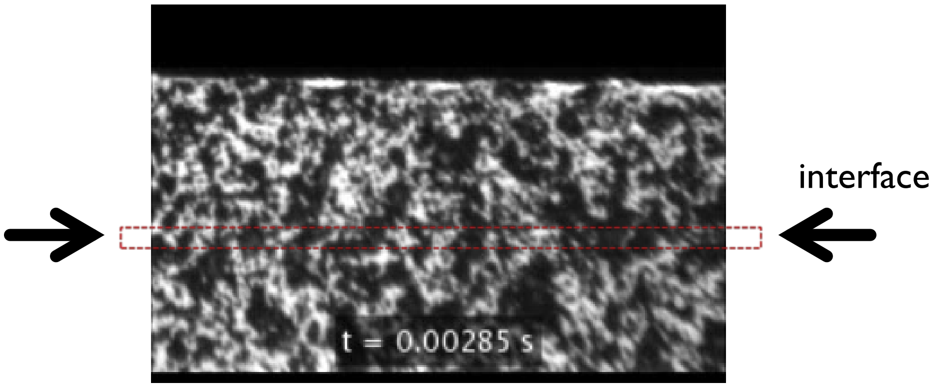
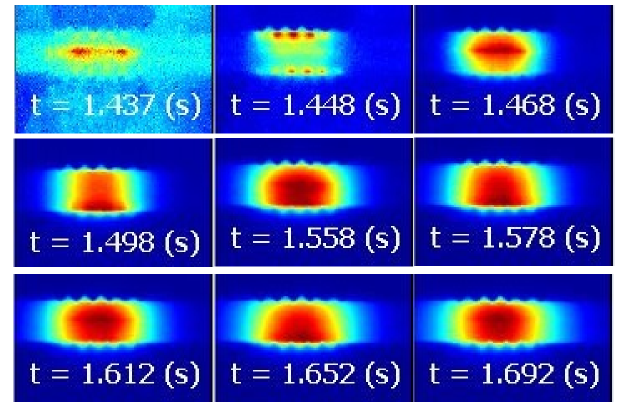
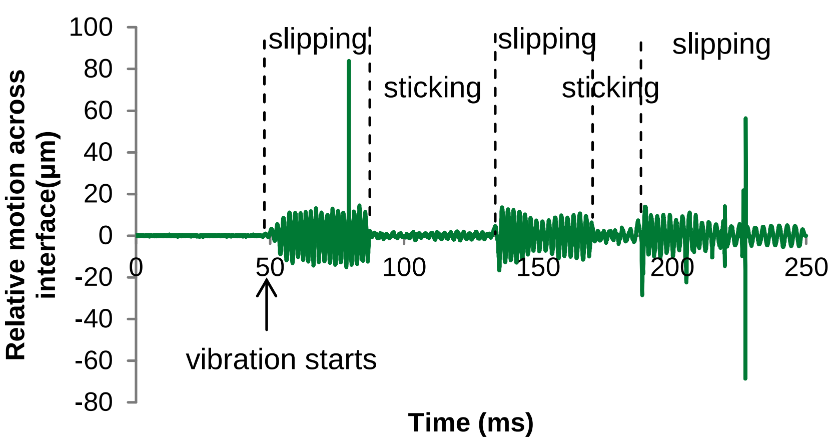
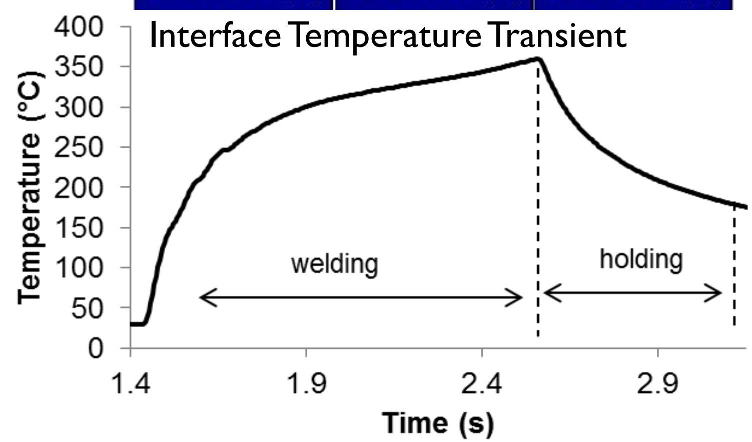
ACCOMPLISHMENTS:
ULTRASONIC WELDING: PROCESS MEASUREMENTS









- Microscopic interface motion, bonding and interface heat generation under high frequency ultrasonic vibration has been analyzed.

