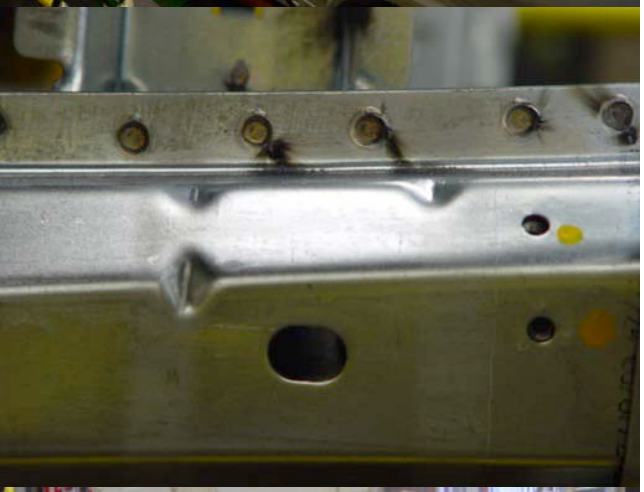

On-Line Weld NDE with IR Thermography

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Oak Ridge National Laboratory

May 17, 2012

Project ID # LM054

This presentation does not contain any proprietary, confidential, or otherwise restricted information

OAK RIDGE National Laboratory

Overview

Timeline

- Start: June, 2008
- End:
  - Phase I: June, 2010
  - Phase II: June, 2013
- Percent complete:
  - Phase I: 100%
  - Phase II: 50%

Budget

- Total project funding
  - DOE share: $1,300K
  - Industry in-kind share: $210K
- Funding received in FY11: $450K
- Funding for FY12: $256.8K

Barriers

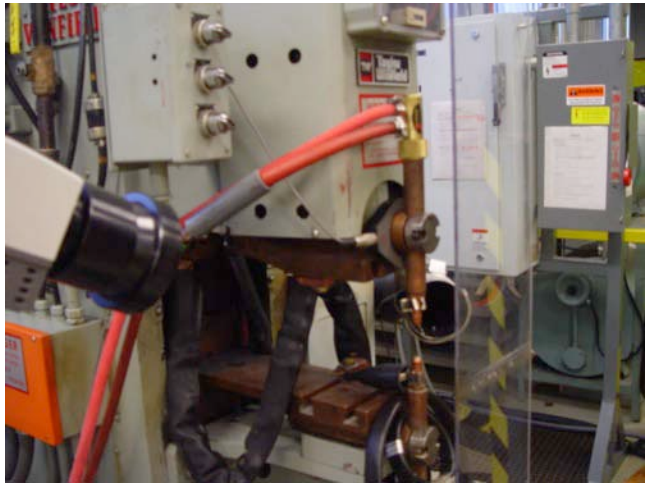
- Barriers addressed
  - Non-destructive techniques for the evaluation of the integrity of joints made with lightweight materials.

Partners

- Interactions / collaborations
  - Chrysler, Ford, and GM
  - ArcelorMittal
  - AET Integration Inc.
  - AMD NDE Steering Committee
  - A/SP Joining Team
- Project lead
  - Oak Ridge National Laboratory

Project Objective

- Develop an online non-destructive evaluation (NDE) technology for spot weld quality monitoring based on infrared (IR) thermography that can be adopted reliably and cost-effectively in high-volume auto production environment for weld quality assessment
  - An expert system (hardware and software) for both post-weld and real-time on-line weld quality inspection
  - Weld quality database covering wide range of weld configurations (materials, thickness, coatings) common in auto-body structures

