Project ID: LM062

Improving Fatigue Performance of AHSS Welds

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Overview

Timeline

- Project start date: March 2011
- Project end date: February 2014
- Percent complete: 25%

Budget

- Total project funding
  - DOE share: $1,350K
  - Contractor share: $650K
- Funding received in FY11: $420K
- Funding for FY12: $450K

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
- Project lead
  - Oak Ridge National Laboratory

AHSS – Advanced high strength steel

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Objectives

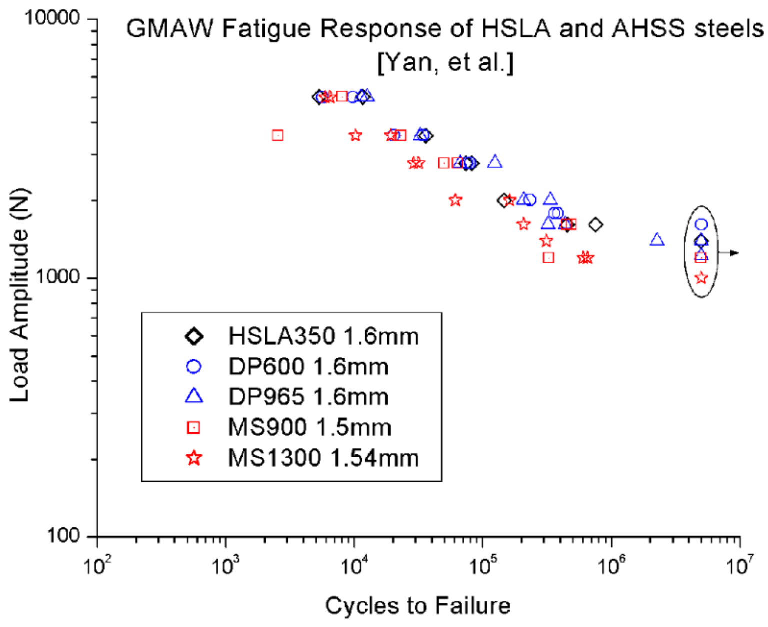
- Establishing the technical basis and demonstrating the viability of innovative weld residual stress mitigation technology that can substantially improve the weld fatigue performance and durability of auto-body structures.
- Developing cost-effective and practical technology suitable for high-volume vehicle production environment

Relevance / Technology Gap Analysis

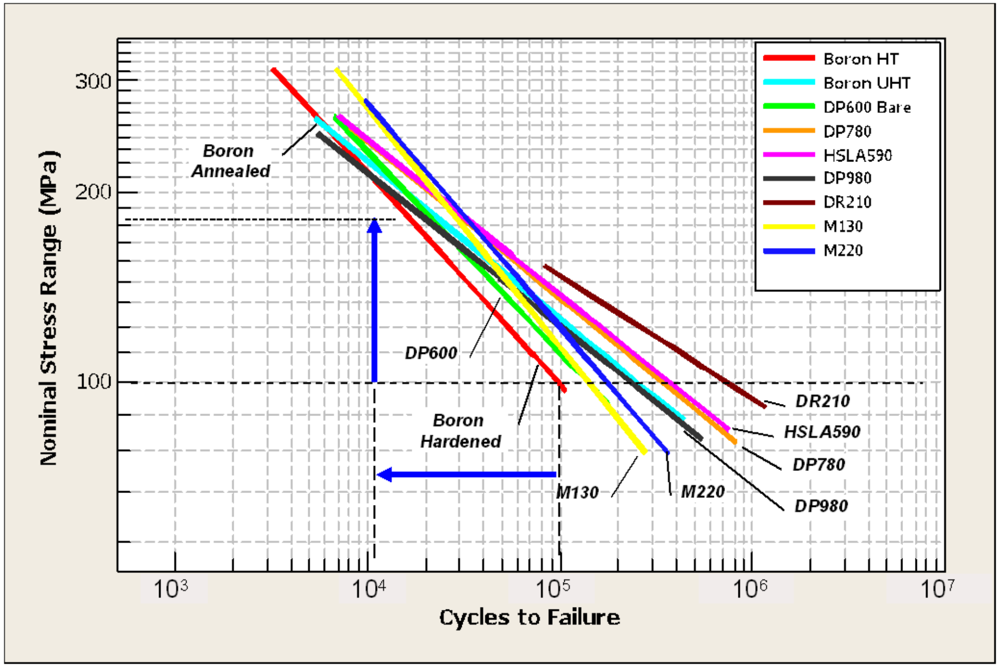
- Recent studies by A/SP, DOE Lightweight Materials Program and others have shown that, unlike the base metal case, welds of AHSS do not exhibit appreciable increase in fatigue strength (i.e. weld fatigue strength is insensitive to the steel type and grades of current AHSS).
- Down-gaging of AHSS for 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).