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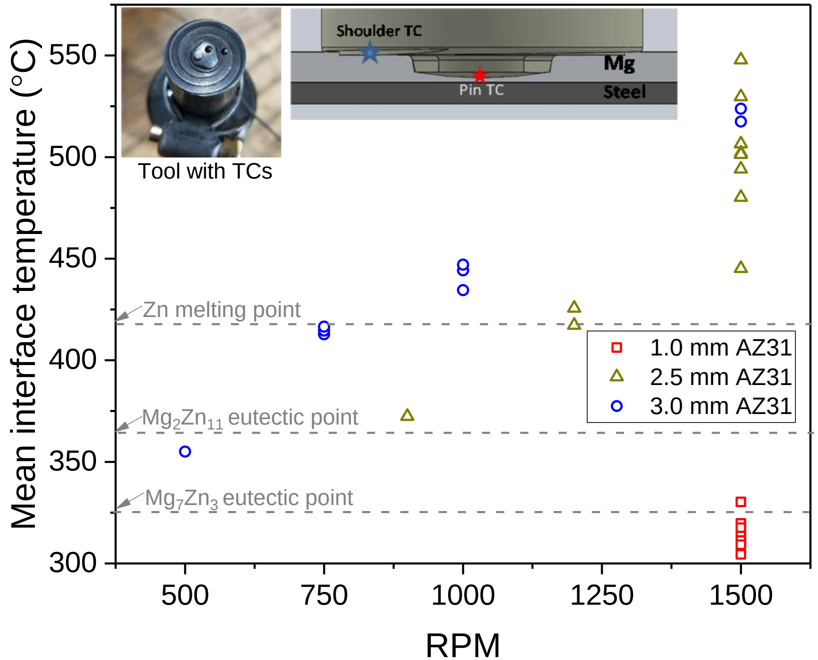
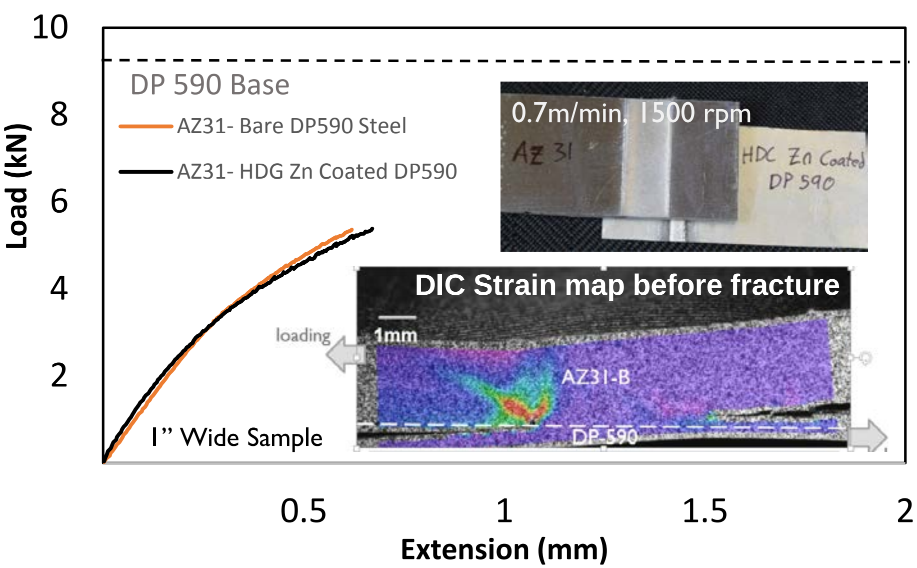
ACCOMPLISHMENTS: FRICTION STIR WELDS: PROCESS MEASUREMENTS