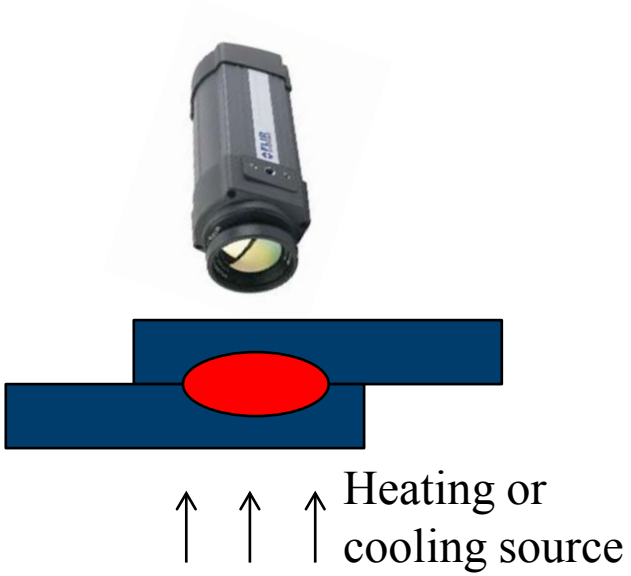


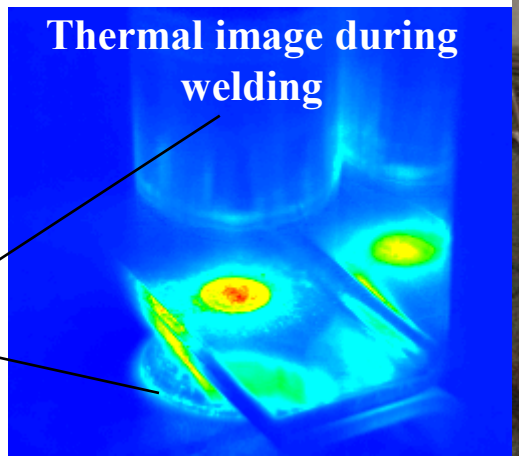
Relevance: Technology Gaps that This Project Addresses

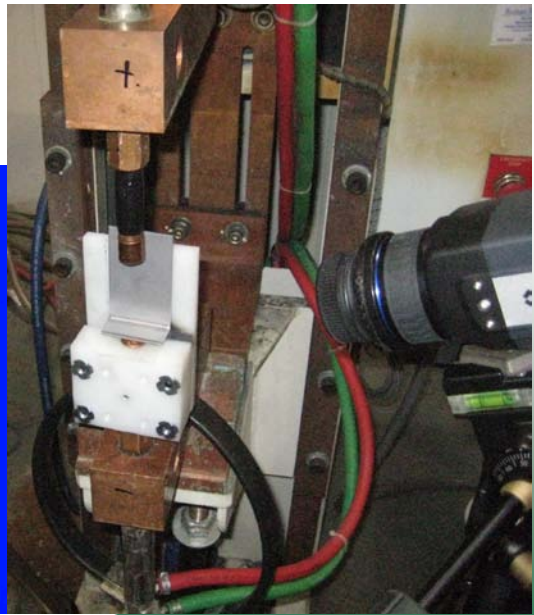
- Today industry primarily relies on destructive testing to ensure the spot weld integrity of critical auto-body structures
  - Labor intensive, slow and expensive (rework and scraps)
  - Less effective for advanced high-strength steels, aluminum and other lightweight materials
- The destructive evaluation of weld quality is based on statistics and random sampling of small portion of as-welded auto-bodies.
  - Impossible to inspect 100% of the welds
  - No efficient method to immediately send feedback to the production lines

Past Attempts on IR Thermography based Weld Inspection

- Postmortem NDE
  - Mostly limited to lab trials
  - Heating/cooling source
    - Pulsed heating <1sec
    - Modulated heating > minutes (impractical for fast inspection)
  - IR signal measured by camera is highly sensitive to surface condition and environment interference
    - Requiring painting of the weld surface (impractical in auto production line)
- Real-time NDE
  - No successful attempts yet







