Project ID: LM062

Improving Fatigue Performance of AHSS Welds

Zhili Feng (PI), Xinghua Yu, Don Erdman and C. David Warren

Oak Ridge National Laboratory

Wenkao Hou, Steve Kelly, Benda Yan and Sriram Sadagopan

ArcelorMittal Global R&D

Overview

Timeline

- Project start date: March 2011
- Project end date: September 2014
- Percent complete: 75%

Budget

- Total project funding projection
  - DOE share: $1,250K
  - Contractor share: $650K
- Funding in FY13: $100K
- Funding for FY14: $300K

Barriers

- Barriers addressed
  - **F. Joining and assembly:** *High-volume, high-yield joining technologies for AHSSs*
  - **C. Performance:** *Durability of welded AHSS structures*
  - **D. Predictive modeling tools:** *Low cost manufacturing of AHSS structures*

Partners

- Interactions / collaborations
  - ArcelorMittal
  - Colorado School of Mines
  - ESAB
  - Stoody
  - US Army TARDEC
- Project lead
  - Oak Ridge National Laboratory

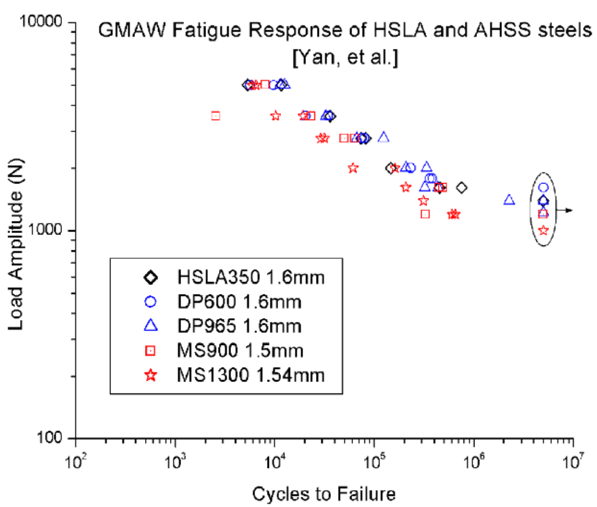
Objectives

- Establishing the technical basis and demonstrating the viability of innovative weld residual stress mitigation technology that can substantially improve the weld fatigue performance and durability of auto-body structures.

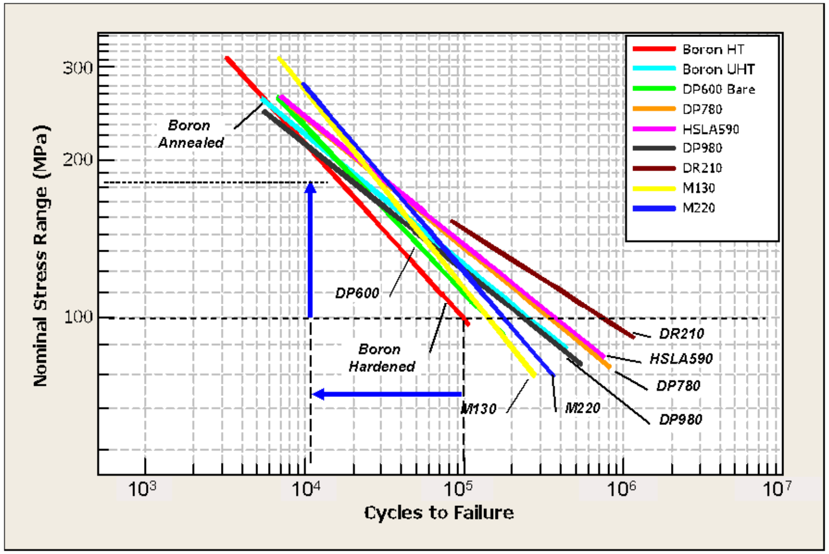
- Developing cost-effective and practical technology suitable for high-volume vehicle production environment

Relevance / Technology Gap Analysis

- Recent studies by A/SP, DOE Lightweight Materials Program and others have shown that, unlike the base metal case, welds of AHSS do not exhibit appreciable increase in fatigue strength (i.e. weld fatigue strength is insensitive to the steel type and grades of current AHSS).
- Down-gaging of AHSS for light-weighing would result in increase in applied stresses in the weld region, and potentially shorten the fatigue life and durability of body structures.
- Fatigue performance of welded joints is a critical element in durability because the likeliest fatigue failure location are often at welds
- Therefore, the use of AHSS for light-weighing must be accomplished by approaches to improve the fatigue performance of the weld joint (John Bonnen and R.M. Iyengar, 2006, Int. Auto. Body Congress).



Yan et al (SAE 2005)



Feng et al (SAE 2009)

Factors Governing Weld Fatigue Strength

- Stress concentration due to weld geometry and weld surface quality/discontinuity
  - SCF = 6-9 from FEM analysis for lap joint under tensile loading
  - Previous DOE VT project on weldability of AHSS (led by ORNL) showed feasibility of improving weld fatigue life by smoothing the weld profile to reduce stress concentration. But such approach was difficult to implement in production
- **High tensile residual stresses at the weld toe and other critical locations**
  - **Subject of this project**
- Weld microstructure change
  - HAZ softening has minimal influence, according to åprevious DOE VT project on weldability of AHSS (led by ORNL)

Approach: Improve Weld Fatigue Strength by Altering Weld Residual Stress

- Principle – Suppress the high-tensile residual stresses at the weld toe
  - Post weld treatments (such as laser shock peening) have been effectively applied in aerospace industry and air force
  - But too expensive and difficult to apply to auto body structures

- Our concept – in-process residual stress modification during welding
  - Utilizing volumetric changes due to low temperature phase transformation phase transformation (LTPT) by means of special weld filler wire
  - Applying proactive thermomechanical management during welding
    - Applicable to Al, Mg welds as well

