Project ID: LM062

Improving Fatigue Performance of AHSS Welds

C. David Warren (PI),
Zhili Feng (Presenter), Dongxiao Qiao,
Wei Zhang, and Xinghua Yu
Oak Ridge National Laboratory

Benda Yan and Wenkao Hou
ArcelorMittal Global R&D

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Overview

Timeline

- Project start date: March 2011
- Project end date: September 2014
- Percent complete: 50%

Budget

- Total project funding projection
  - DOE share: $1,350K
  - Contractor share: $650K
- Funding received in FY12: $450K
- Funding for FY13 (expected): $250K

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

AHSS – Advanced high strength steel

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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).

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

- **High tensile residual stresses at the weld toe and other critical locations**

- Weld microstructure change
  - HAZ softening has minimal influence

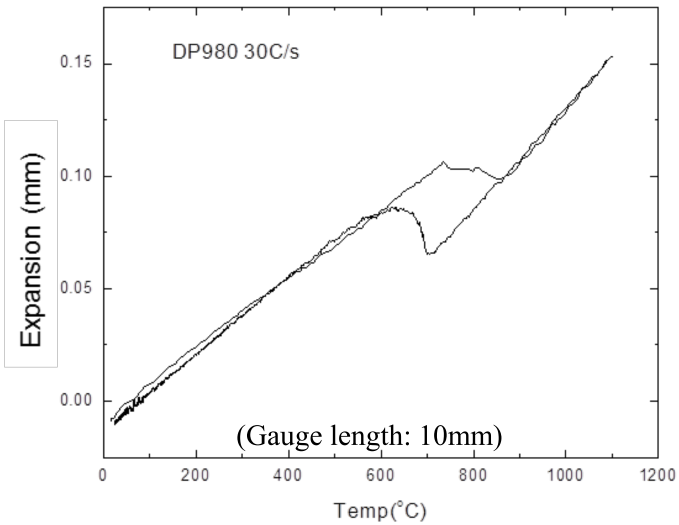
Approach: Improve Weld Fatigue Strength by Altering Weld Residual Stress

- Principle - Create compressive 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 industry

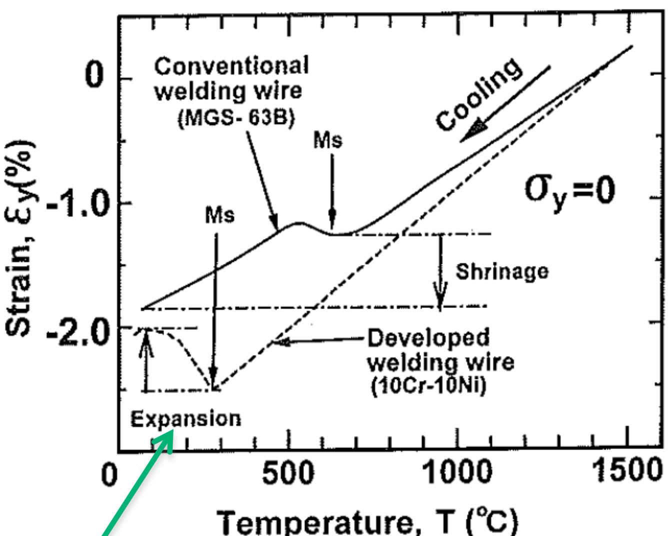
- Our concept – in-process residual stress modification during welding
  - Utilizing volumetric changes due to low temperature phase transformation phase transformation (LTPT) by means of special filler metal
  - Proactive thermomechanical management during welding
  - Applicable to Al, Mg welds as well

Technical Basis: Principles of LTPT for Weld Residual Stress Control

- Utilize volume expansion during martensitic transformation to reduce weld residual stress in critical region



Base metal: phase transformation accrues at high temperature* (about 700 °C in this material)



LTT filler metal: phase transformation accrues at low temperature(about 300 °C in this material)

Low temperature expansion will compensate thermal shrinkage and induce compressive stress

*Dilatometric analysis of phase transformation behavior DP980 steel heated at 30C/s by Z. Yu, Z. Feng, W. Zhang, et al, ORNL
**A. Ohta, K. Matsuoka, N. T. Nguyen, Y. Maeda and N. Suzuki: 'Fatigue strength improvement of lap welded joints of thin steel plate using low transformation temperature welding wire', Weld. J. 2003, 82, 77s–83s.