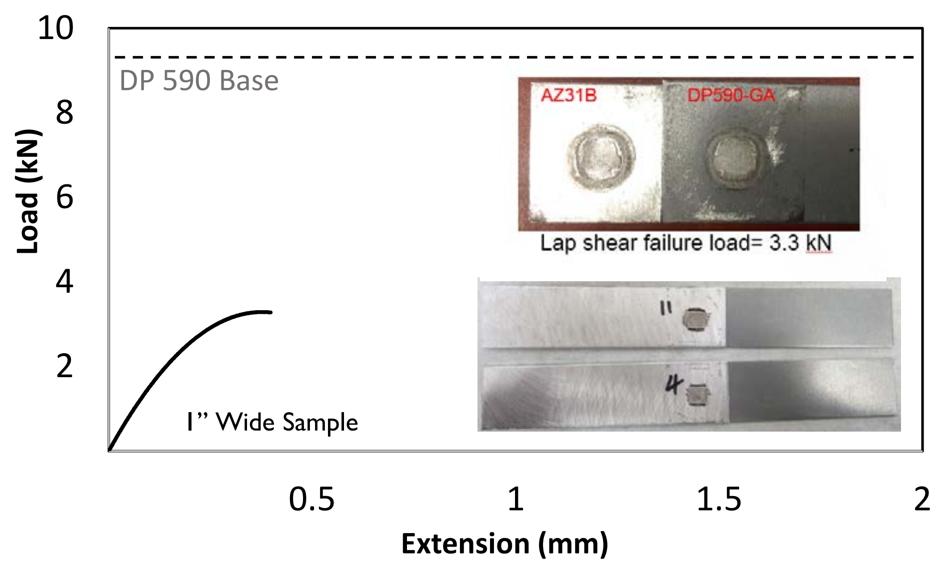
- For both joining processes the methods of measuring process variables (including in-situ interface temperature, forces, power) has been established.
- A series of joints were made at various interface conditions at temperatures ranging from 310°C-550°C.

ACCOMPLISHMENTS:
MECHANICAL CHARACTERIZATION

FSW



USW



- Joints made utilizing joint-line disruption (Scribe/ USW) has resulted in joint strength corresponding to ~68MPa (based on estimated bond area).
- Fracture mode was interfacial for both the cases.
- Strain localized at the hook region on the top sheet loaded side.

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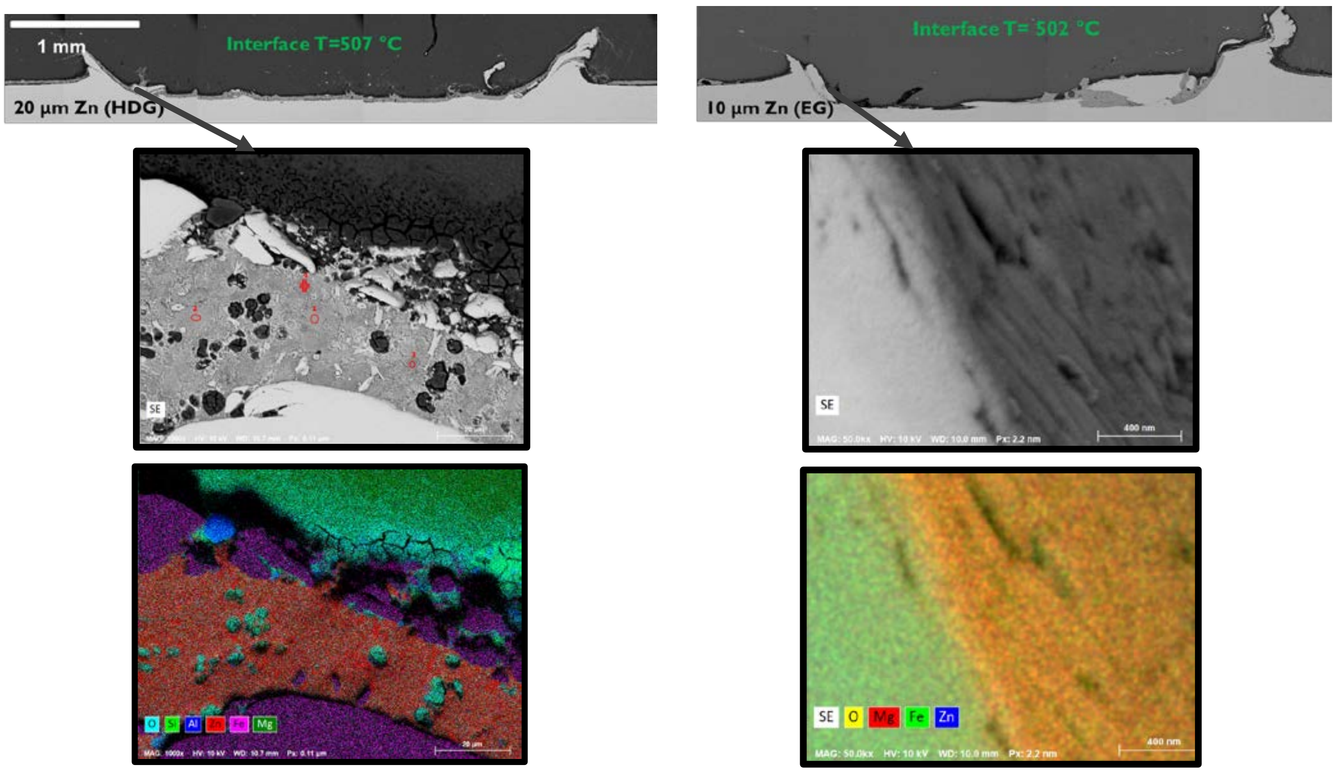
ACCOMPLISHMENTS: INTERFACE CHARACTERIZATION