R&D Plan

- Develop and demonstrate in-process weld residual stress control techniques (means of innovation)
  - Filler metal development based on LTPT principle, considering the strength matching to different AHSS, alloying effect, and other factors unique to AHSS and auto industry
  - In-process pro-active thermomechanical management – specific to auto environment
  - Applying integrated weld process modeling to accelerate the development
  - Gleeble test to experimentally determine the phase transformation temperature as function of alloying

- Residual stress measurement (confirming the root cause)
  - Neutron diffraction, X-Ray and hole drilling measurement of residual stress around the weld
  - In-situ synchrotron diffraction and in-situ laser inteferometric measurement of stress development during welding

- Fatigue testing (confirming the end results)
  - Extensive coupon level tests
  - Selected component level test

Milestones

Phase 1 (03/11 to 02/12)

- Literature review
- Baseline study of LTPT technique
- LTPT candidate alloy composition – first round

Phase 2 (03/12 to 9/13)

- Weld residual stress measurement – first round
- LTPT weld fatigue life testing and validation – first round
- Proactive RS management concept design

Completed

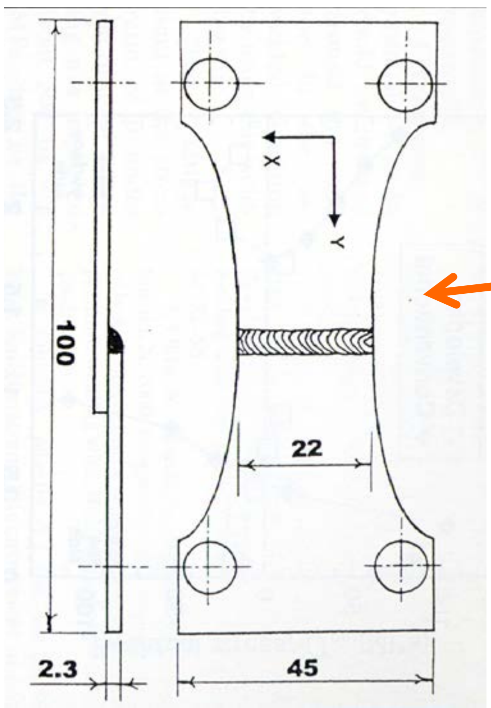
Phase 3 (09/13 to 09/14)

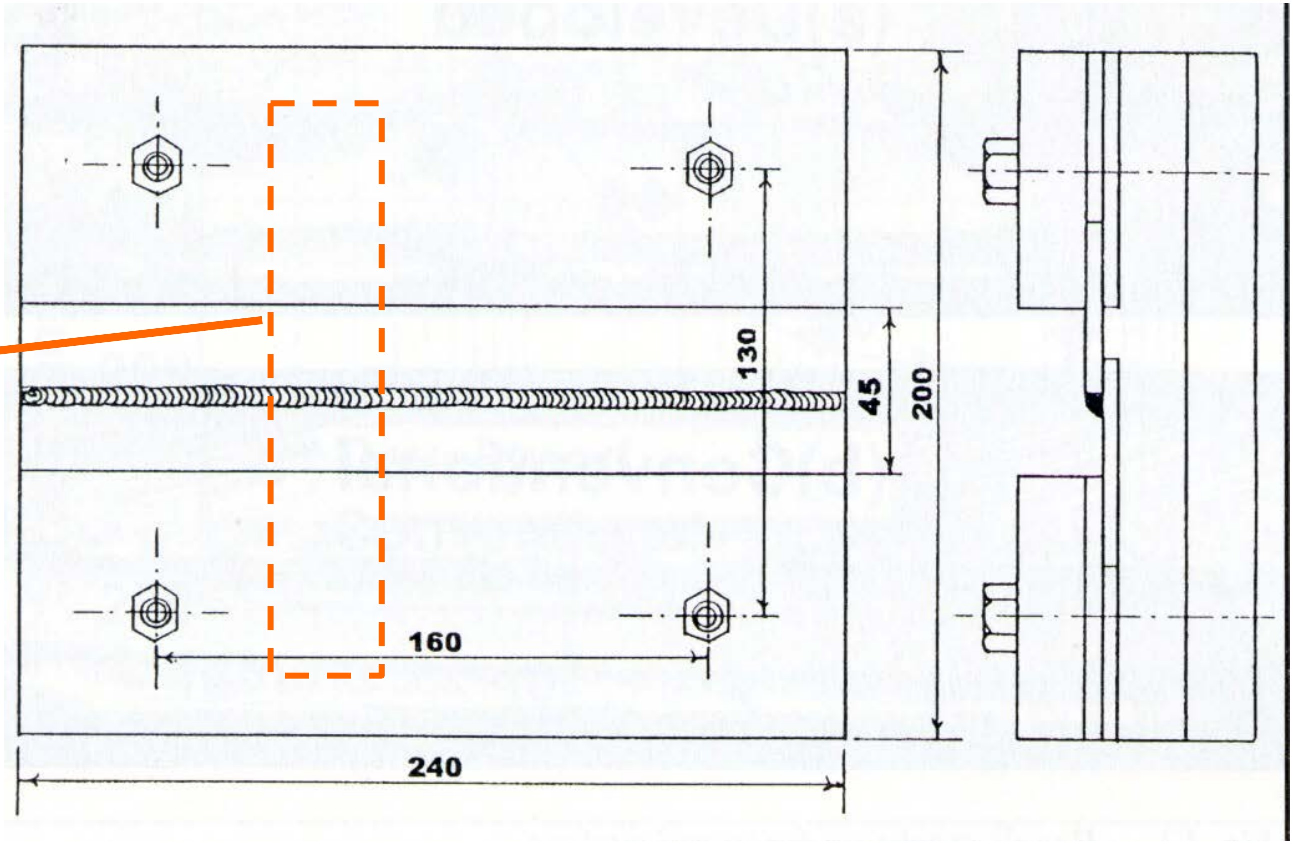
- LTPT filler metal - round two
- Proactive RS demonstration
- BIW fatigue CAE tools