Technical Basis: Effectiveness of LTPT on Weld Fatigue Life

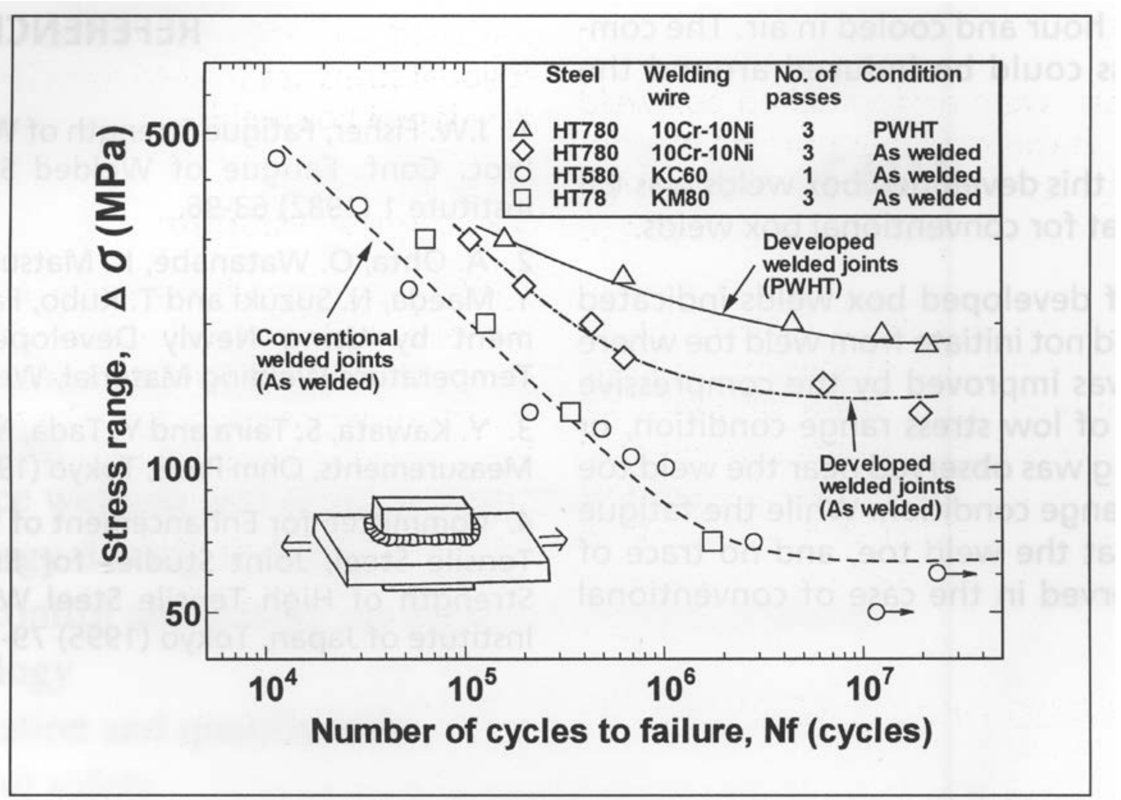


Fig. 6. S-N diagram of box welded joints.

Ohta et al, 2000

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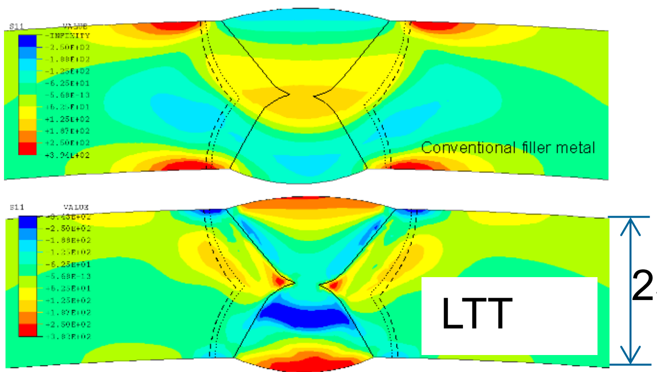
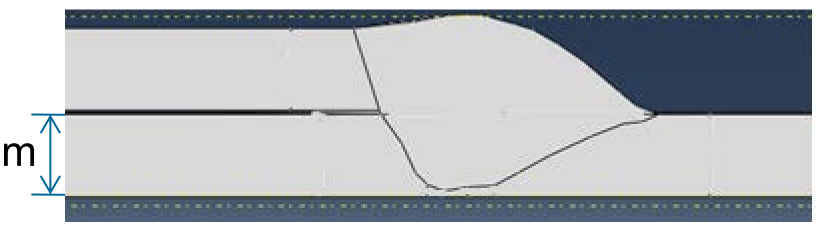
Technology Gap

- Most research focused on thick section butt weld;
- Applicability of weld joint configurations specific to auto BIW is not established





Feng et al., 2002

The difference:

Mechanical constraint and heat sink:

Factors influencing weld residual stress

Proposed Work and Technical Approach

- 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

Completed

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
- Proactive RS management system prototype