Project Milestones

Month/Year	Milestone or Go/No-Go Decision
Jun-10	Demonstrate feasibility – detection of major weld quality Phase I Go/No-Go Decision (**Passed**)
Nov-10	Produce additional spot welds with different weld quality attributes made with RSW and weld bonding different steels, coating, thickness and stack-up configurations (**Completed**)
Feb-11	Modeling of post-mortem inspection to identify quantifiable IR thermal signatures and refine/optimize heating device and procedure (**Completed**)
Apr-11	Confirm the capability of low-cost IR camera (**Completed**)
Dec-11	Develop IR image acquisition module and analysis algorithms module for both real-time and post-weld inspection (**Initial versions completed**)
Dec-11	Destructive weld quality tests (On-going, with expanded sets of welds)
June-12	Development of expert software and prototype system including image acquisition, user interface, ability to adaptive learning and decision making (Initial prototyping system integrating software and hardware developed)
Dec-12	IR weld NDE guideline (On-going)
June-13	Prototyping and field demo (On-going)

Phase II Tasks and Schedule

	FY2010				FY2011				FY2012				FY2013			
Quarter	**Q1**	**Q2**	**Q3**	**Q4**	**Q1**	**Q2**	**Q3**	**Q4**	**Q1**	**Q2**	**Q3**	**Q4**	**Q1**	**Q2**	**Q3**	**Q4**
Task 1: IR Measurement Techniques																
1.1 Producing welds																
1.2 Postmortem techniques																
1.3 Real-time technique																
1.4 Destructive weld quality test																
1.5 Modeling																
1.6 Field trip and testing																
Decision Gate																
Task 2: IR Export Software																
2.1 IR signature algorithm																
2.2 User interface																
2.3 Image acquisition module																
2.4 Adoptive learning/training																
2.5 Beta testing																
Decision Gate																
Task 3: IR Weld NDE Guideline																
3.1 Guideline and manuals																
Decision Gate																
Task 4: Prototyping/Field Demo																
4.1 Prototype system																
4.2 Field demonstration																
4.3 Tech transfer																
Decision Gate																

Completed tasks

Passed decision gates

On-going tasks

Future decision gates

Project is expected to complete in 2nd quarter of FY2013 due to later start in third quarter of FY2010

Project Approach/Strategy

- Phase I Concept Feasibility (FY08-FY09)
  - Demonstrate the feasibility of IR thermography based spot weld quality inspection technology to detect various weld quality/defect attributes (post-weld and real-time inspections)
- Phase II Technical Feasibility (FY10-FY13)
  - Refine and optimize the robust IR image analysis algorithm that can provide quantitative measure of the quality and the level of defect (if any) of spot welds
  - Develop the cost-effective prototype system (hardware and software) operated in high-volume auto production environment
  - Develop a database covering wide range of weld configurations common in auto-body structures