Different types of interfaces were observed ranging from Eutectic layers (left) and a "mixed" layer consisting of Mg, Fe, Zn found to be closely bonded with AZ31 and steel layer (right).

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RESPONSES TO PREVIOUS YEARS REVIEWERS' COMMENTS

- Project is a new start in FY18

COLLABORATION AND COORDINATION

- Modelling and Experimental teams from both the labs are working together in this project.
- Bi-weekly meetings between the different teams help facilitate sharing of information and feedback on results and upcoming tasks.
- Results of this project will be disseminated through journal publications, conference presentations.

<u>Core Research Team</u>

- ORNL: Zhili Feng, Jian Chen, Yong Chae Lim, Hui Huang, Xin Sun
- PNNL: Piyush Upadhyay, Darrell Herling, Glenn Grant, Xiujuan Hellen Jiang, Reza E Rabby, Tim Roosendaal

REMAINING CHALLENGES AND BARRIERS

- In-depth characterization and deeper understanding of interface chemistry at wide range of temperatures and surface conditions is required to link interface conditions to desirable joint properties.
- There is a need to establish effective methods to obtain mechanical properties of interface region.
- There is a need to decouple metallurgical and mechanical contribution to bonding.

PROPOSED FUTURE WORK

- Complete interface characterization of developed joints in welding conditions, with and without Zn coatings.
- Perform micro-DIC, Nano-indentation and micro tensile testing to assess mechanical properties of several joint interfaces.
- Further develop joints with additional interface layers (coatings) and joint line feature improvements (create different joint-line disruptions).
- Perform instrumented experiments to validate predictive model in coordination with “interface by design” project.