In progress

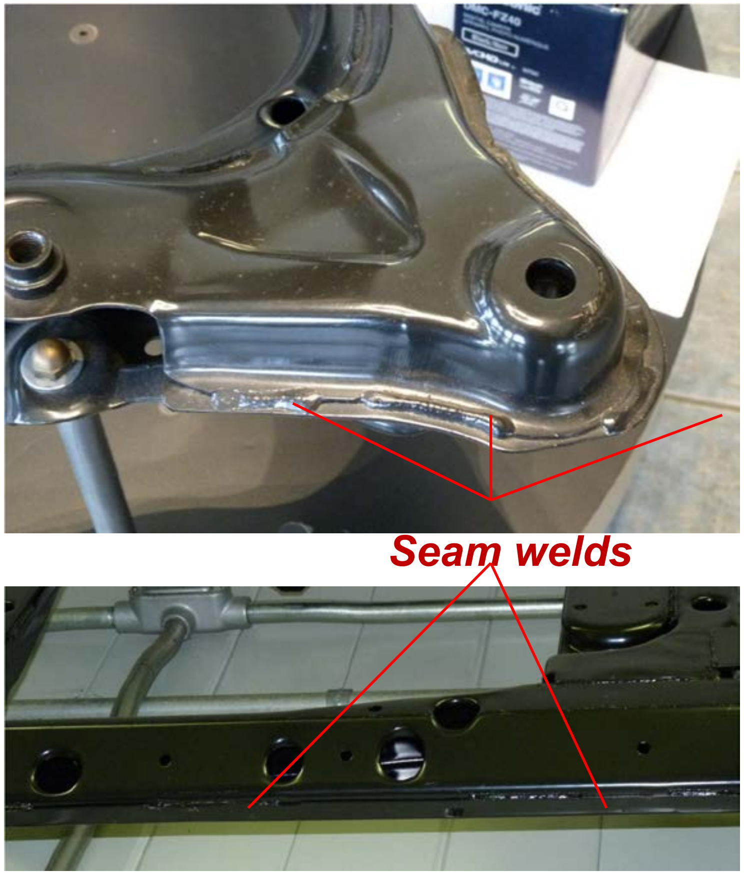
Phase 3 (09/13 to 09/14)

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

Started

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

Weld Fatigue Sample Design based on Automotive Industry Survey (FY2011 Work)



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

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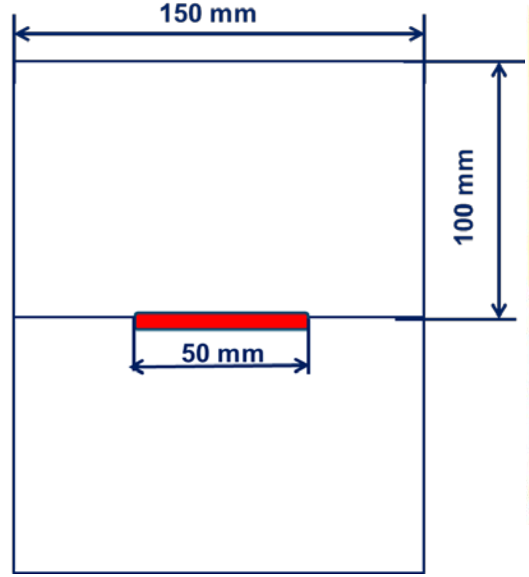
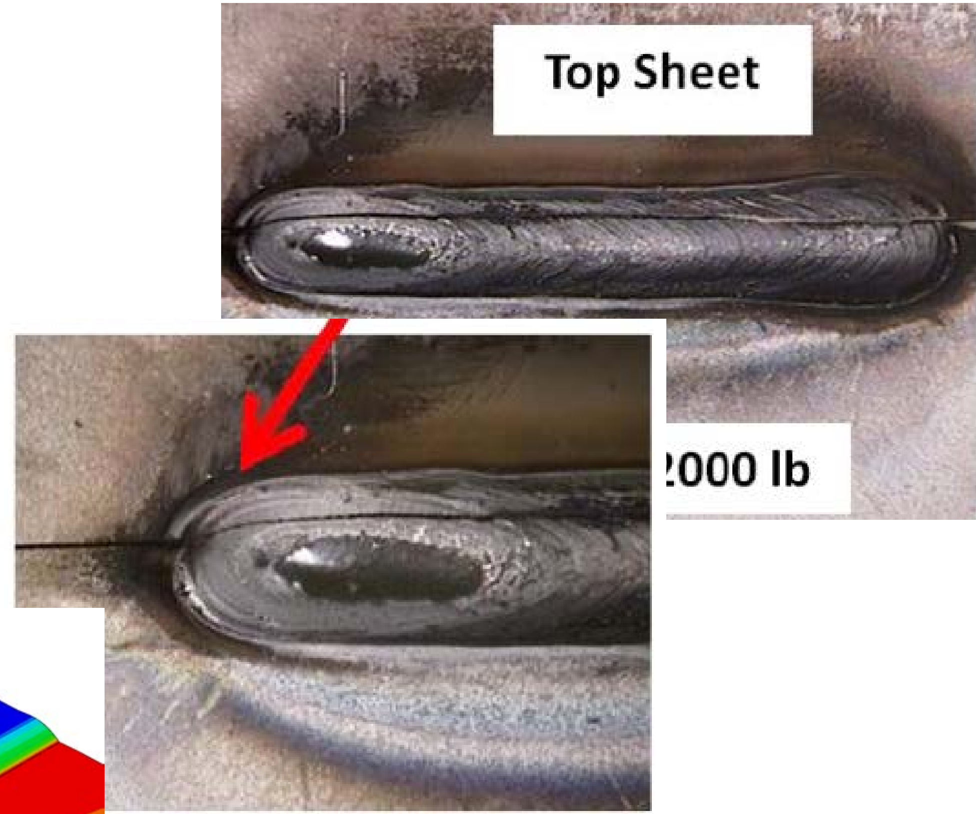
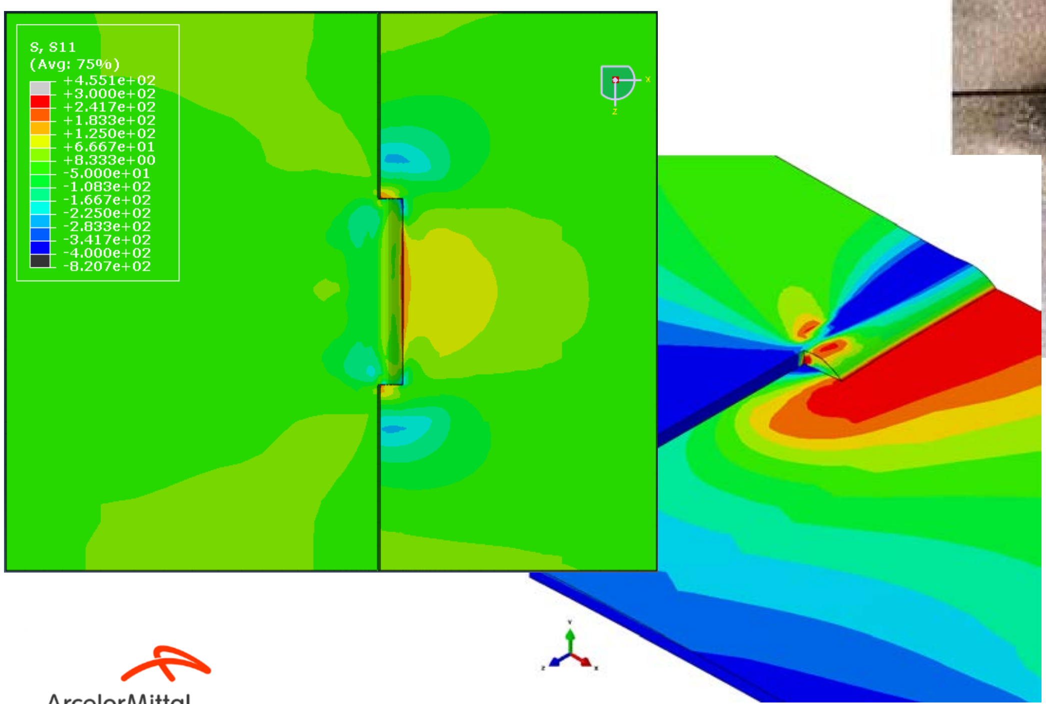