In-progress

LTPT – Low-temperature phase transformation
RS – Residual stress
BIW – Body-in-white
CAE – Computer-aided engineering

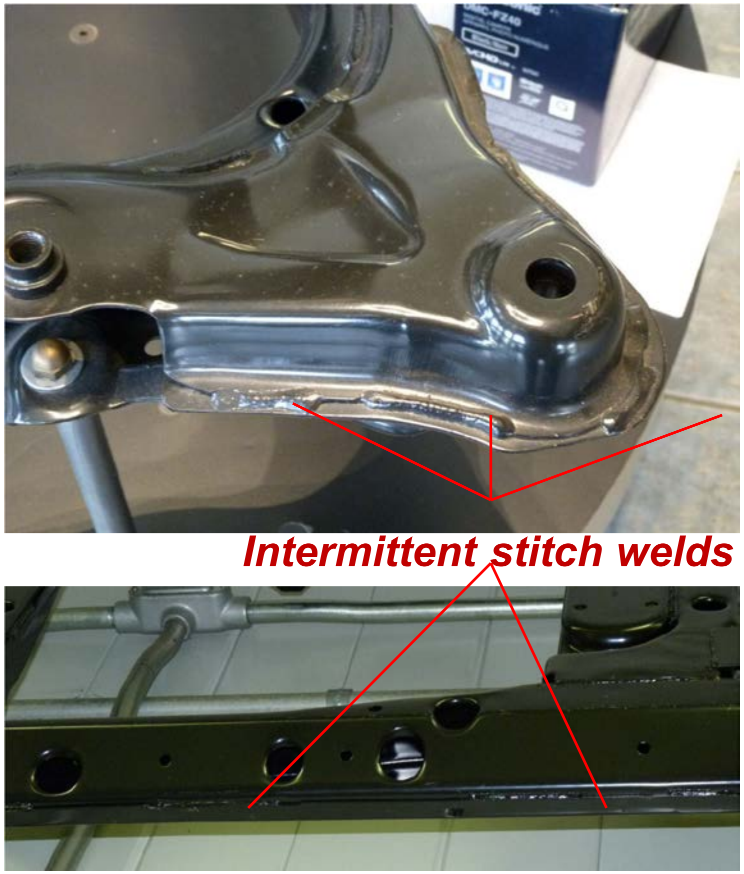
Issue: Typical Weld Fatigue Test Specimen Configuration in Previous Study May Not Retain Weld Residual Stress of The Weld Region



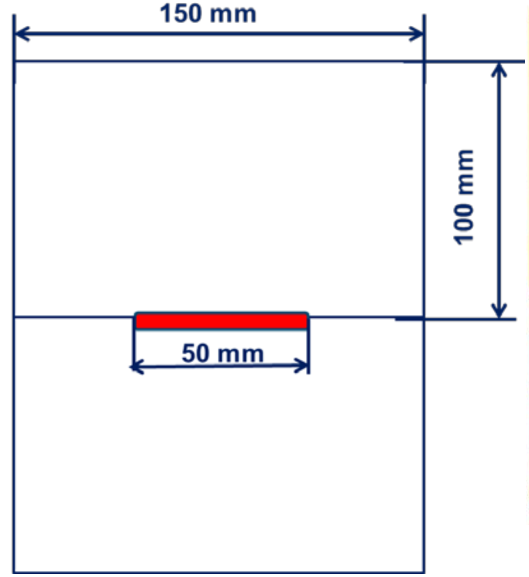


A. Ohta, et al. 2003.

Weld Fatigue Sample Design based on Industry Survey



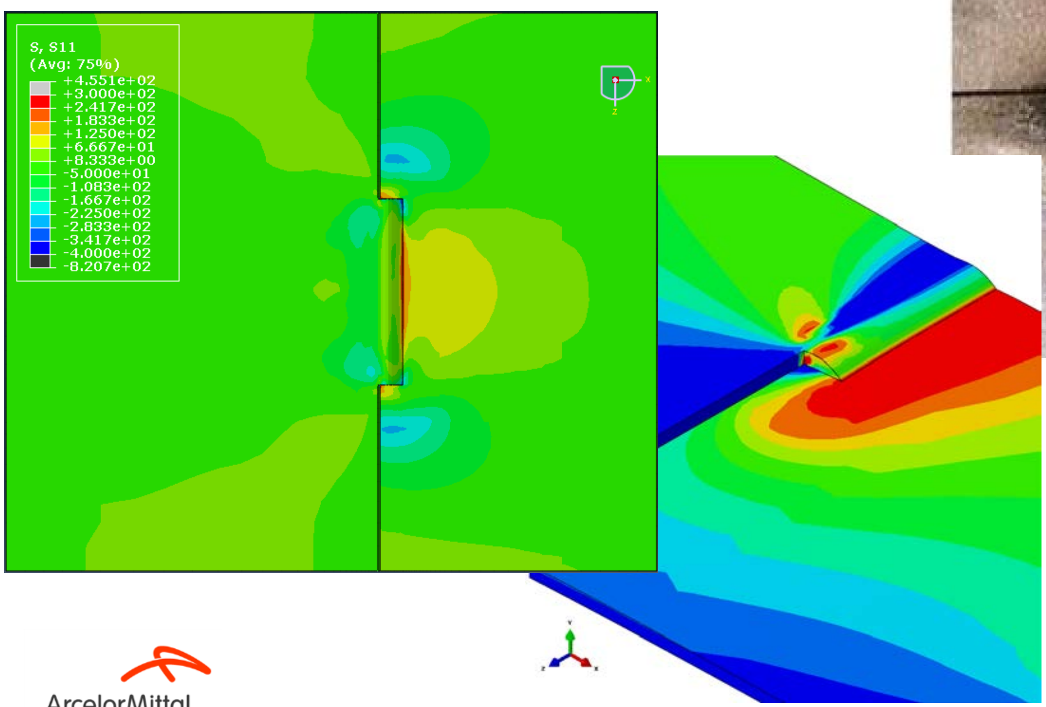
Surveyed major automotive original equipment manufacturer (OEMs) to identify weld patterns representative of those in vehicle AHSS structures