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

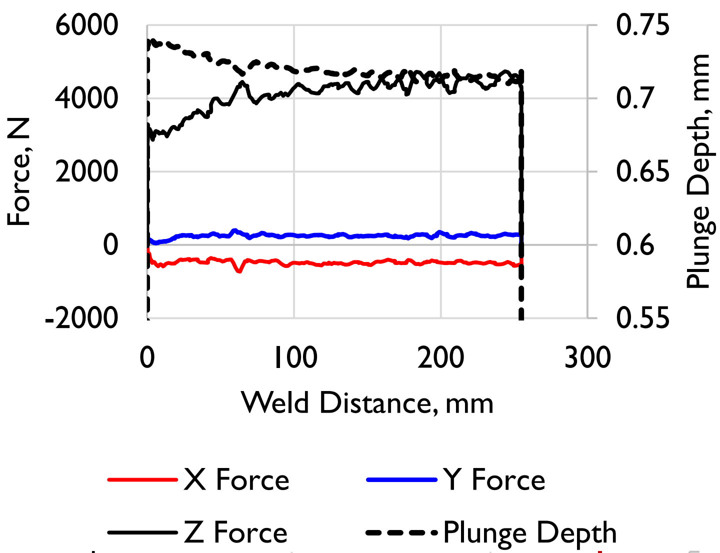
SUMMARY

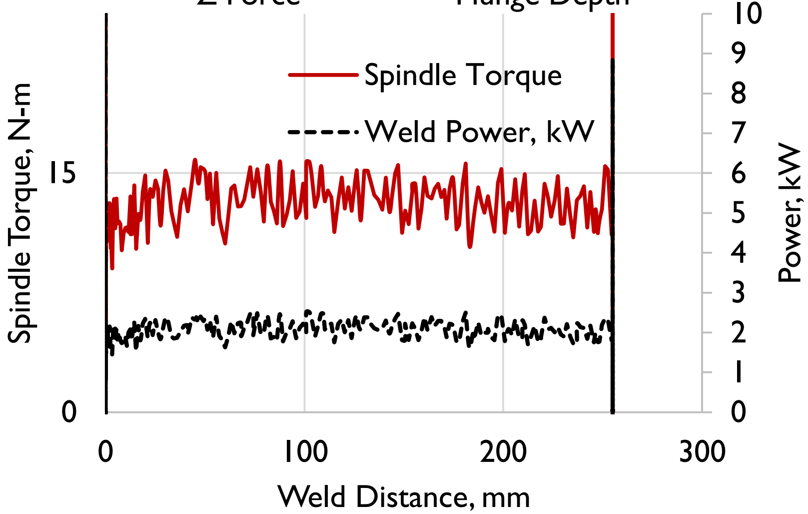
The goal is to develop an applied understanding of localized metal forming and associated metallurgical bonding in Magnesium to Steel joint. By utilizing several advanced characterization techniques, we intend to correlate processing parameters and variables to resulting chemistry and properties in order to tailor the joint interface that maximizes strength, ductility and corrosion resistance.

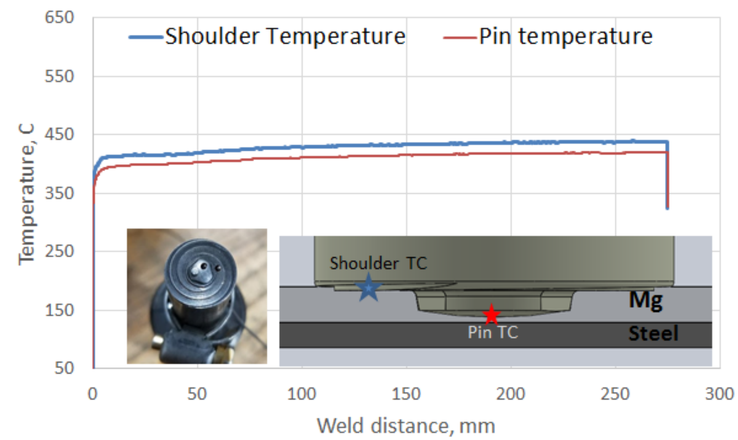
- This year we kicked off this collaborative project and established material set, welding schedule, tooling and instrumentation.
- Joint line disruption processes resulted in joint strength of 5.2kN/ 25.4mm joint. Mixed interface layer found in this joints are being investigated. USW process has resulted in lap shear strength of ~3.3kN/25.4mm.
- For USW microscopic interface motion, bonding and interface heat generation under high frequency ultrasonic vibration are being investigated.

TECHNICAL BACKUP SLIDES

DATA COLLECTED DURING FSW PROCESS







- Process data collected during each welding includes tool forces, input power and tool temperature (a proxy for interface temperature during joining).
- This generated dataset will serve as input for computational model in "interface by design" project.