- Designed weld fatigue test sample that mostly resembles the actual stress/strain conditions in vehicle structures
- Based on lap joint, i.e., the most commonly used weld type in automotive structures
- Robotic gas metal welding system with cold metal transfer commonly used for BIW

Progress – Weld failure under fatigue loading

- 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





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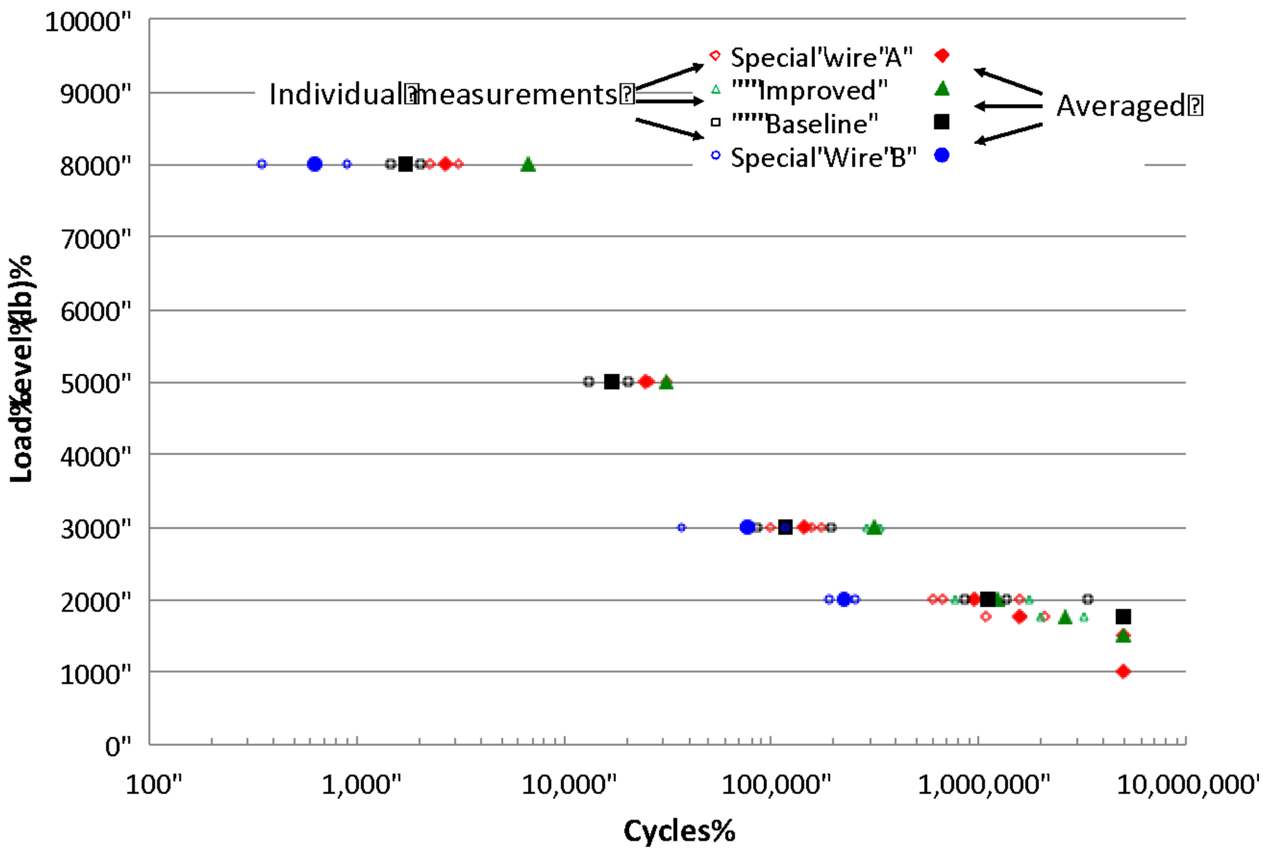
Accomplishment – Fatigue Testing

