FSW & USW Solid State Joining of Magnesium to Steel

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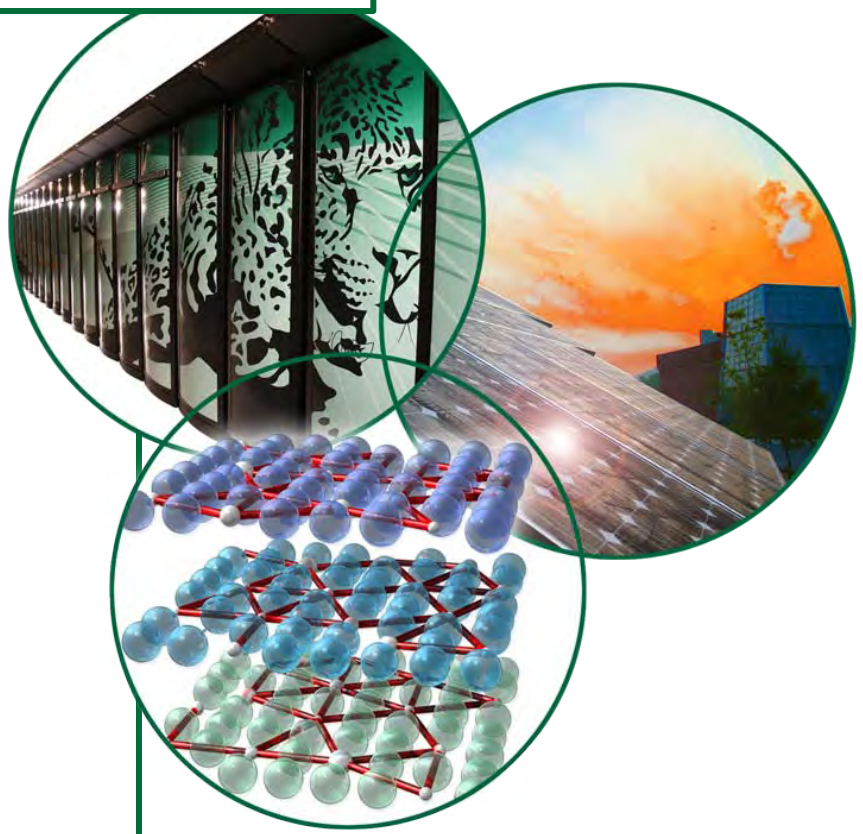

Project ID # LM031

U.S. DEPARTMENT OF ENERGY

Pacific Northwest NATIONAL LABORATORY

OAK RIDGE NATIONAL LABORATORY
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Overview

Timeline

- Start – April/May, 2008
- End – September, 2011
- 70% complete

Barriers

- Large difference in physical properties makes conventional welding impossible
- Magnesium and steel are mutually insoluble so strong bonding could be problematic
- No accepted method for metallurgical bonding

Budget

- Total project funding – $1.35M
- Funding in FY2010
  - $0.654M
- Funding in FY2011
  - $0.436M

Partners

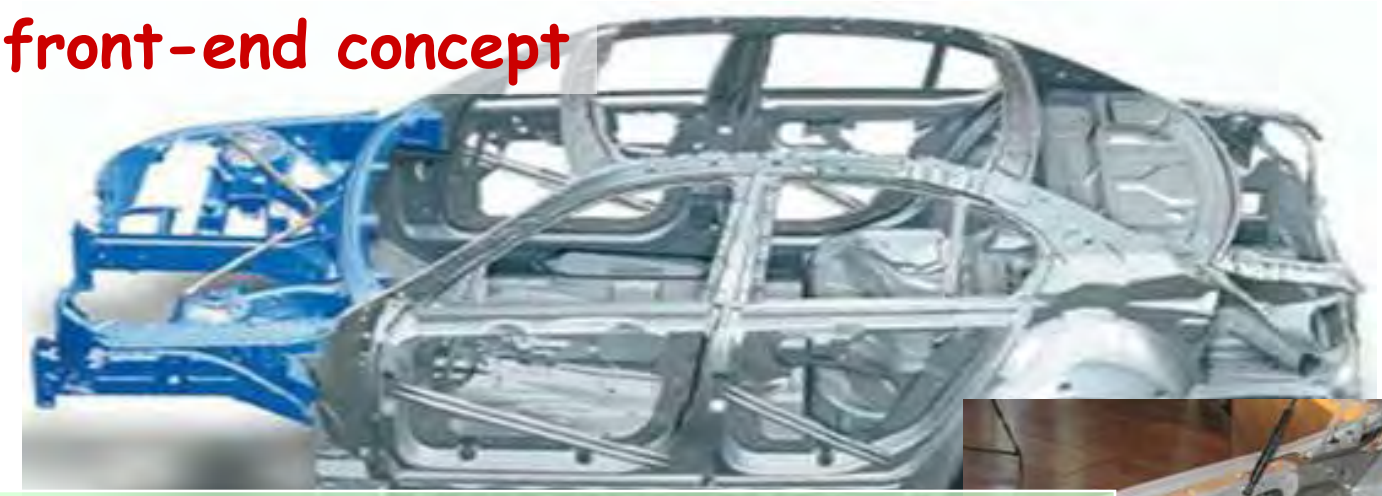
- Chrysler
- GM
- University of Michigan