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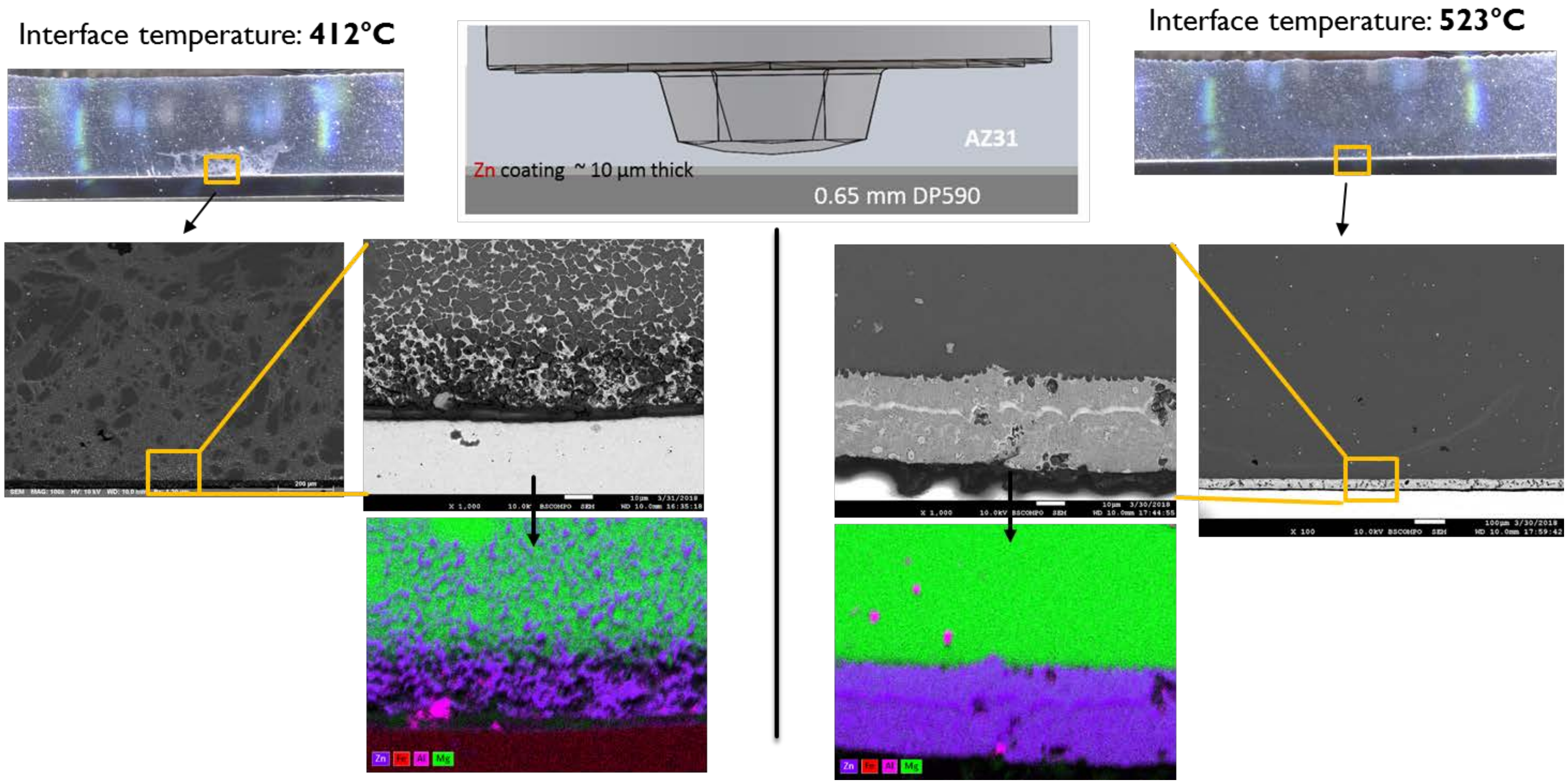
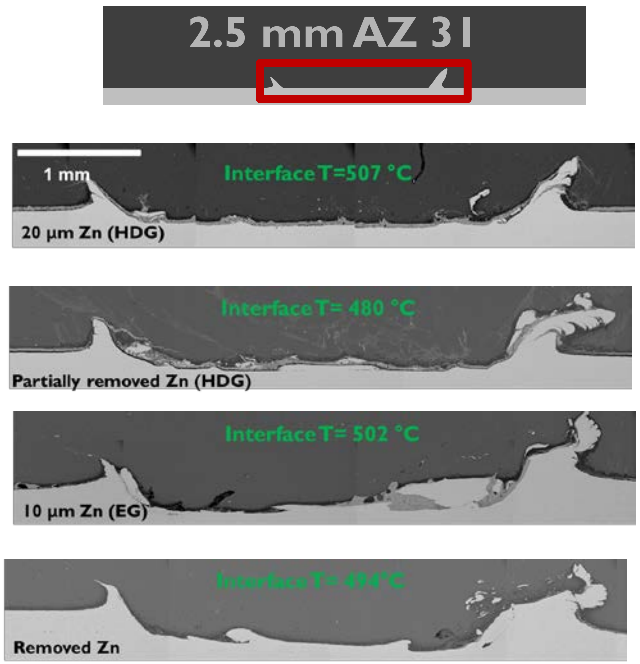
Effects of temperature at joint interface (Conventional FSW)