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)

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Factors Governing Weld Fatigue Strength

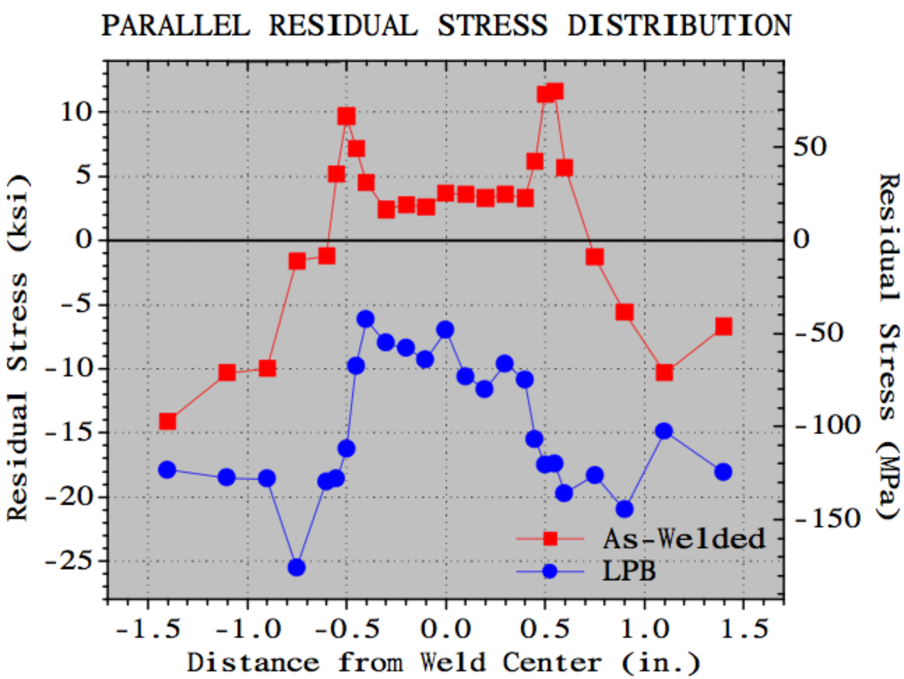
- Stress concentration due to weld geometry and weld surface quality/discontinuity
  - SCF = 6-9 from FEM analysis for lap joint under tensile loading
- <u>**High tensile residual stresses at the weld toe and other critical locations**</u>
- Weld microstructure change (limited knowledge)
  - HAZ softening has minimal influence

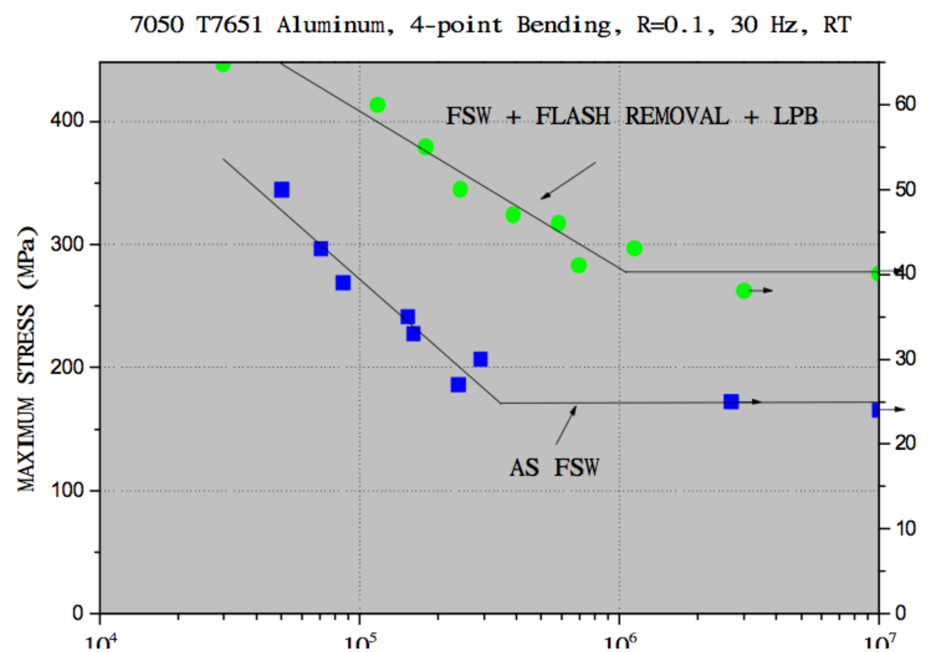
Approach: Improve Weld Fatigue Strength by Altering Weld Residual Stress

- 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
- We have worked on weld residual stress control and mitigation extensively in the past.