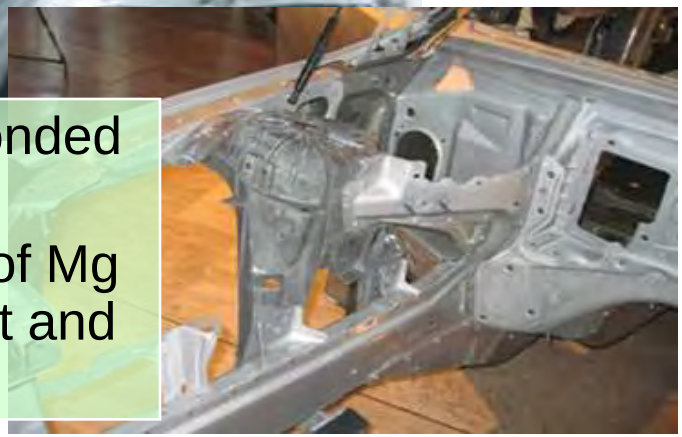
Relevance: Project Objectives

- Develop the solid-state technologies of friction stir linear and spot welding (FSW/FSSW) and Ultrasonic Spot Welding (USW) for joining Magnesium to Steel
- Develop an applied understanding of:
  - The localized metal deformation processes their importance to potential metallurgical bonding
  - How the process parameters influence joint strength, integrity, microstructures
  - How both processes interact with existing corrosion protection methods (coatings) and how they affect the overall corrosion performance

Relevance: Effective technologies for Mg-steel bonding will support strategies for vehicle weight reduction

Mg front-end concept





- Mg sheet, extrusions and castings must be bonded to steel passenger compartment
- FSW and USW can enable better integration of Mg components and provide opportunities for cost and performance improvements

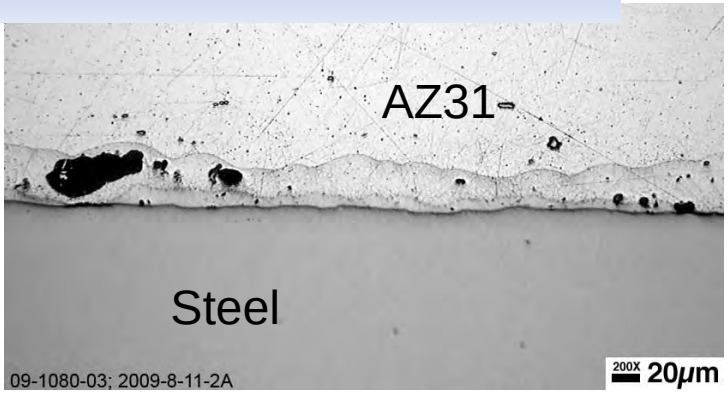
- Solid-state technologies like FSW/FSSW and USW have potential for Mg-steel welding while avoiding various metallurgical issues