- A total of four LTT wires have been evaluated, with mixed results
  - Several root causes that resulted in low fatigue lives have been identified
- A new approach to further control the stress distribution around the weld start and stop resulted in improvement in weld fatigue strength



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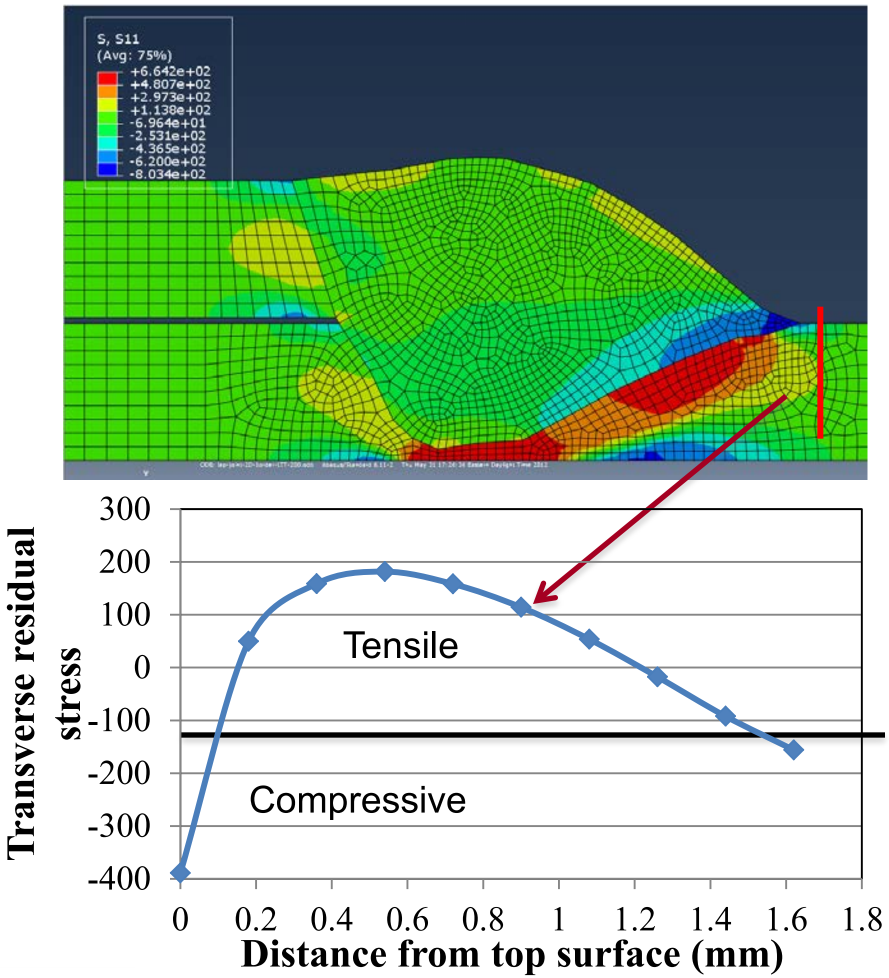
Progress – Understanding the mechanisms through ICWE modeling

- 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*

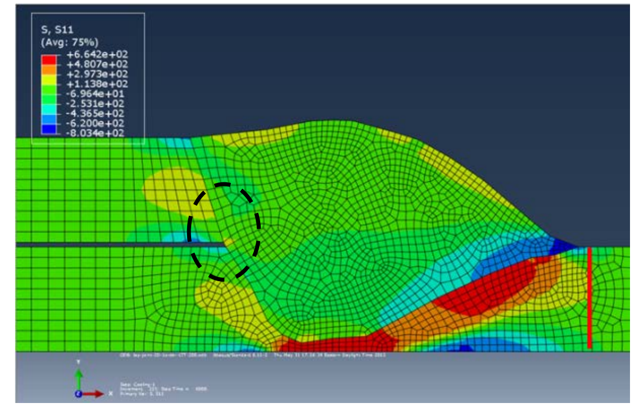
Longitudinal residual stress in the fusion zone is also compressive