Technical Basis for Technical Approach: Benefit of Compressive Surface Residual Stress

- Low Plasticity Burnishing (Hornbach et al)





Technical Basis for Technical Approach: Effectiveness of LTPT on Weld Fatigue Life

(Ohta et al, 2000)

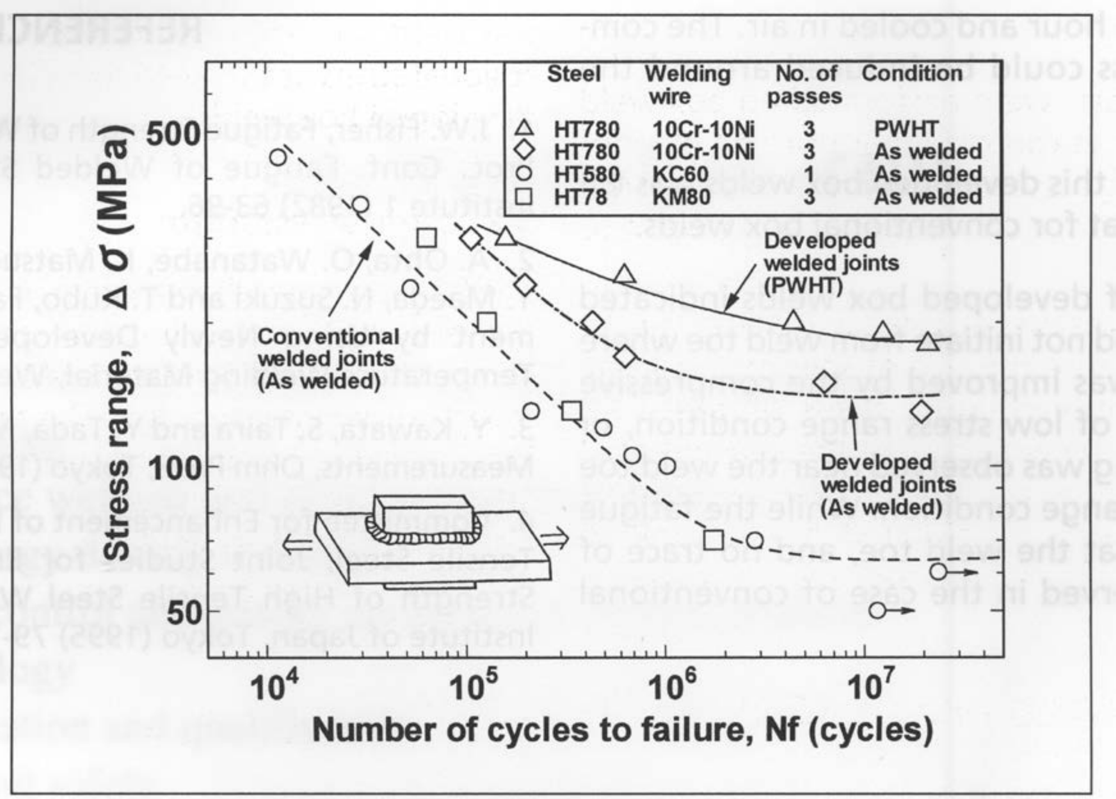


Fig. 6. S-N diagram of box welded joints.

Applicability of weld joint configurations specific to auto BIW is not established

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-activel thermomechanical management – specific to auto environment
  - Assisted by ORNL's 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

Year 1 (03/11 to 02/12)

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

Completed

Year 2 (03/12 to 02/13)

– 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

Started

Year 3 (03/13 to 02/14)