Relevance: Milestones

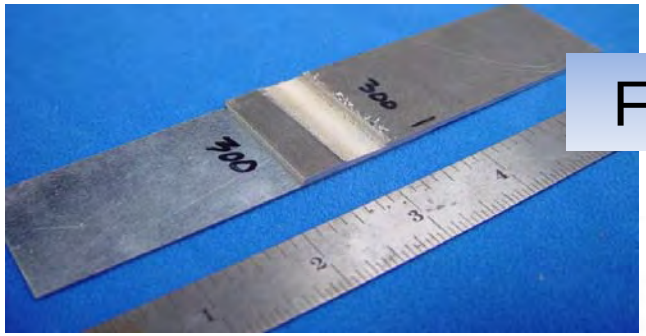
- The lap-shear strengths of USW spot welded magnesium-steel joints made with bare steel will be compared to those made with zinc-coated steel to determine the strength increase associated with chemical reactions between magnesium and zinc. The ability to achieve strength levels exceeding the Task 2 decision gate of 1.5 kN will be demonstrated. October 2010
- The stress level needed to achieve fatigue life of 10^6 loading cycles will be determined for ultrasonic spot welded lap-joints and the potential of weld-bonding with adhesives to increase the fatigue strength of magnesium-steel ultrasonic spot welded lap-joints will be demonstrated. October 2011