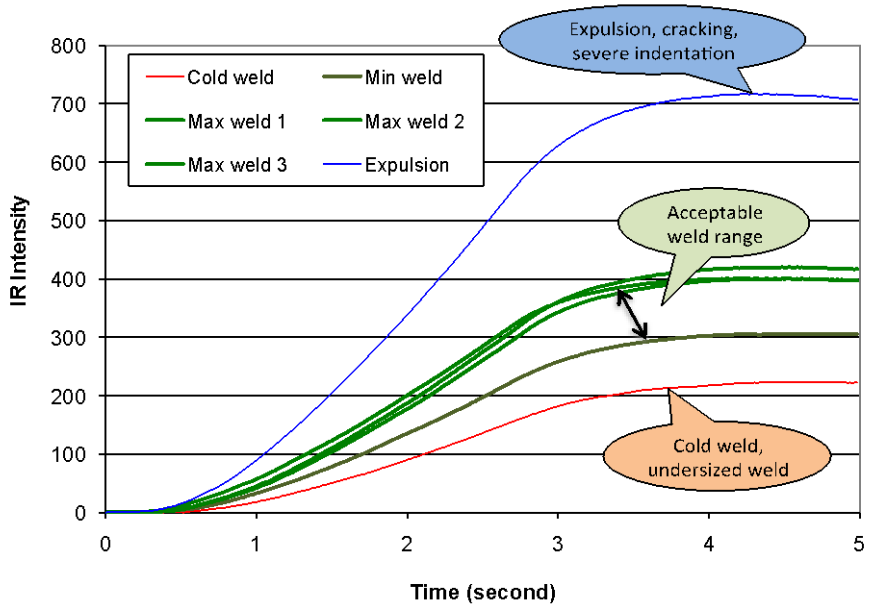
Approach: Weld Quality Metrics

- Ranked by industry advisory committee in the order of importance (high to low)
  - Weld with no or minimal fusion
  - Cold or stuck weld
  - Weld nugget size
  - Weld expulsion and indentation
  - Weld cracks
  - Weld porosity

- Needs to positively identify the above weld defects/attributes

Accomplishments (Phase I Feasibility)

- Post-weld IR inspection
  - Techniques to increase the IR signal-to-noise ratio
- Real-time IR Monitoring
  - Using the heat flow during welding
- Weld samples with controlled weld quality/defects attributes
  - Destructive examination to characterize and quantify them
- As-welded surface condition
- Initial development of an expert system to correlate IR signal to weld quality attributes



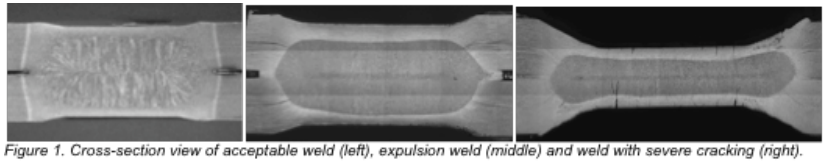


Figure 1. Cross-section view of acceptable weld (left), expulsion weld (middle) and weld with severe cracking (right).

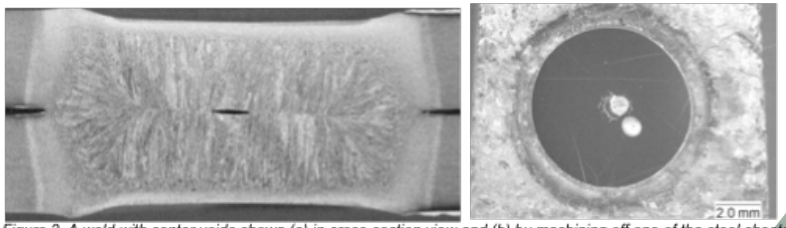
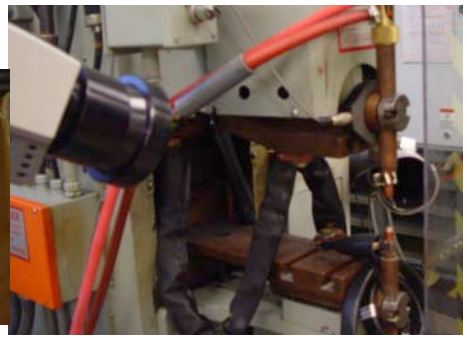