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

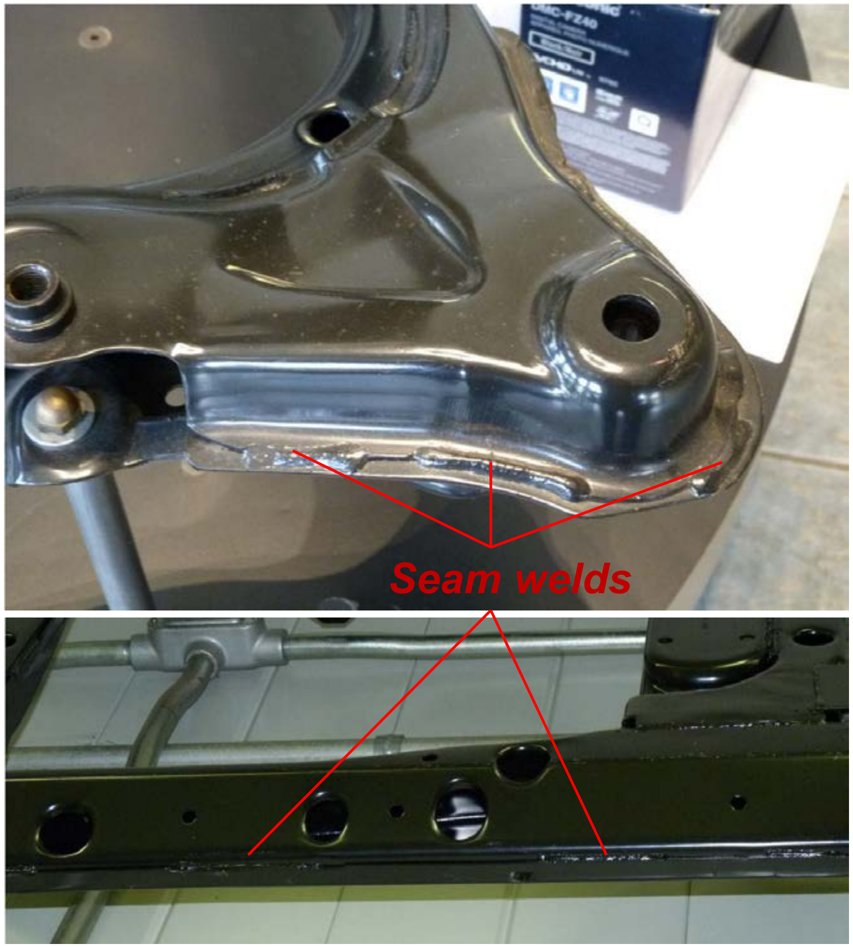
LTPT – Low-temperature phase transformation
RS – Residual stress
BIW – Body-in-white
CAE – Computer-aided engineering

Accomplishment – Literature Review

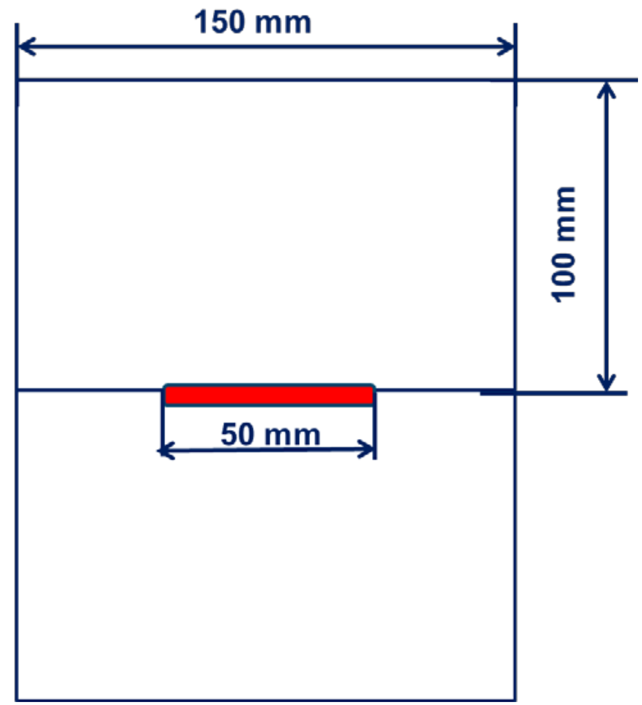
Completed literature review and the state-of-the-art assessment of weld fatigue life improvement strategies pertaining to auto body structure applications.

- **Post-weld methods:**
  Heat treatment, laser shot peening, low plasticity burnishing, sand blast peening, coining, machining to improve weld toe profile
- **In-situ methods:**
  Special filler metal to mitigate residual stress
  Special weld process to mitigate weld residual stress