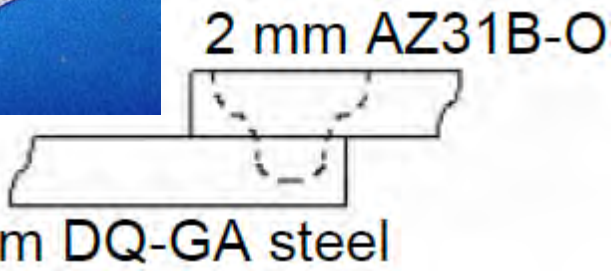
Approach/Strategy

USW microstructure



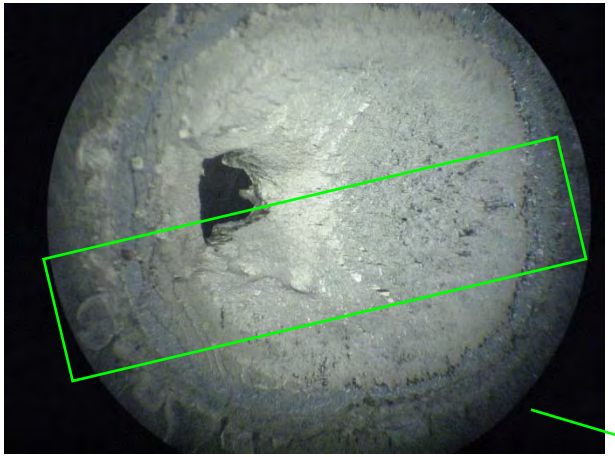
FSW Lap Joint

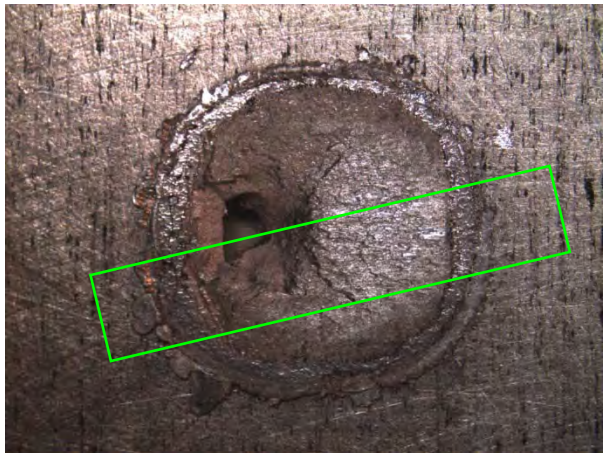




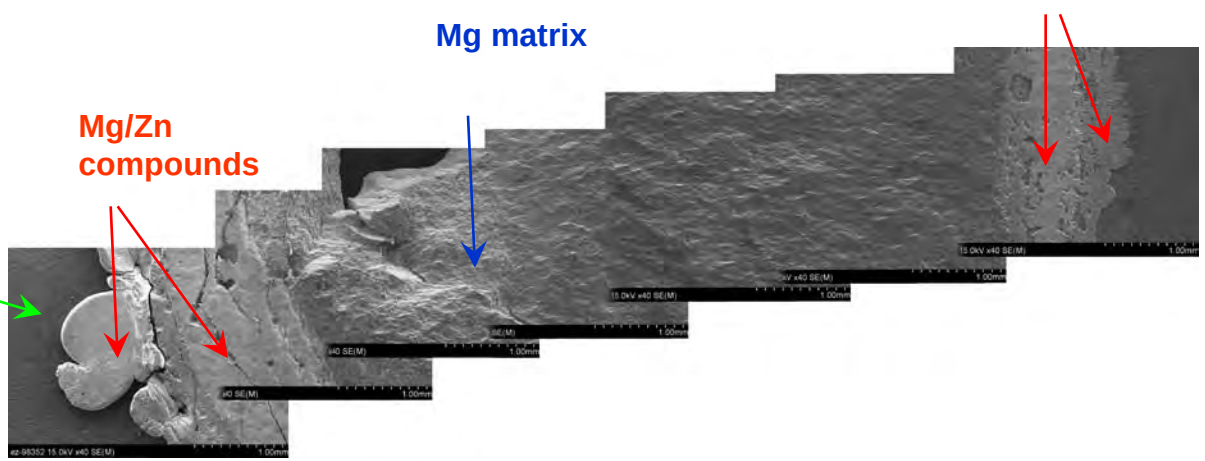
- Lap welds are emphasized due to their importance in vehicle construction
- Parametric studies guided by lap-shear strength are used to define parameters and procedures for acceptable welding
- FSW and USW tooling was developed
- Microstructure analysis is being used to determine both mechanical and metallurgical contributions to joint strengths
- Corrosion behavior and strategies for controlling it are being evaluated