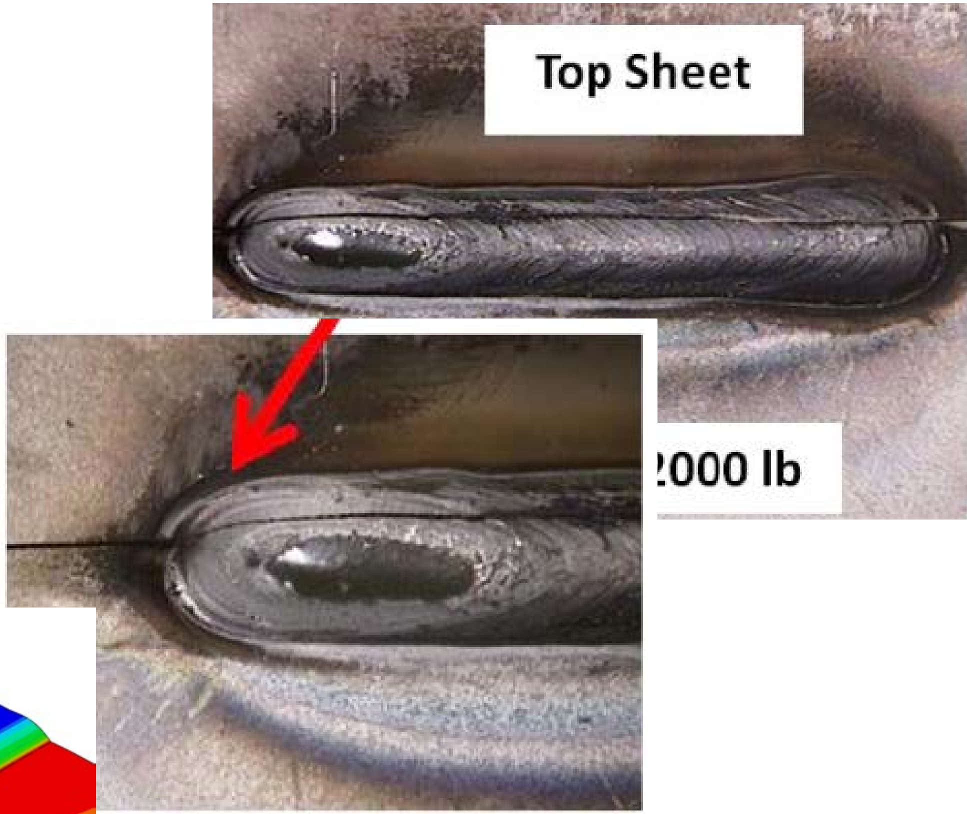


- Designed weld fatigue test sample that mostly resembles the actual stress/strain conditions in vehicle structures
- Based on lap joint, i.e., the most commonly used weld type in automotive structures
- Robotic gas metal welding system with cold metal transfer commonly used for BIW

Accomplishment: Understanding Weld Failure under Fatigue Loading by Modeling & Experiments

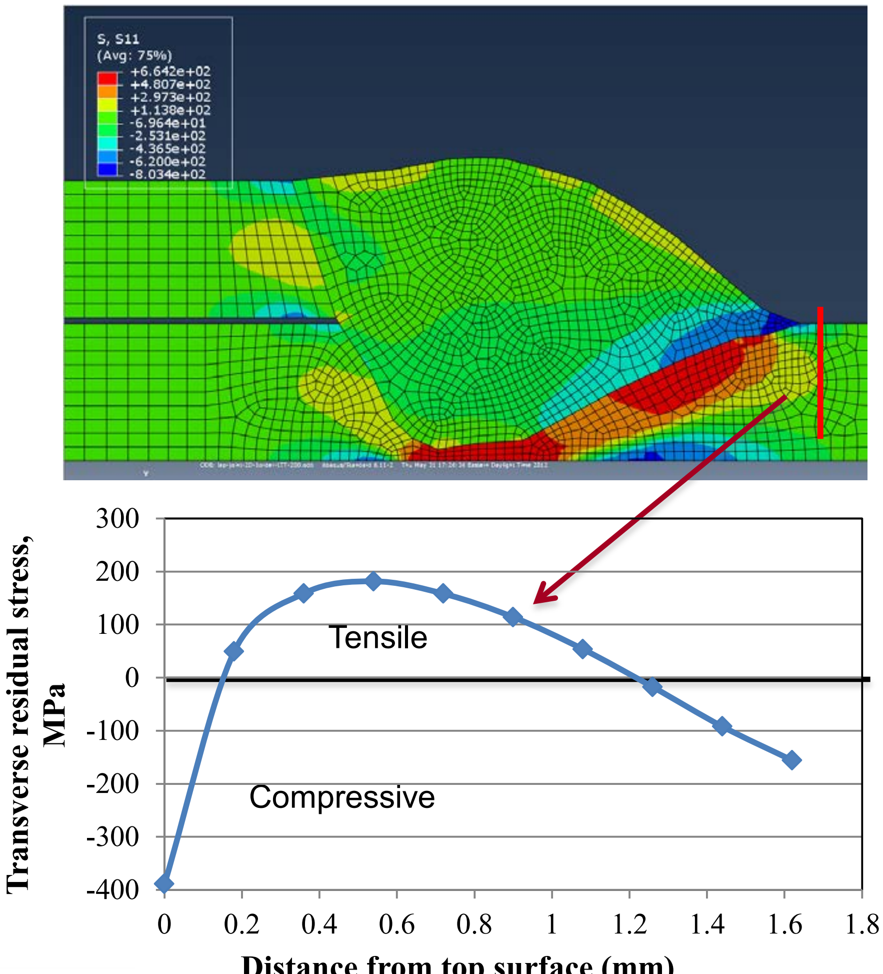
- Revealed the dominant role of weld start and stop in controlling fatigue failure in short stitch welds in BIW structures
- Presented unique challenges in managing stresses