Accomplishment – Weld Fatigue Sample Design based on Automotive Industry Survey

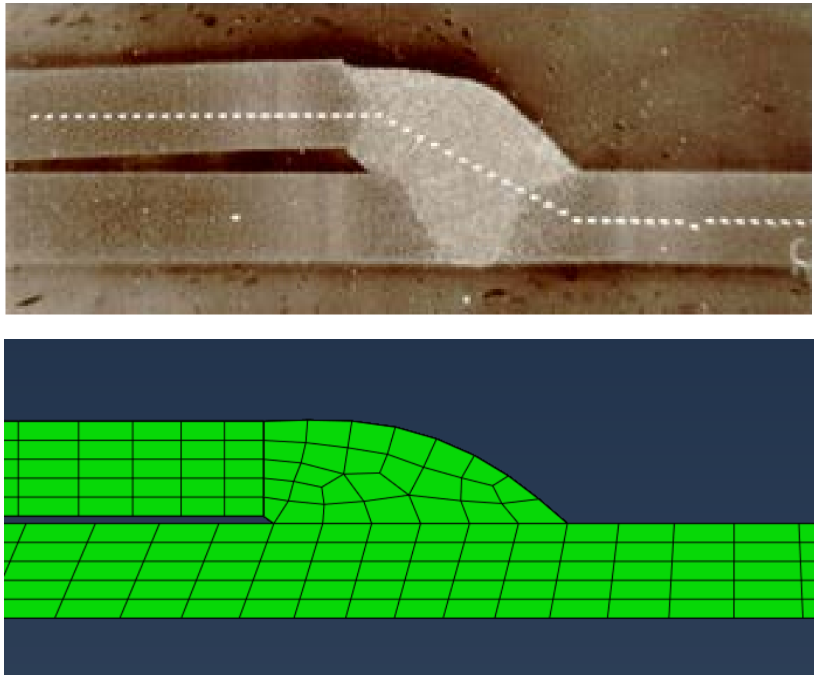


Surveyed major automotive original equipment manufacturer (OEMs) to identify weld patterns representitive of those in vehicle AHSS structures

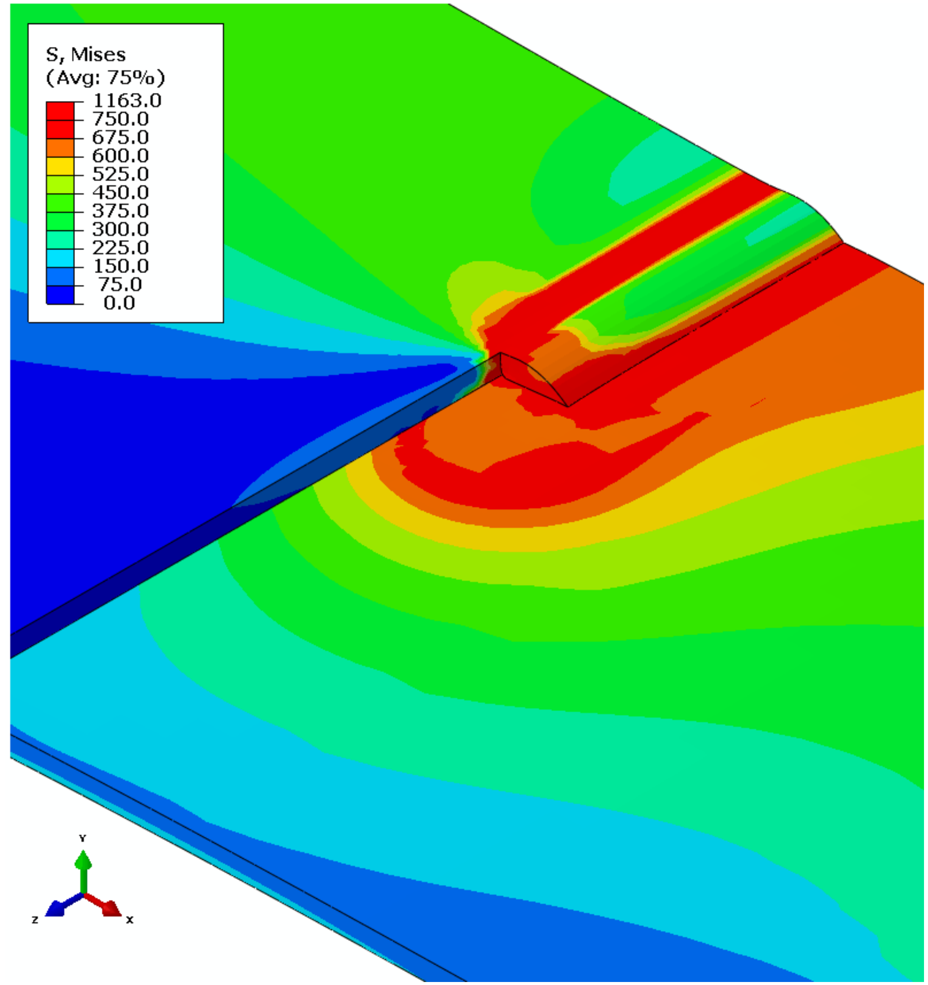


- Designed weld fatigue test sample that mostly resembles the actual stress/strain conditions in vehicle structures
- Based on lap joint, i.e., the most commonly used weld type in automotive structures