FY2010 Accomplishment: Fractography confirmed details of USW spot weld failures



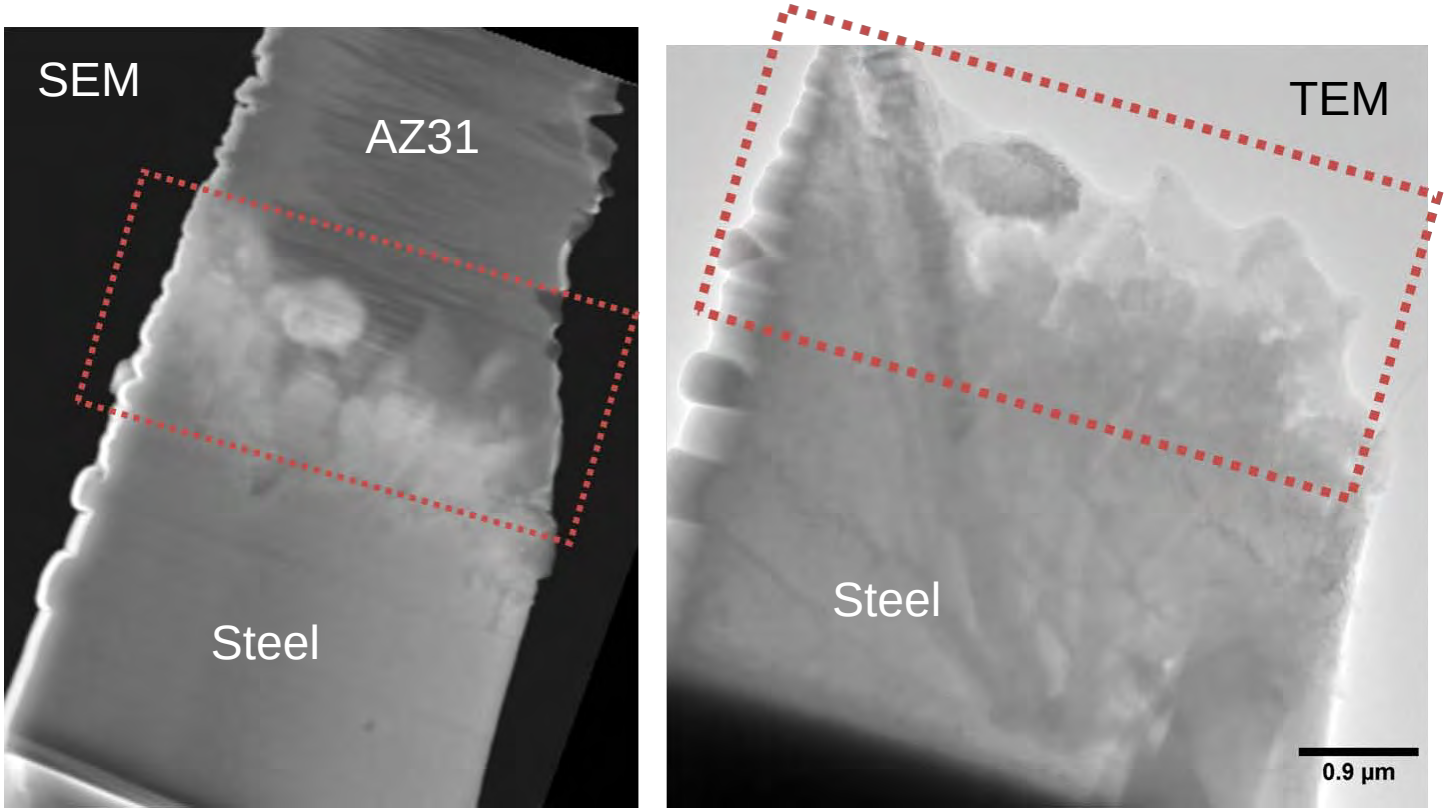


Scanning electron micrograph



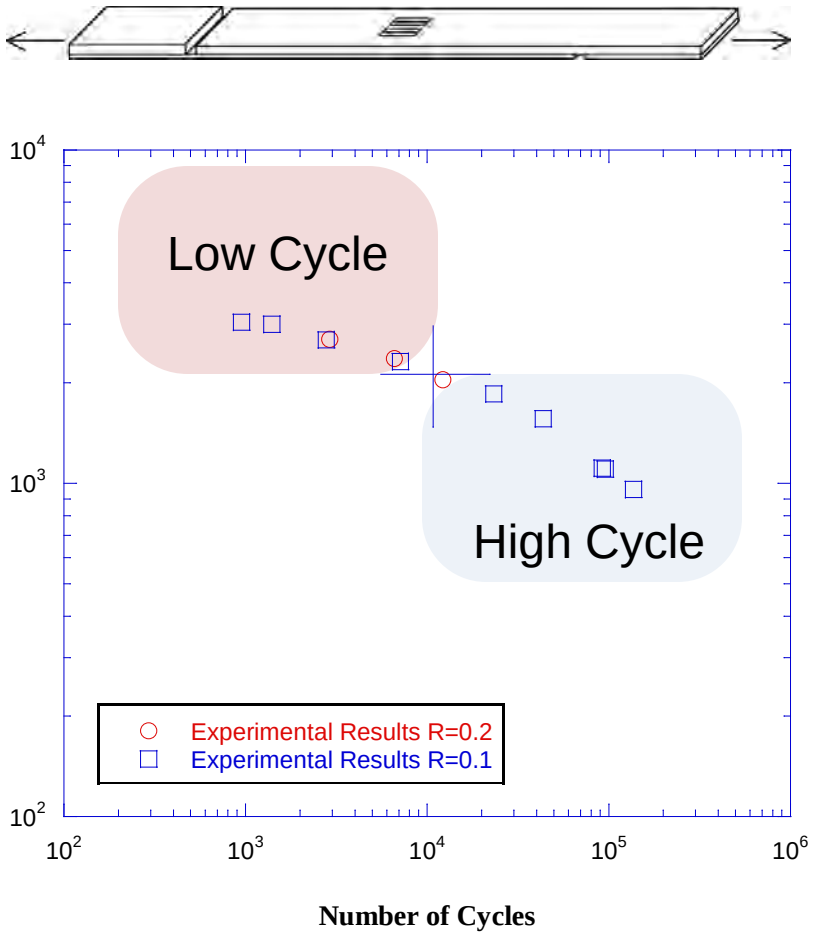
- Failure path was through AZ31 in high-strength joints
- Mg/Zn compounds are additional evidence of reactive melting between AZ31 and zinc coating on steel

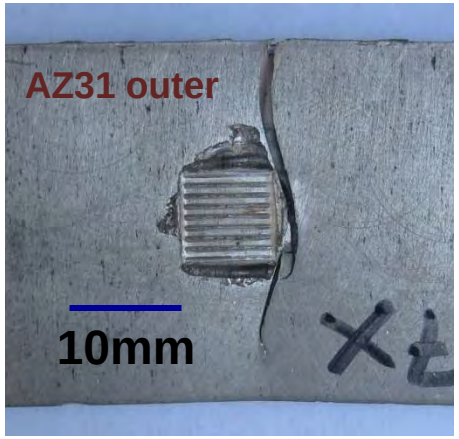
FY2010 Accomplishments: Characterization of AZ31/zinc-coated steel interface