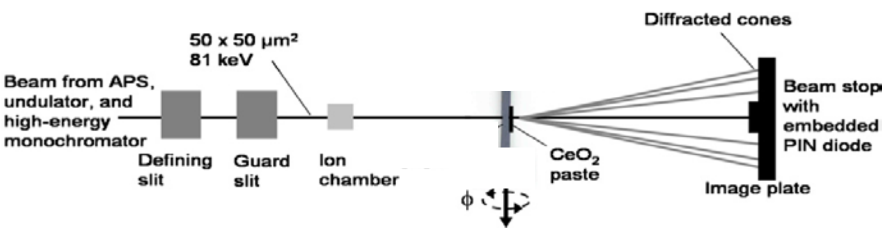
The effect on the weld root side is less profound

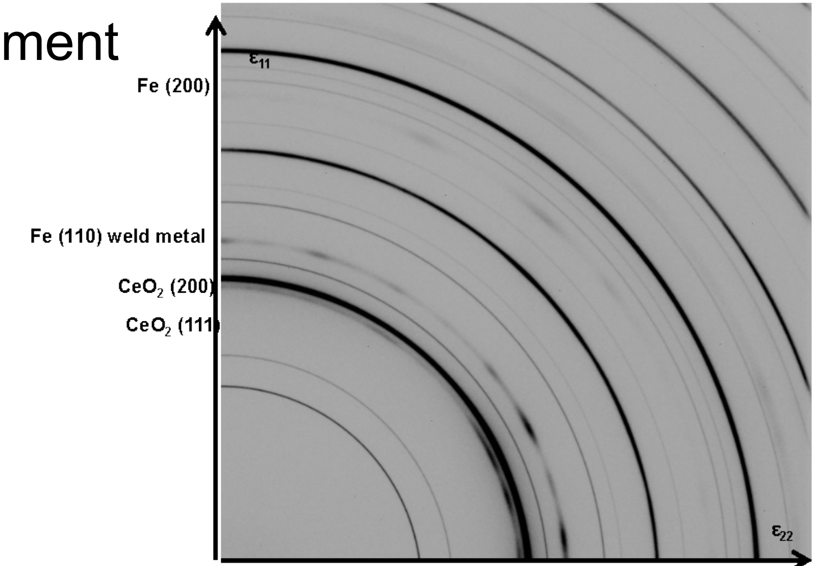
*Ohta, 2003

Progress – Understand the mechanisms through residual stress measurement

- Challenges in determining the weld residual stresses at the weld root
  - Difficult to apply common residual stress measurement techniques (X-ray, hole drilling)
- Application of high-energy synchrotron diffraction
  - Completed the first round of experiment
  - Data are being analyzed

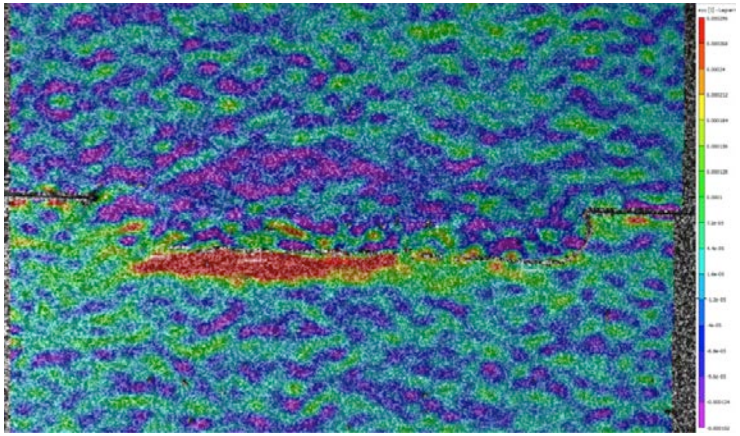






Progress – Understanding the mechanisms through in-situ measurement

- Digital image correlation (DIC) technique was applied to study the stress distribution around the weld region during mechanical testing
- Provided the necessary information on the characteristic stress distribution pattern in a short-stitch weld, to facilitate the technology development



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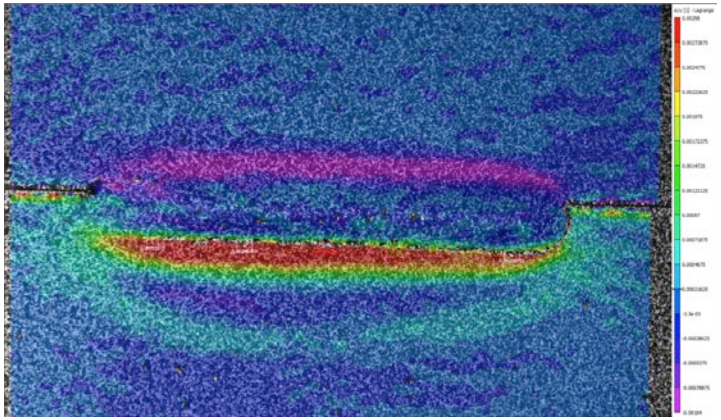