Accomplishment – Optimization of Fatigue Geometry using Computer Modeling

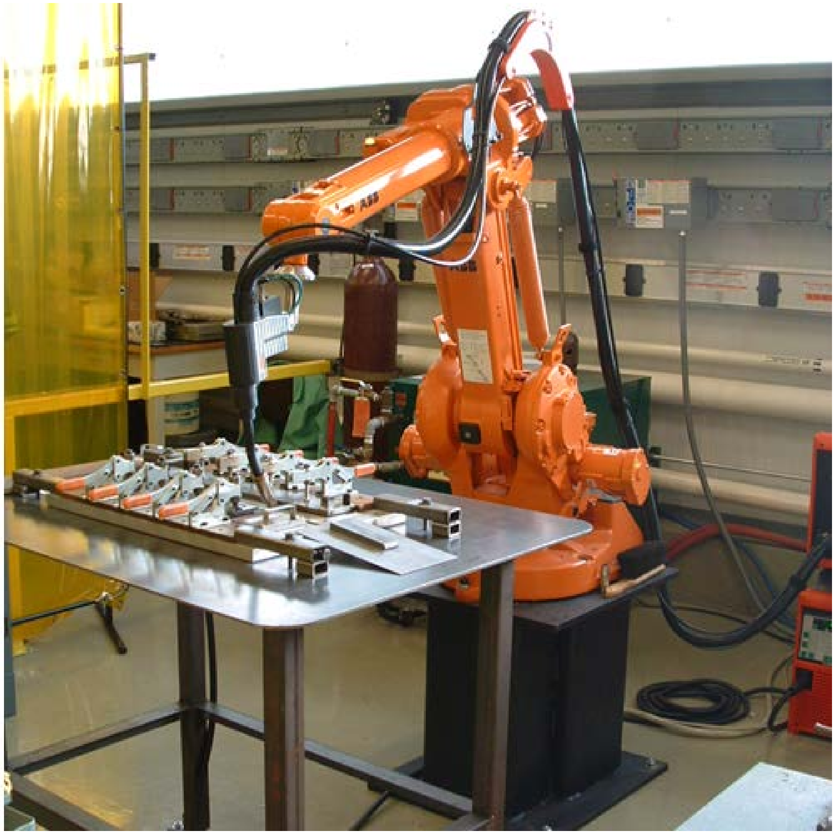


Cross section of weld: actual weld (top picture) vs. model (bottom picture)



Predicted stress distribution used to help optimize the geometry of fatigue sample and fixtures

Accomplishment - Baseline Study of LTPT



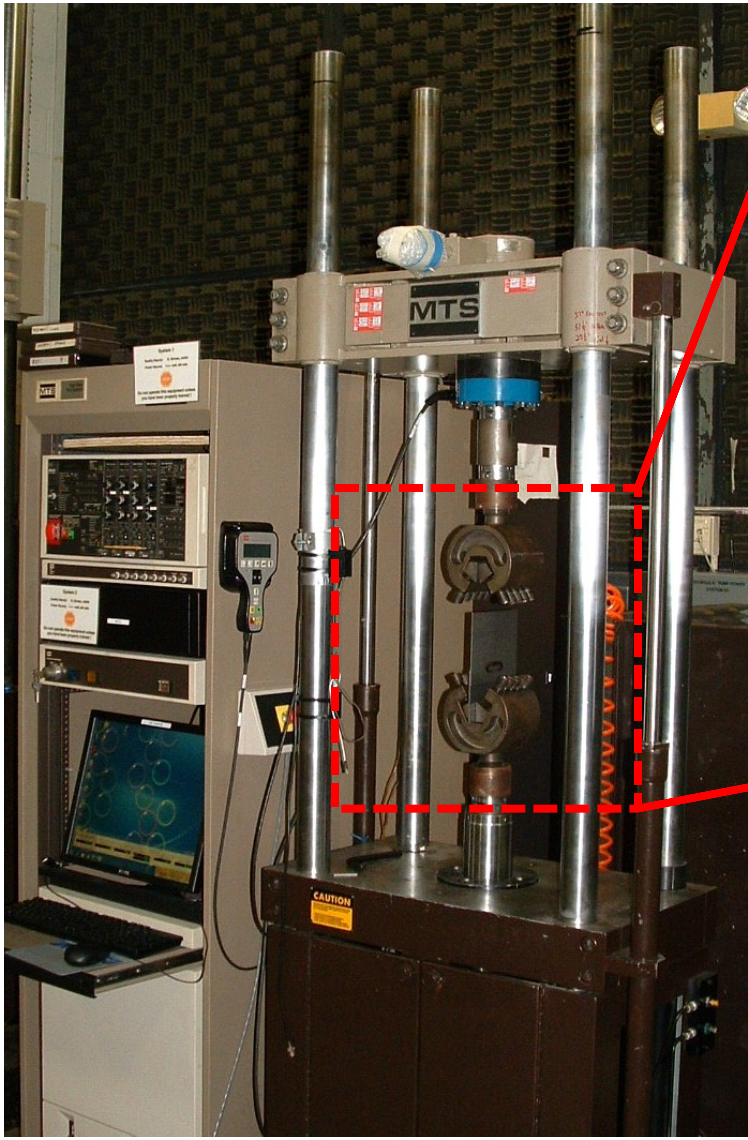
Cold metal transfer arc welding system at ArcelorMittal