- Interface layer (outlined) was identified as Al_6Fe by electron diffraction and microchemical analysis
- Confirms that metallurgical reactions contributed to strong bonding

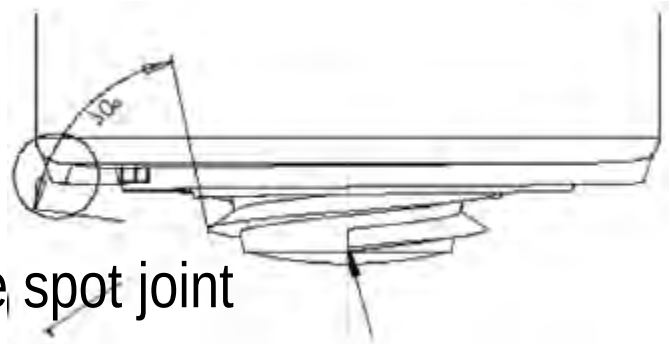
FY2010 Accomplishments: USW Spot Weld Fatigue Testing



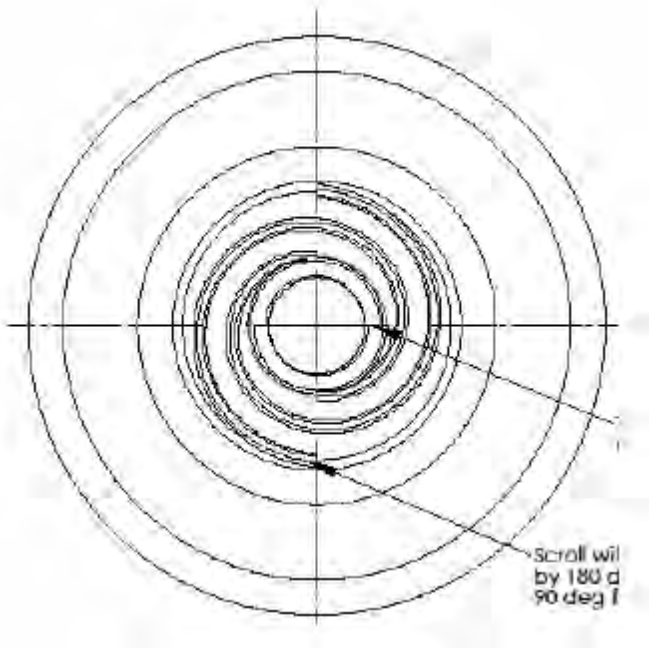


- Low-cycle (< ~10,000 Hz) fails by nugget pull-outs
- High-cycle fails through AZ31
- Additional fracture analysis is continuing
- Fatigue modeling is continuing

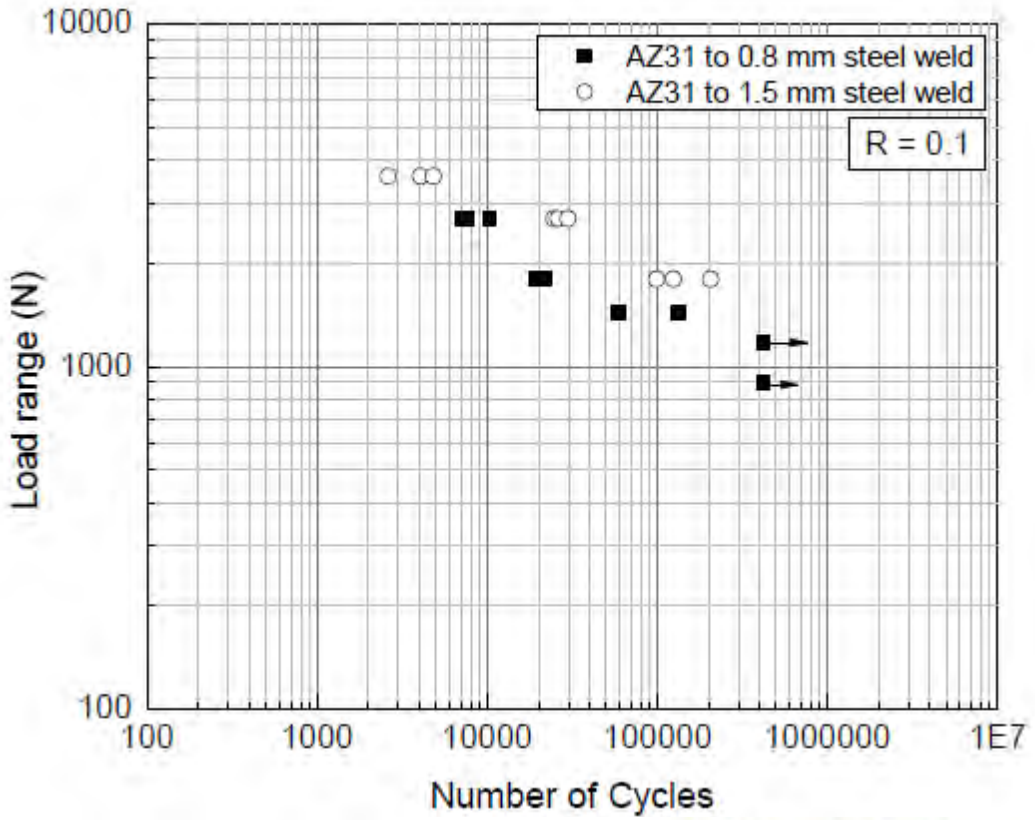
FY2010 Accomplishments: **FSSW Tooling and Parameter Development**