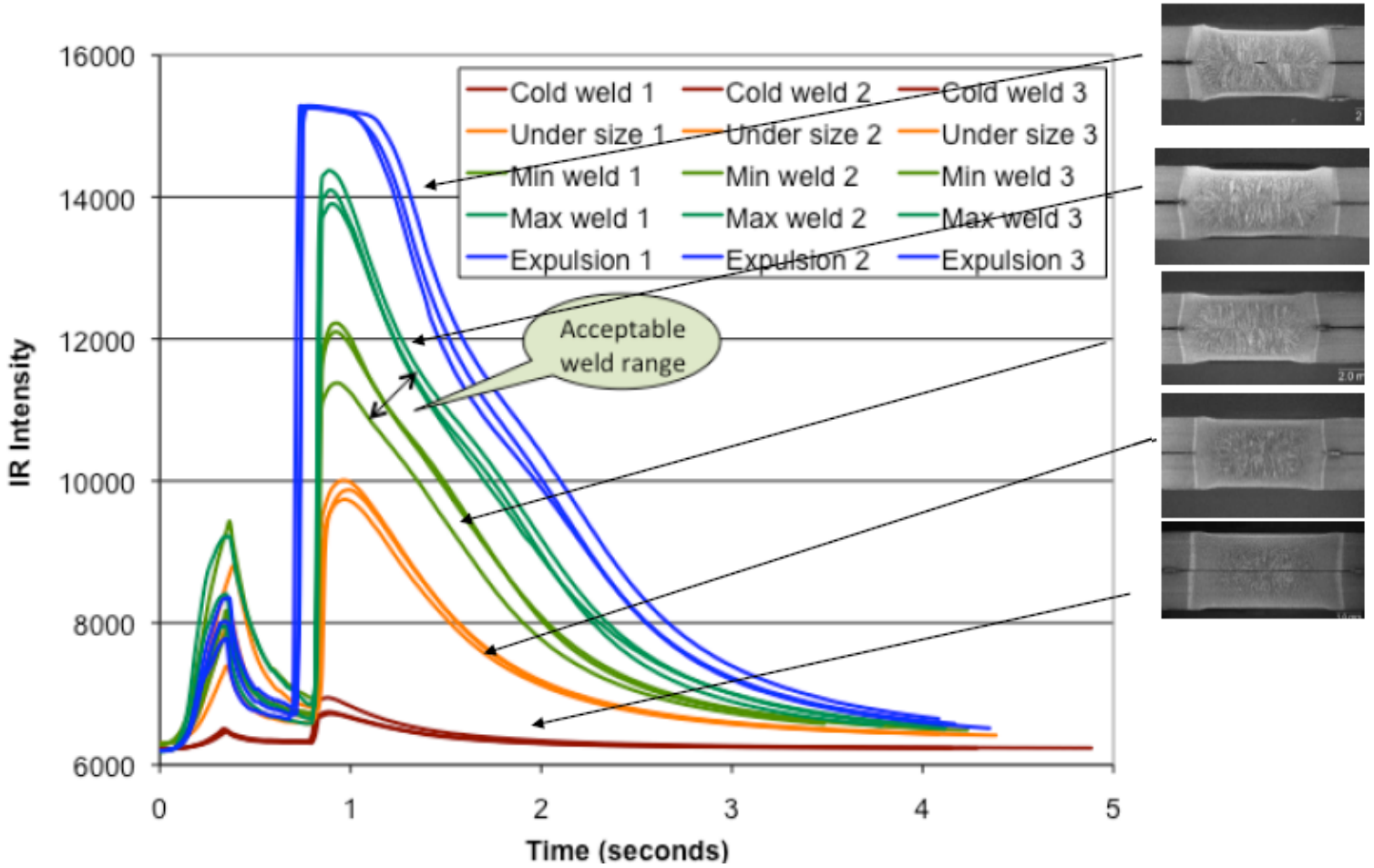
Figure 2. A weld with center voids shown (a) in cross-section view and (b) by machining off one of the steel sheets.



All welds produced by ArcelorMittal as industry in-kind contribution

Accomplishment: (Phase I Feasibility) Real-time IR NDE

Successfully distinguished the acceptable weld range



Accomplishment: Low-Cost Camera

Phase I: Indigo Phoenix, $200K

Phase II: FLIR A325, $20K

- Dual use: both real-time monitoring and post-mortem NDE
- Initial cost estimate of entire system: $30K-$35K
  - IR camera: $20K
  - Heating/cooling device: $8K
  - Computer and software: $2K
- Post-mortem and real-time benchmarking tests using Phase I welded samples confirmed the new camera has sufficient sensitivity and resolution

Accomplishment: Large Matrix of Materials relevant to AHSS Intensive Vehicle Structure