High load

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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
  - Development of LTPT filler metal chemistry
- ESAB
  - Fabrication of LTPT filler wires based on provided chemistry
- US Army
  - Technology development and application for lightweighting

Future Work

- Apply the integrated weld process and performance model to identify effective means of controlling the key parameters influencing the weld fatigue life
- Refine weld filler metal and welding process control methodology for weld fatigue life enhancement
- Conduct coupon level and component level welding and fatigue life testing to verify the fatigue life improvement strategy
- Develop case-by-case application guidelines to apply the technologies in automotive body structure fabrication

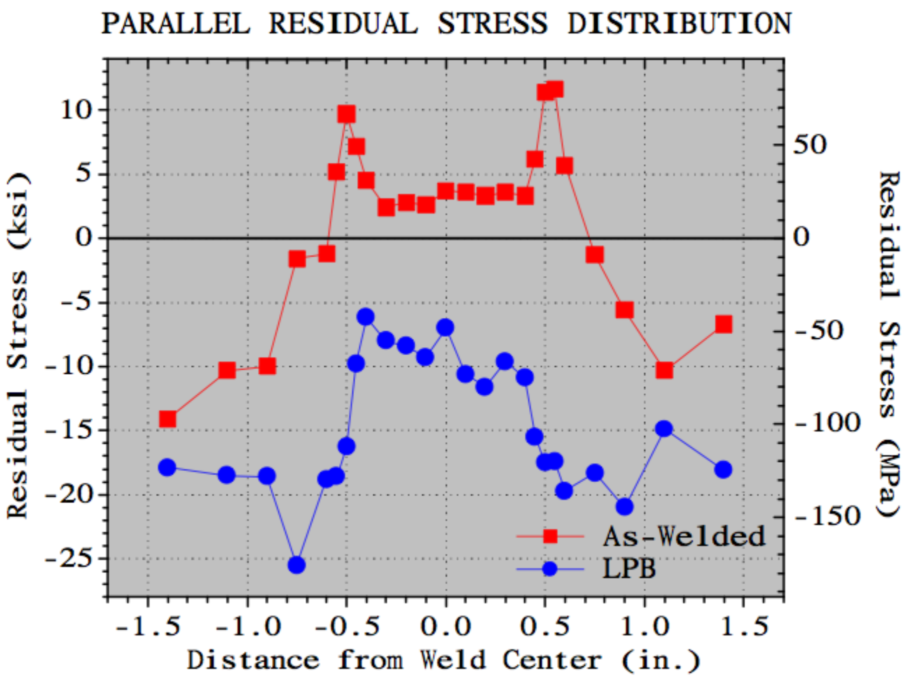
Summary

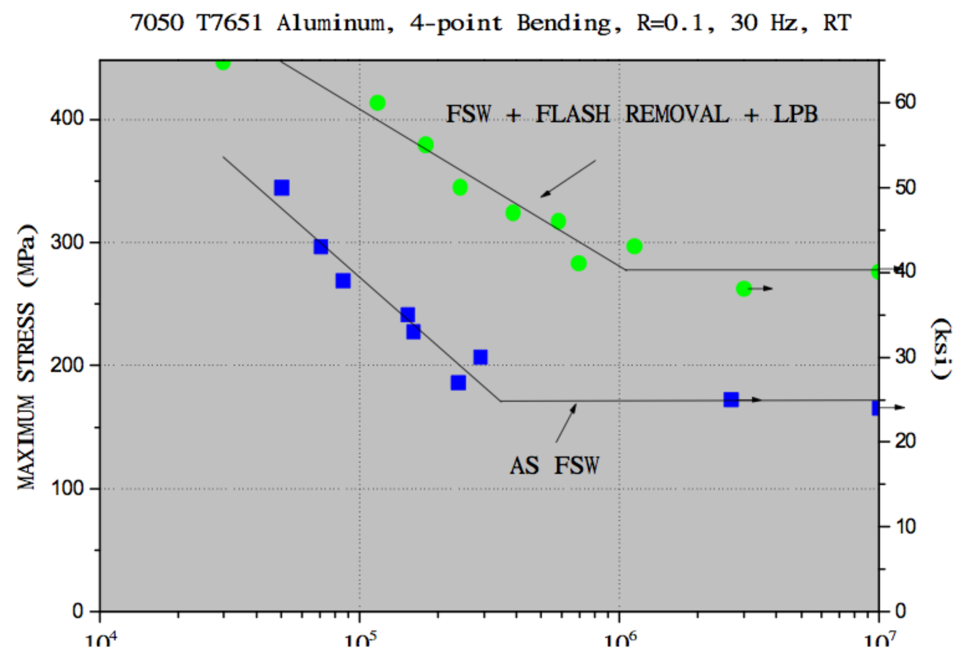
- Completed initial round of welding stress control R&D to improve weld fatigue life for AHSS BIW applications
- Identified key factors controlling the fatigue life of lap weld representing auto body structure applications
- Demonstrated the potential of weld fatigue life improvement through weld stress management
- Developed a baseline understanding of the roles of weld residual stresses by integrated weld process and performance model and in-situ experimental observation
- On-going R&D to further refine the process and weld wire chemistry to achieve the project objectives