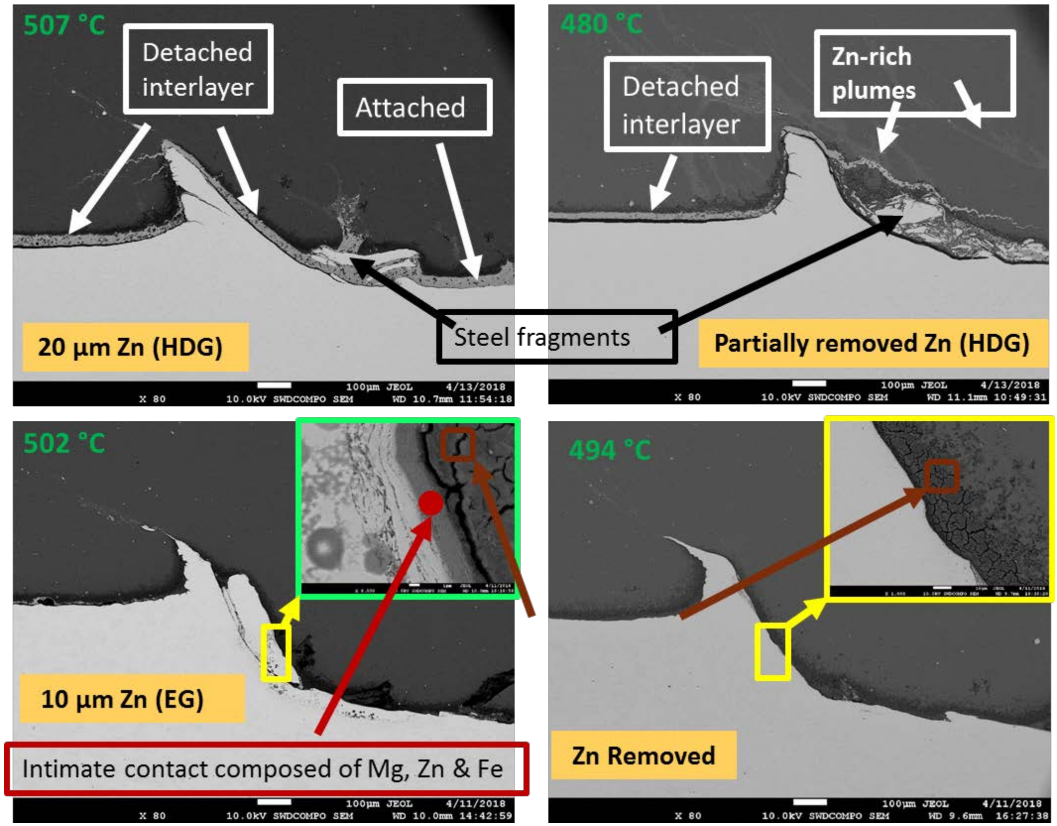


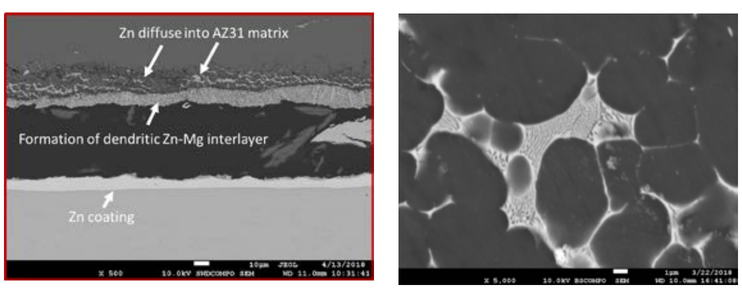
- At lower temperature Zn gets transported up into nugget region, with higher interface temperature Zn mostly stays at the interface. Load carrying capacity for both the joints are similar. Zn+ Mg eutectic remain at the interface, but is only bonded to the upper Mg nugget and not bonded to steel at the bottom. Note that for this set of welds the FSW tool does not interact with steel directly.
- For conventional FSW, for 20µm and 10µm Zn coated steels we have not observed viable joint strength thus far. While there are differences in observed joint strength (hand peel tests) with different types of Zn coatings, the joint strength is low.