Steel Grades, Coating, Thickness	Post-mortem	Real-time
• DP590 Galvanized 1.2mm • DP590 Galvanized 1.2mm	X	X
• DP590 Galvanized 1.8mm • DP590 Galvanized 1.8mm	X	X
• DP980 Cold rolled1.2mm • DP980 Cold rolled1.2mm	X	X
• DP980 Cold rolled1.2mm • DP980 Cold rolled 2.0mm	X	X
• DP980 Cold rolled 2.0mm • DP980 Cold rolled 2.0mm	X	X
• Boron Aluminized 1.0mm • Boron Aluminized 1.0mm	X	
• Boron Aluminized 1.0mm • Trip780 HDGA 1.0mm	X	
• DP980 HDGA 1.0mm • DP980 HDGA 1.0mm	X	
• Boron 2.0mm • Boron 2.0mm		X
• DP600 HDGI 2.0mm • Trip780 HDGA 2.0mm		X
• Boron 2.0mm • Trip780 HDGA 2.0mm		X

2T stack

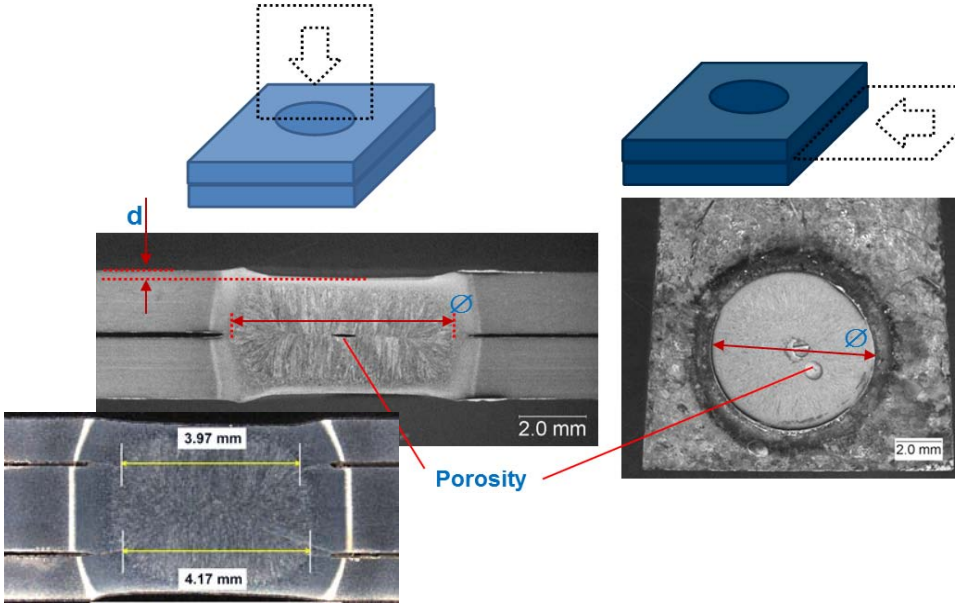
Steel Grades, Coating, Thickness	Post-mortem	Real-time
• Boron 2.0mm • Boron Aluminized 1.0mm • Boron 2.0mm		X
• DP600 2.0mm • DP600 HDGI1.0mm • DP600 2.0mm		X
• DP980 HDGA 2.0mm • DP980 HDGA 1.0mm • DP980 HDGA 2.0mm		X
• TRIP780 HDGA 2.0mm • TRIP780 HDGA 1.0mm • TRIP780 HDGA 2.0mm		X