- Tooling Conclusions from Initial work:
  - Less convexity needed to preserve Mg in the spot joint
  - Possible benefit from more aggressive threads to drive downward
- Parameter Development
  - Goal: faster welds with comparable strength
  - Need to drive RPM (functional basis)
    - PHI: pseudo heat index
    - RPM and plunge rate
  - Plunge rates increased to more than 1 mm/s
  - Weld times reduced nearly 10x

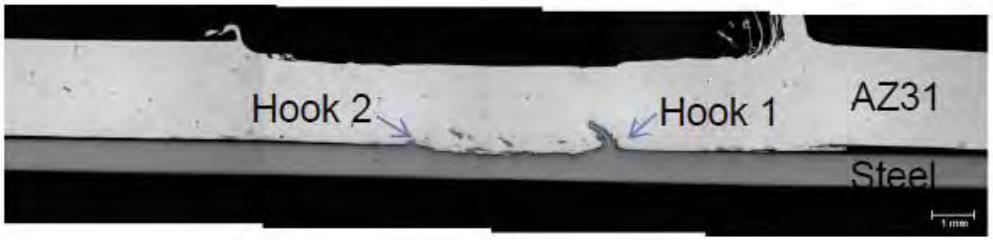


FY2010 Accomplishments: **Fatigue Test data for Mg/Steel linear FSWs**

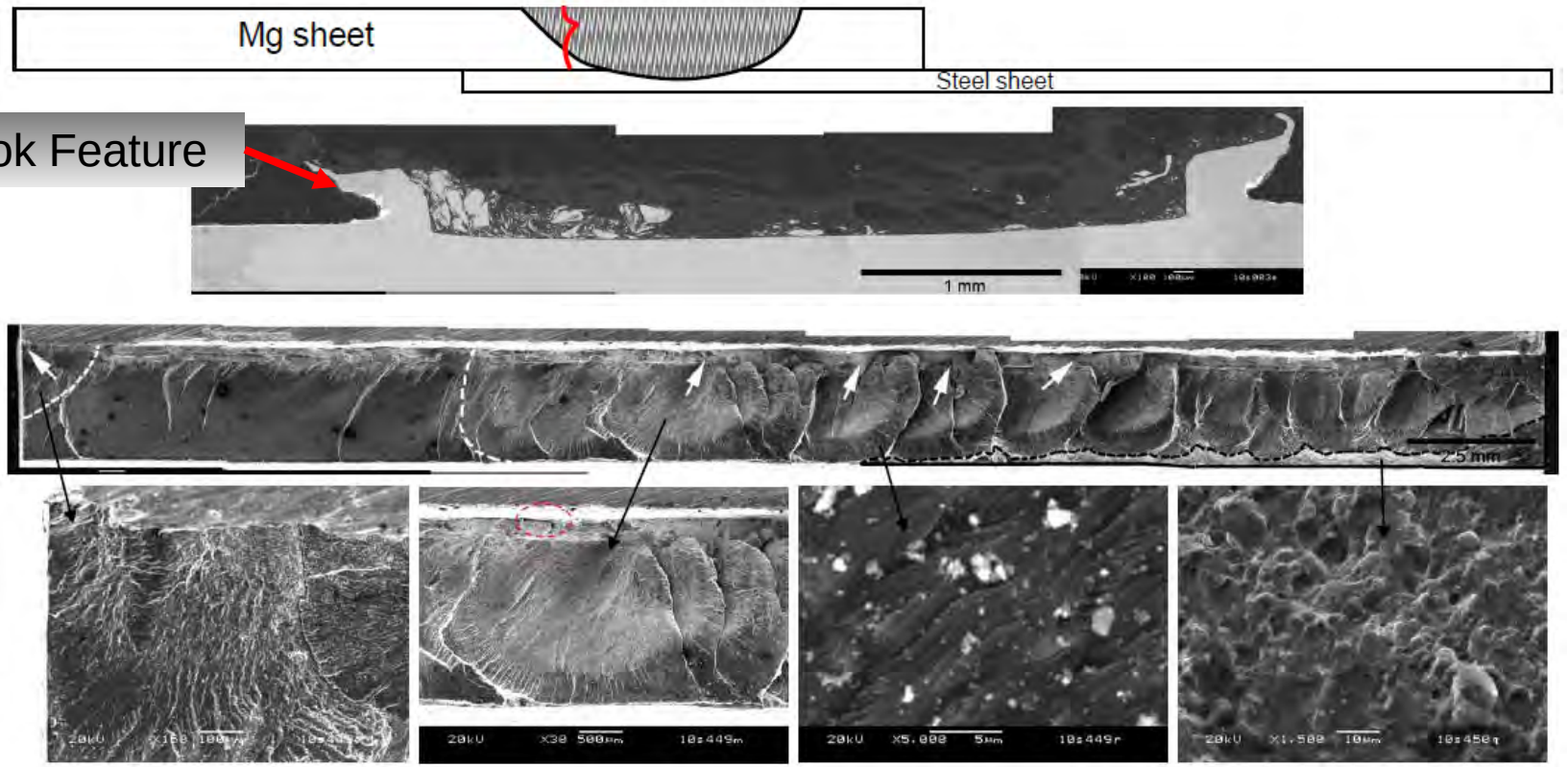


- Slight difference in fatigue lives of the two different Mg/Steel joints is due to higher failure load of HSLA steel
- Major mode of failure was fracture of top Mg sheet fracture
- Hook feature enhance strength properties

AZ 31 + 0.8 mm Steel



FY2010 Accomplishments: Fatigue Fractography Results



- Schematic (top) shows typical failure initiation site near hook feature
- as the crack propagates, numerous cracks start appearing along the Mg/steel interface (white arrows)
- Better fatigue performance is anticipated if the bottom steel sheet is uncoated

Collaborations/Coordinations

- Conference calls are regularly held with OEMs
  - Actively followed by Chrysler and GM
  - Open invitation to Ford
  - Progress is summarized
  - Guidance is provided for technical activities
- Results are shared with Magnesium Front-End Project Participants
- University Michigan (Prof. Jwo Pan) is supporting fatigue testing, analysis, and modeling

Proposed Future Work

Emphasis on corrosion performance and mitigation

- “Weld-bonding”, i.e., hybrid joints of FSW or USW coupled with adhesives
  - Adhesives could help seal joints from environmental exposures
  - Static and Dynamic testing of hybrid joints
- Welding with Mg which is pre-coated to control corrosion
  - Coated Mg will be acquired from OEMs
- Characterization of Zn thickness on corrosion behavior
- Corrosion testing per MFERD guidelines
- Mechanical testing/characterization of corrosion specimens

Summary

- Feasibility of joining Mg alloy to steel was convincingly demonstrated
  - Welding Mg to steel was initially considered virtually impossible
  - USW Mg-steel spot weld strength is comparable with strength of Mg-Mg resistance spot welds
  - Importance of zinc coating on steel for achieving high strength of USW Mg-steel spot welds was clearly demonstrated
  - Importance of tool design and process control for both linear and spot FSW was demonstrated
  - Linear FSWs have strengths exceeding those of weaker member in Mg-steel joints
  - Both USW and FSW welds have encouraging fatigue strengths