Accomplishment: Understand the Mechanisms through Integrated Weld Process-Microstructure-Proerty Modeling

- Systematically evaluated the effect of LTPT on weld residual stress



Compressive transverse weld residual stress near weld toe

Transverse WRS along thickness direction shows similar trend with measurement from literature*

Longitudinal residual stress in the fusion zone is also compressive

The effect on the weld root side is less profound

*Ohta, 2003

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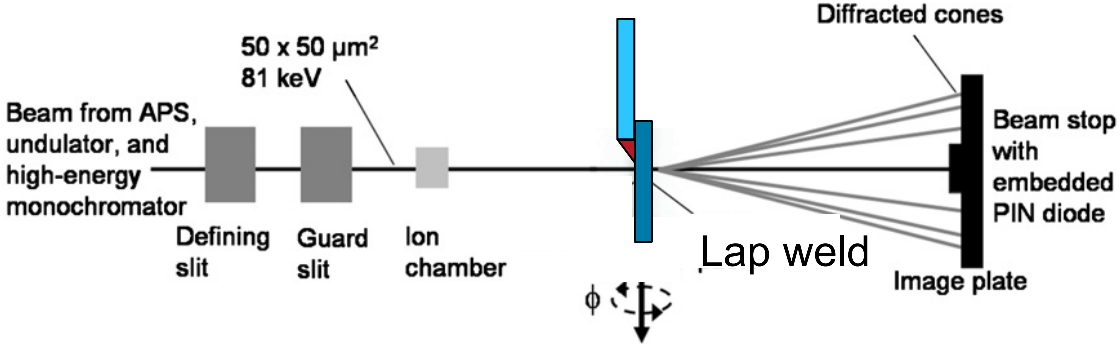
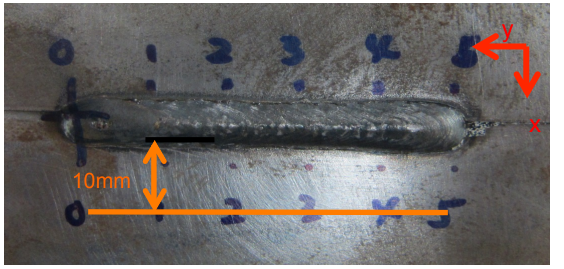
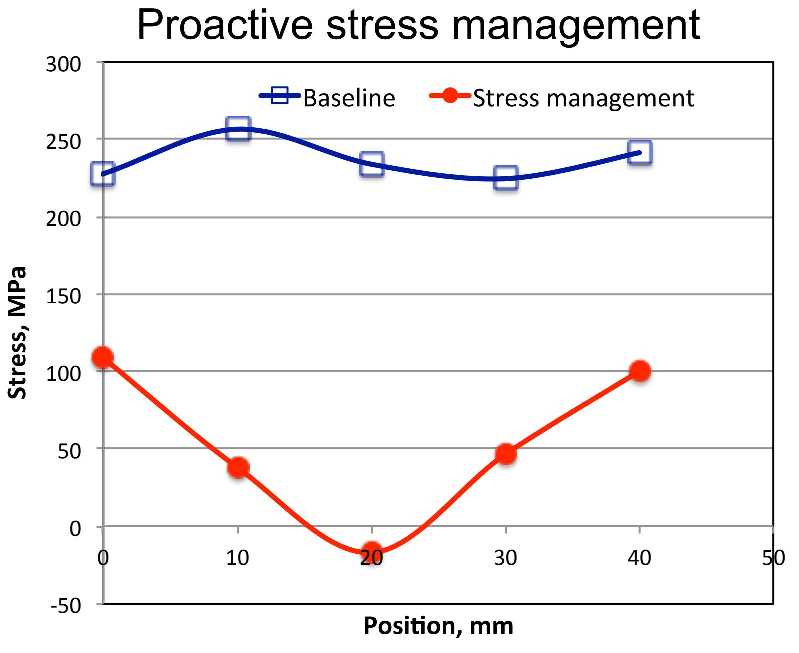
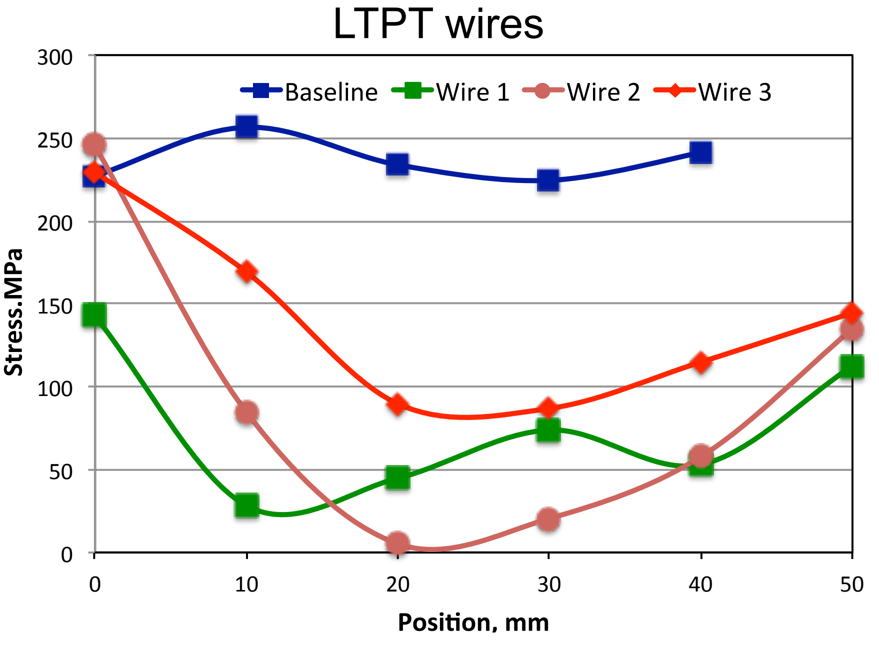
Accomplishment: High-Energy Synchrotron X-Ray Measurements Confirmed the Residual Stress Modification Approach