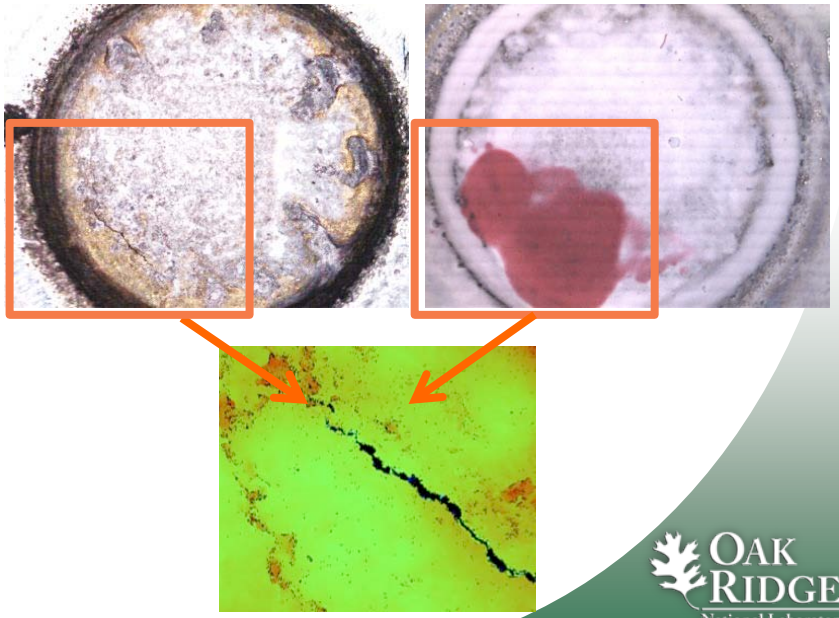
3T stack

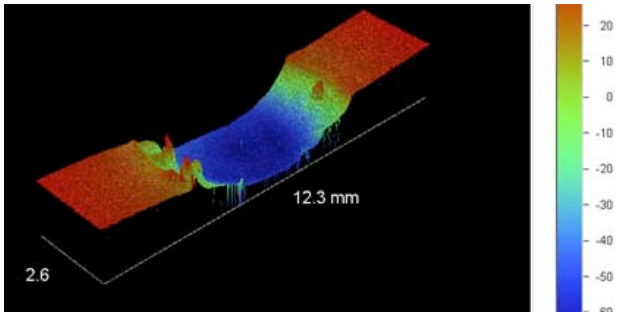
- *Each combination including spot welds with varying attributes (i.e., nugget size, indentation & defects)*
- *Blanks corresponding to those yet to be evaluated*

Accomplishment: Destructive Examination of Weld Attributes

- Sectioning welds
  - Nugget size (Φ)
  - Internal defects: porosity, and expulsion
  - Surface indentation (d)
- Dye penetrants
  - Surface cracking
- Surface micro-profiling
  - Surface indentation
  - Surface cracking