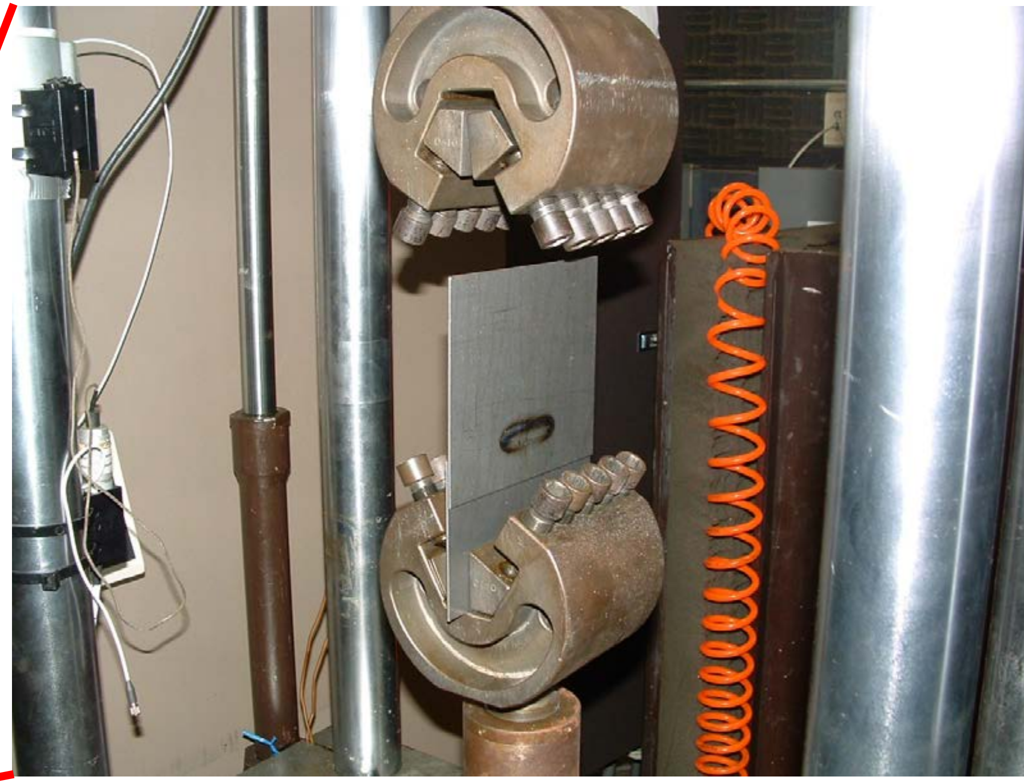
Test plate welded with conventional wire

Test plate welded baseline LTPT wire

- *Three baseline LTPT wires with different compositions have been used to make testing welds, and to be compared with conventional wire for fatigue strength (preliminary testing in year 1)*
- *A brand new robotic gas metal arc welding system with cold metal transfer function was used to generate fatigue test samples.*