Technical Back-Up Slides

Technical Basis: Benefit of Compressive Surface Residual Stress

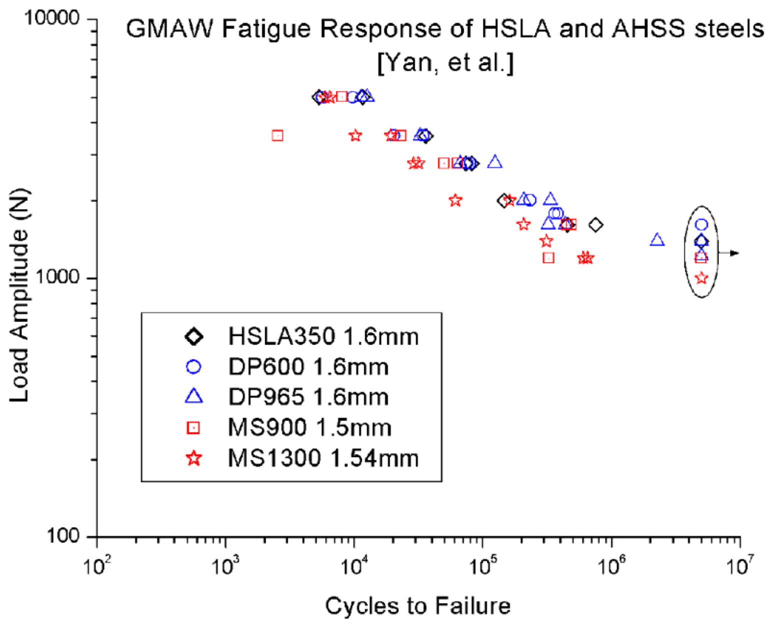
- Low Plasticity Burnishing (Hornbach et al)



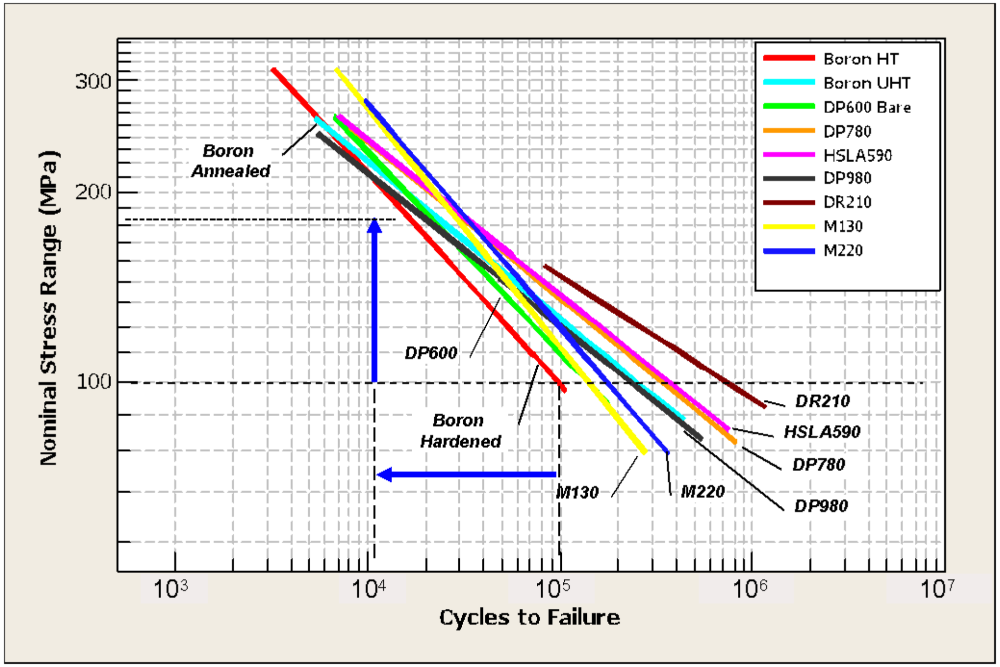


Relevance: Fatigue strength of AHSS weld is insensitive to steel types and grades

- GMAW fillet welds are shown; spot welds are similar



Yan et al (SAE 2005)



Feng et al (SAE 2009)

Technical Approaches

- Low-Temperature Phase Transformation Technique:
  - Utilize special weld filler metal which has low martensitic transformation temperature companied by volume expansion to induce compressive weld residual stress in fatigue crack sensitive area.
- Proactive Thermomechanical Management Technique:
  - Proactively alter differential thermal expansion and contraction sequence of welding through in-process thermal-mechanical control to mitigate tensile stress or induce compressive stress in weld toe, which is a major fatigue crack initiation area.