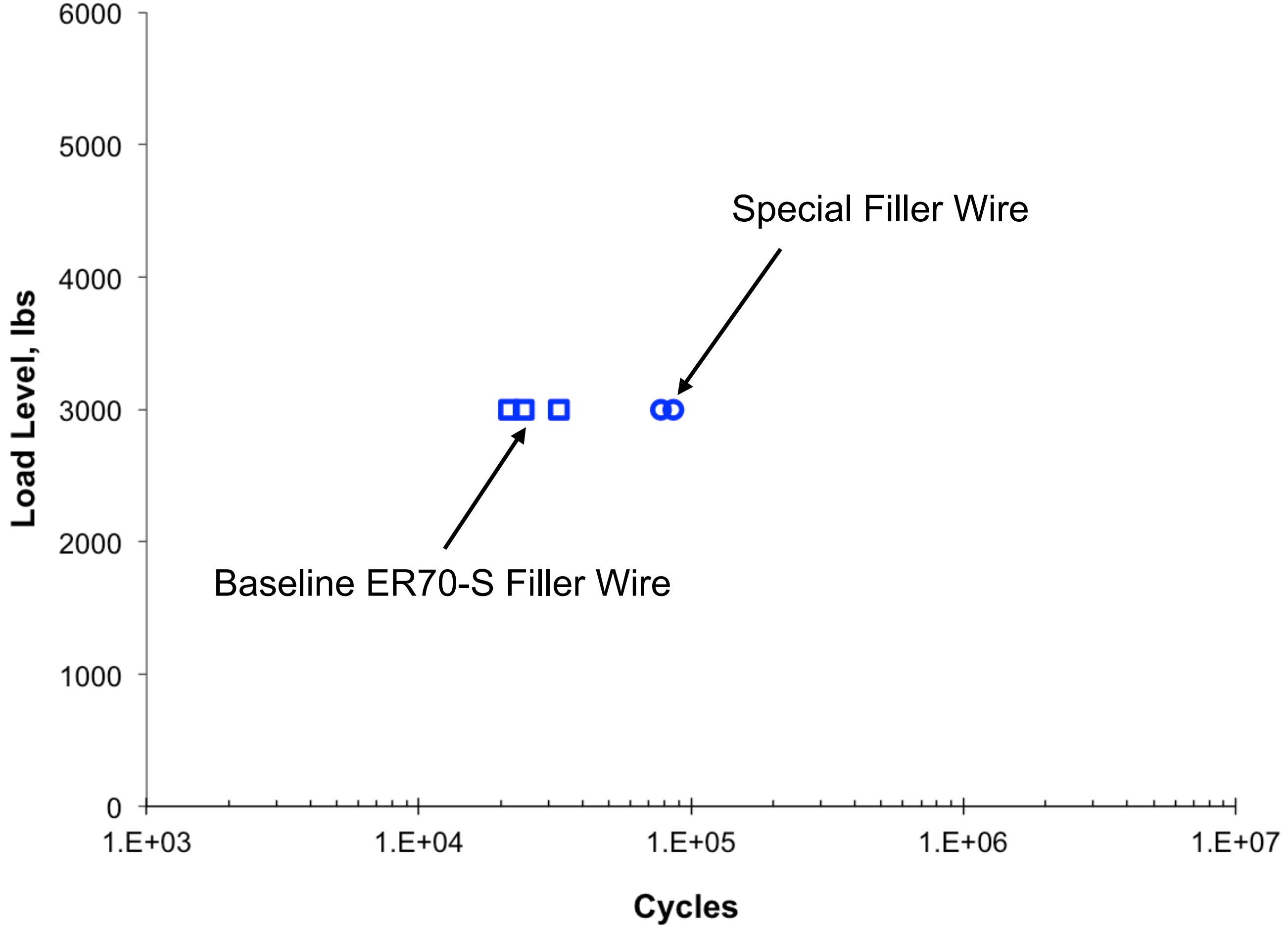








Accomplishment: Development of Special Weld Wire (Second Round, On-going)