Mg- Steel Joint Cross-sections and interfaces



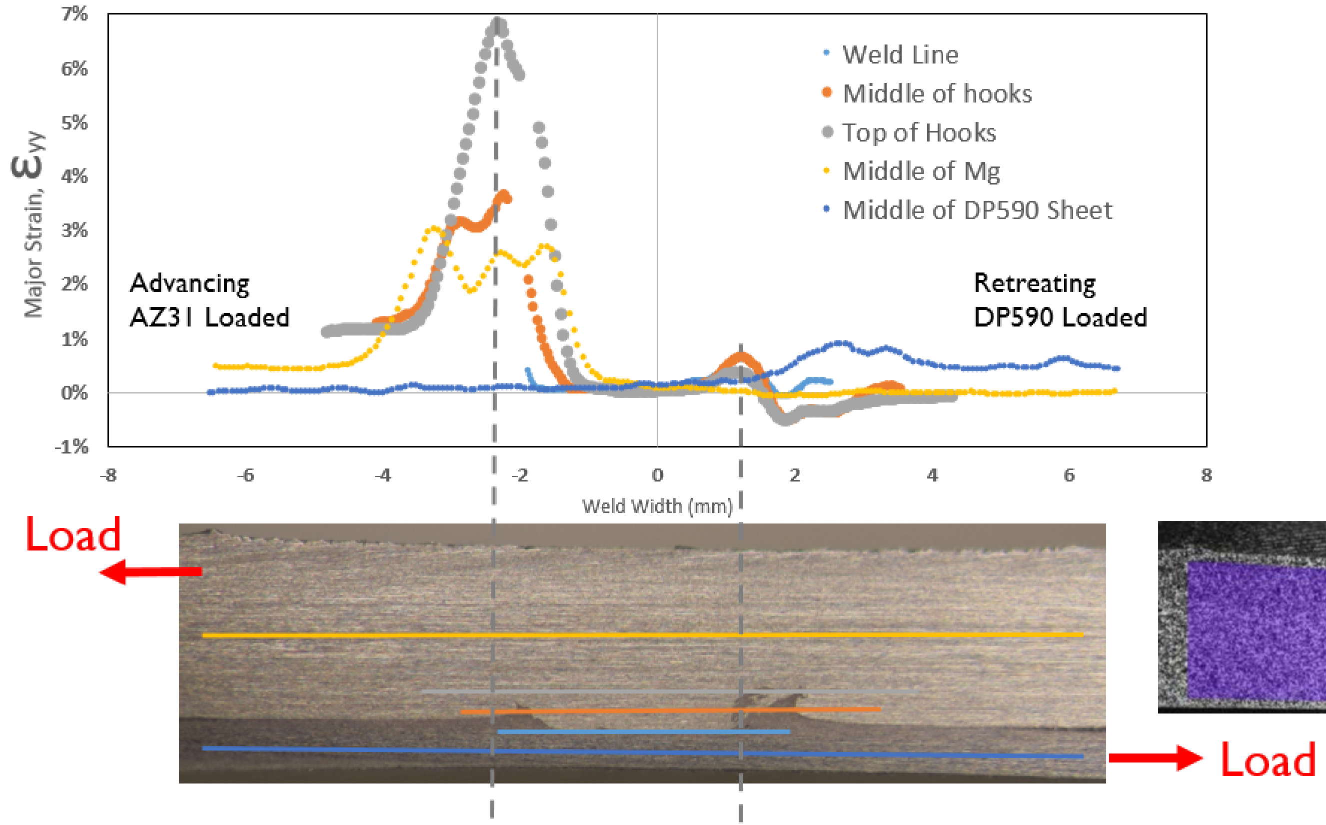
Cross-sections of several Friction Stir Scribe Joints



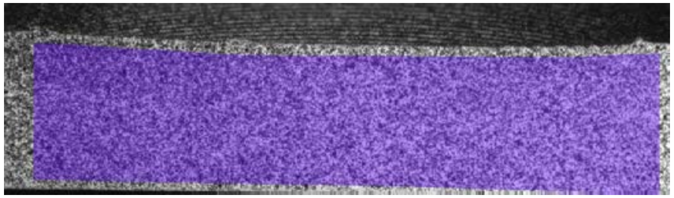


Zn diffusion up into AZ31 grain boundaries in the interface region away from the weld.

STRAIN DISTRIBUTION BEFORE FRACTURE



Video



DIC provides strain path and maps at in the joint during mechanical tests. This can be used as validation tool for interface by design model. In conjunction with Nano-indentation methods the strain at fracture can also be used to provide constitutive property of the interface.

ULTRASONIC WELDING

- Achieved metallurgical bond with a transition layer less than 7µm (1.8mm AZ31B and 1.2mm DP590)
- Achieved 3.3kN shear load (67.4MPa shear strength)