Progress – Ongoing Fatigue Testing

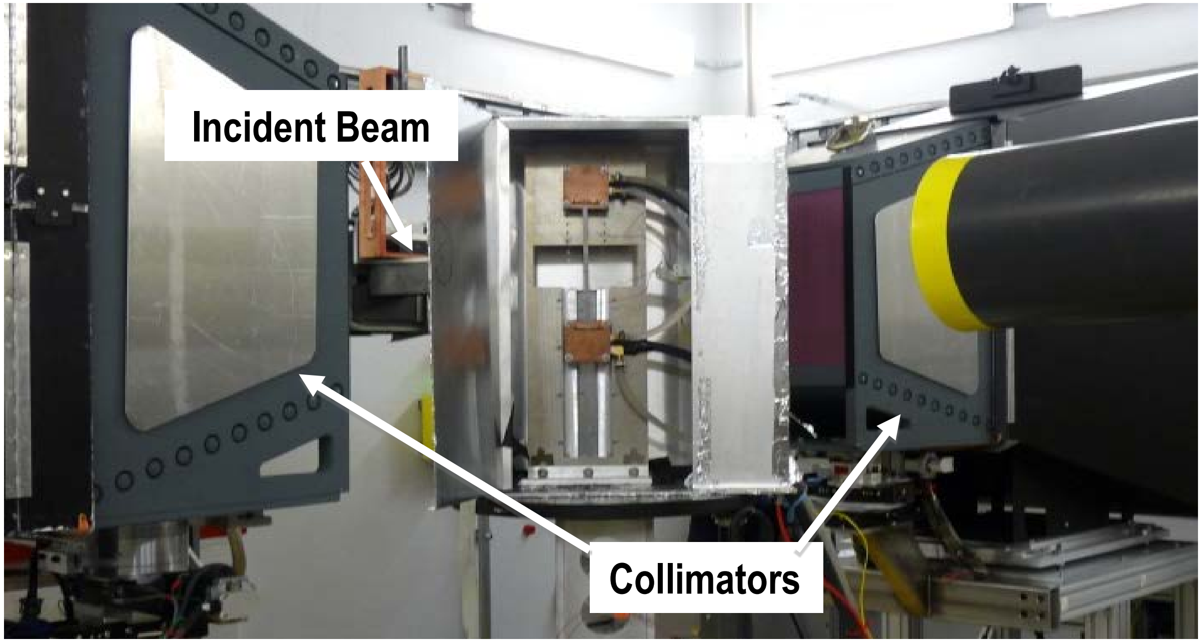


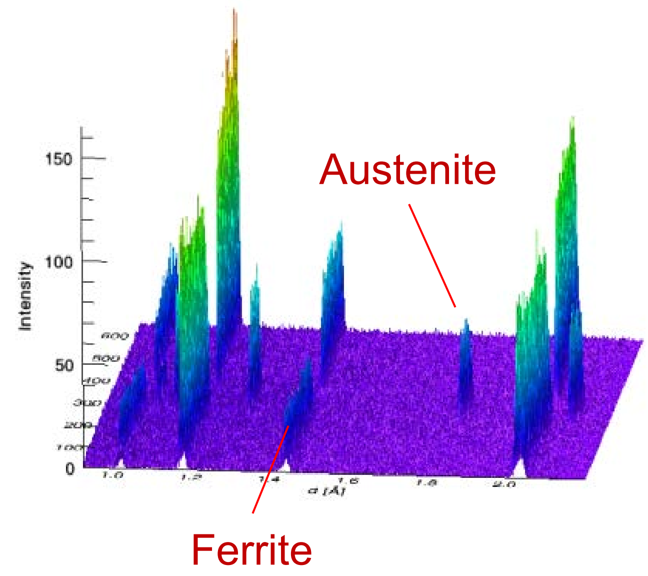


Fatigue testing system at ArcelorMittal:

- A 22KIP MTS machine used for weld fatigue test
- Grips of the machine modified to suit the weld fatigue test samples

Progress – Synergetic Activity on in-situ Phase Transformation Study by Neutron Diffraction





In-situ measurement of phase transformation kinetics during heating and cooling of a high strength steel in a controlled atmosphere box at SNS VULCAN

The established apparatus and testing procedure will be leveraged to study the phase transformation kinetics and associated lattice change for LTPT.

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

Future Work

Year 2 (03/12 to 02/13):

- Apply the integrated weld process and performance model to identify effective means of controlling the key parameters influencing the weld fatigue life
- Develop weld filler metal and welding process control methodology for weld fatigue life enhancement

Year 3 (03/13 to 02/14):

- 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

First year of substantial research and development:

1. Different weld fatigue life improvement techniques are reviewed and ranked in consideration of the unique automotive structure and production requirements.
2. Industry survey of actual automotive welded structures is performed to design the weld fatigue test sample and fixture geometry.
3. New robotic welding system is installed and used to fabricate baseline welds for fatigue testing and weld characterization.
4. Integrated weld process and performance model is being further developed to predict the weld fatigue life.
5. Novel approach of in-situ neutron diffraction experiment developed in a synergetic activity will be leveraged for studying the phase transformation kinetics and associated lattice change for LTPT.

Technical Back-Up Slides

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.