Initial data at 1 load level (DP980). Testing on-going

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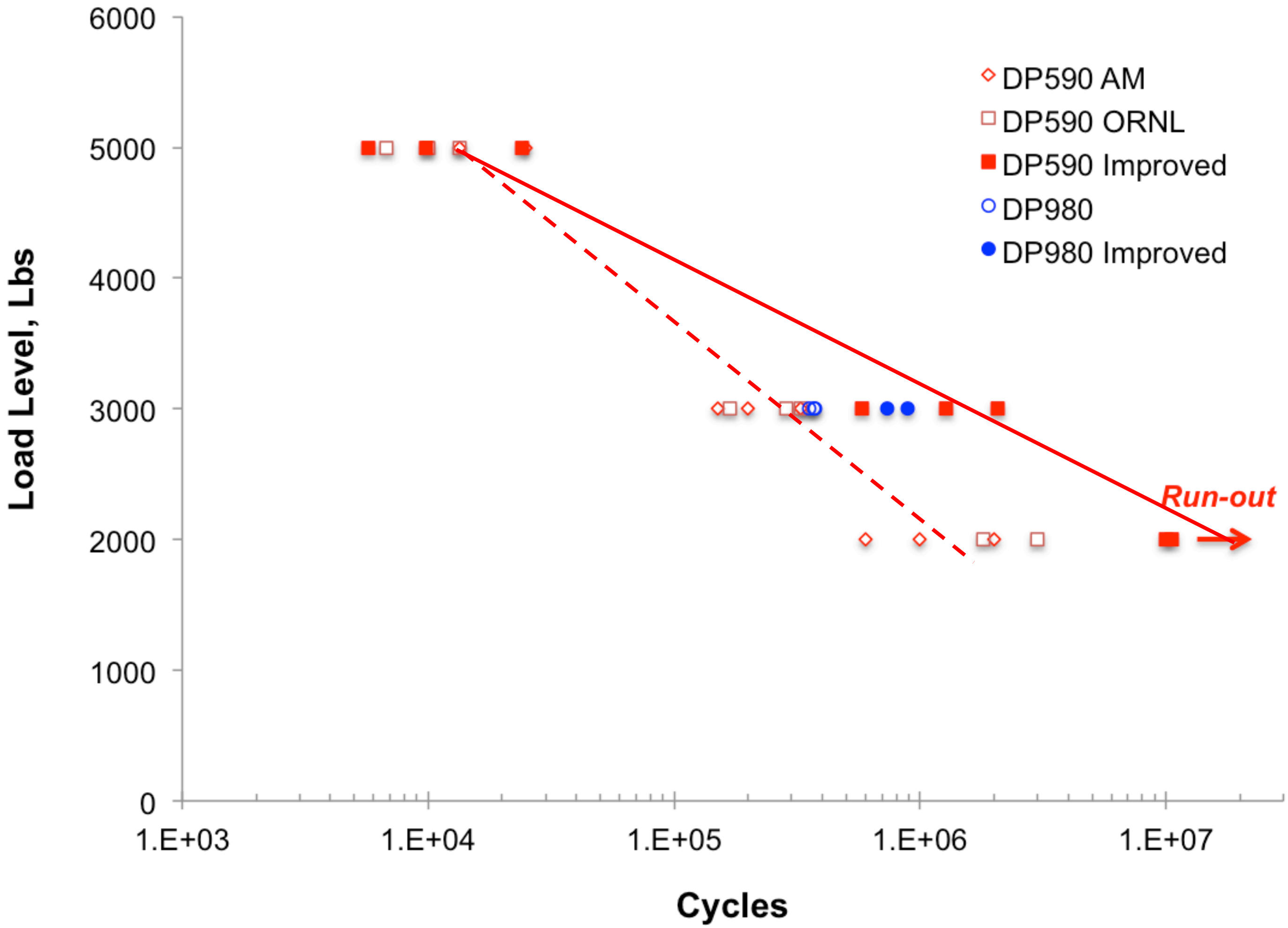
Accomplishment: Weld Fatigue Life Improvement by Proactive Stress Management (Proof-of-Concept Results)



Implementation strategy in production environment need to be developed

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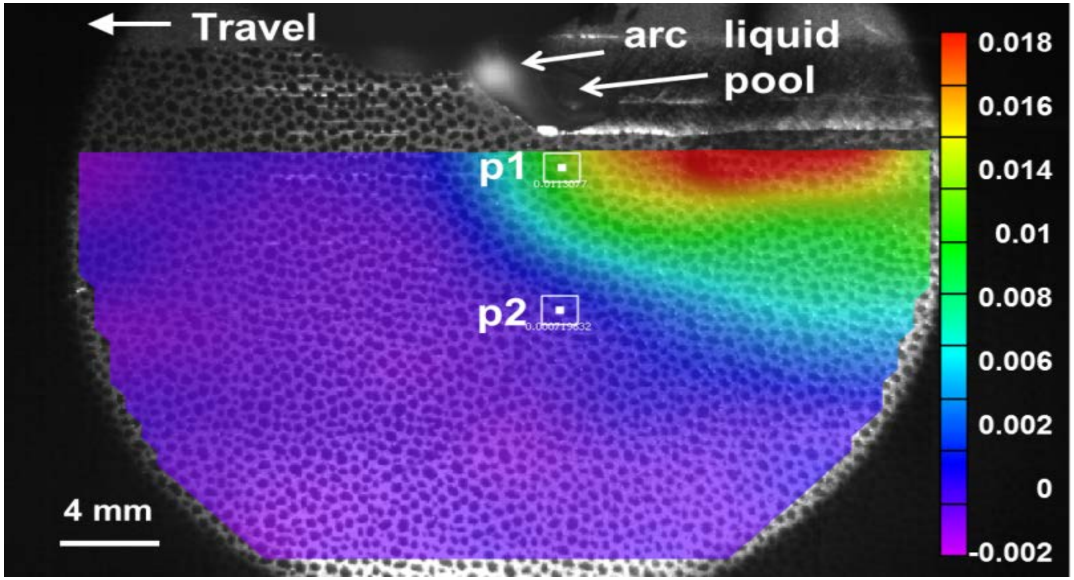
Accomplishment: In-Situ Strain Measurement during Welding

- A special digital image correlation (DIC) based high-temperature strain measurement technique has been developed to directly measure the strain field during welding all the way to the fusion line
- This technique will be utilized to quantify the benefits and assist the further development of the stress management techniques in this project



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Responses to Previous Year Reviewer's Comments

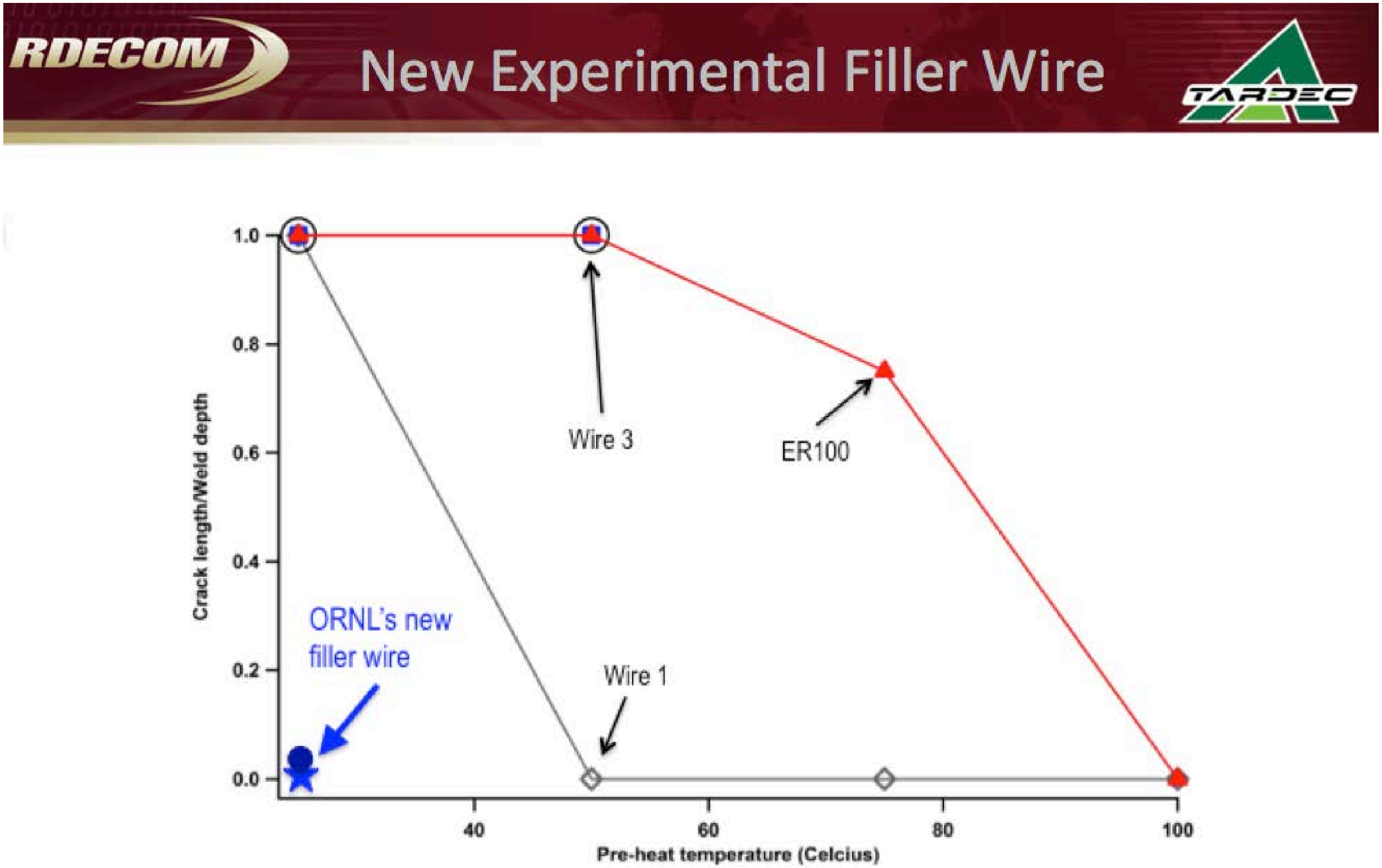
- ***There was little discussion on how the different filler materials were chosen, nor the thermo-mechanical weld process control concepts for improving fatigue life.***
  - *Specific details of the filler material and the thermo-mechanical control are protected under CRADA, and cannot be disclosed this time.*

- ***The lack of progress over the last 12 months (FY12) indicates to the reviewer that something is not going right***
  - *The unique weld residual stress distribution in the short stitch welds presented an unexpected challenge. As such, only marginal improvement in weld fatigue life was achieved with the first round LTPT wire in FY12. Our modeling and experiment work in FY12 and FY13 has led to a fundamental understanding of the residual stress distribution. Accordingly, strategies to control the residual stresses were refined and revised in FY13, which resulted in remarkable substantial improvement in weld fatigue life reported herein.*

Collaboration and Coordination with Other Institutions

- ArcelorMittal
  - Fabricating welds
  - Fatigue testing
  - Residual stress measurement by X-ray diffraction
  - Technology transfer and commercialization
- Colorado School of Mines
  - Fundamentals of LTPT filler metal chemistry
- ESAB/Stoody
  - Fabrication of LTPT filler wires based on provided chemistry
- US Army
  - Technology development and application for lightweighting of armored vehicles (weld hydrogen induced cracking and fatigue)

Collaborative Effort: Supporting Lightweighting of Armored Vehicles



- ORNL's new filler wire is nearly HIC free at room temperature

Future Work

- Apply in-situ high-temperature DIC techniques to quantify and further refine the residual stress control techniques in this project
- Complete the second round special weld wire development and fatigue testing
- Demonstrate the feasibility of proactive thermo-mechanical stress management technique for a specific prototype component
- Develop CAE based guidelines to apply the technologies in automotive body structure fabrication

Summary

- Relevance
  - Novel weld residual stress control technology to substantially improvement the weld fatigue and durability of AHSS body structures
- Approach
  - In-process weld residual stress modification through the use of special weld wires and proactive thermo-mechanical stress management techniques.
- Technical Accomplishments
  - Developed fundamental understanding and identified unique factors of the weld residual stress distribution in short stitch welds commonly used in auto body chassis structures by integrated weld process and performance model and experimental observation
  - Demonstrated substantial weld fatigue life improvement by means of special weld wire.
  - Demonstrated substantial weld fatigue life improvement by means of proactive residual stress management technique in proof-of-concept experiment.
- Collaborations
  - On-going effort to expand the approach for hydrogen induced cracking and weld fatigue life improvement for lightweighting of armored vehicles (supported by US Army TARDEC)