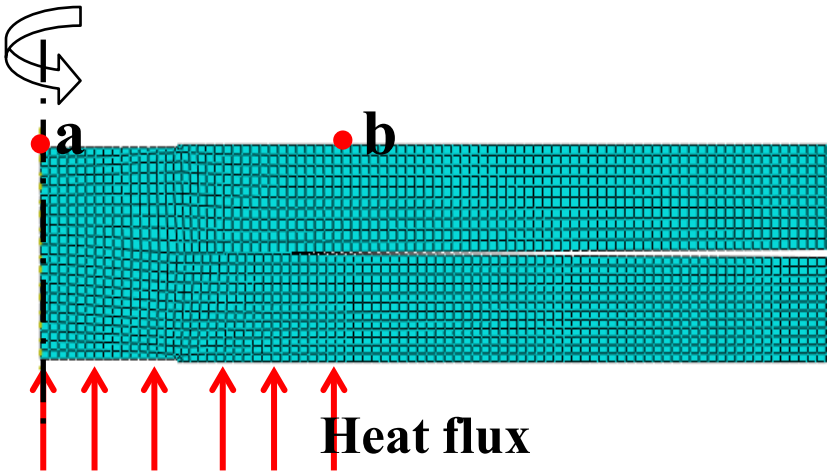


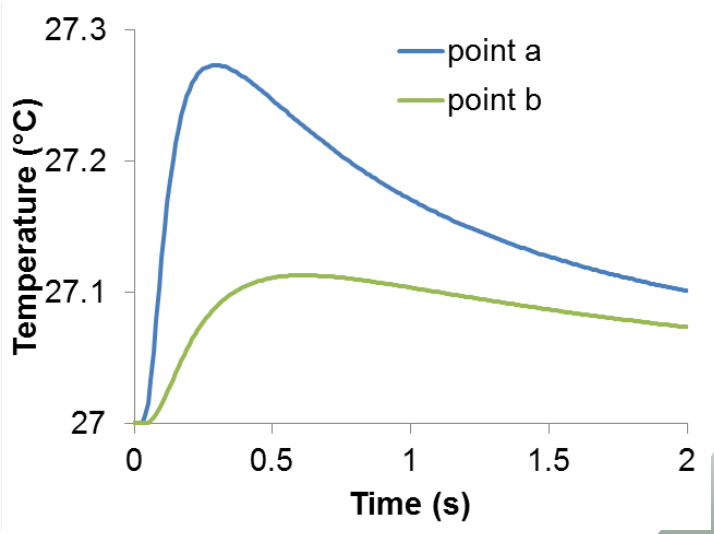




Accomplishment (Post-weld NDE): Computer Modeling

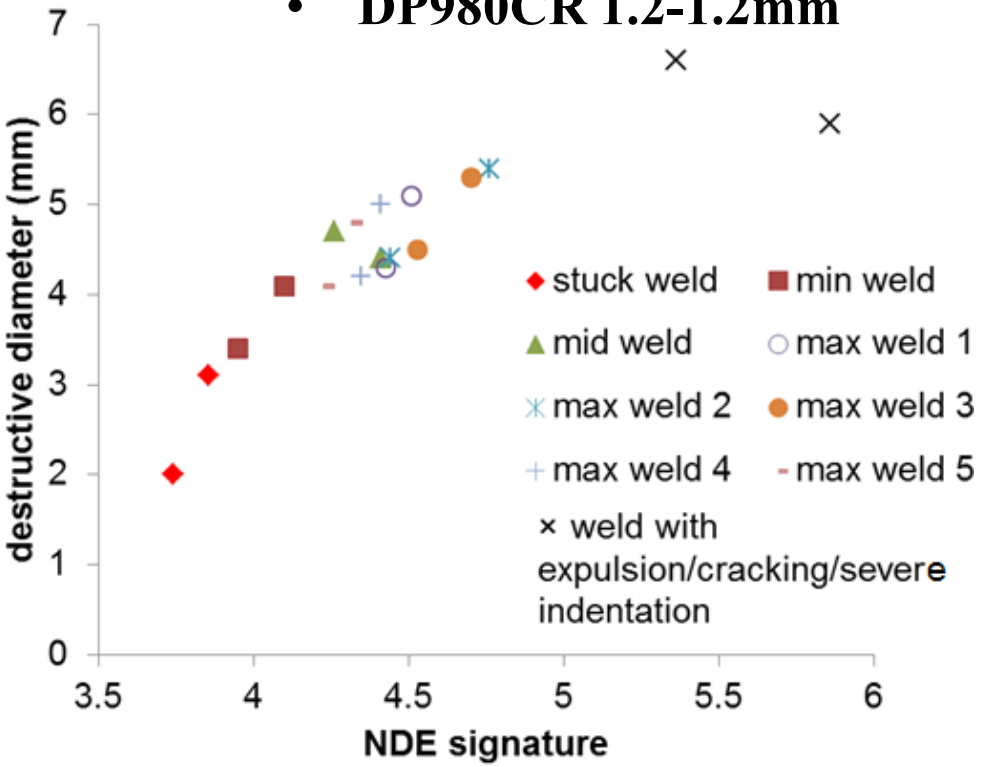
- Assist development of IR signal analysis algorithms of post-weld IR NDE
  - Algorithm in Phase I is based on the measurement of average IR intensity around welds which could be influenced by weld surface conditions
  - New algorithm is developed in Phase II to provide additional thermal signatures, and is insensitive to surface condition. (patent filling)





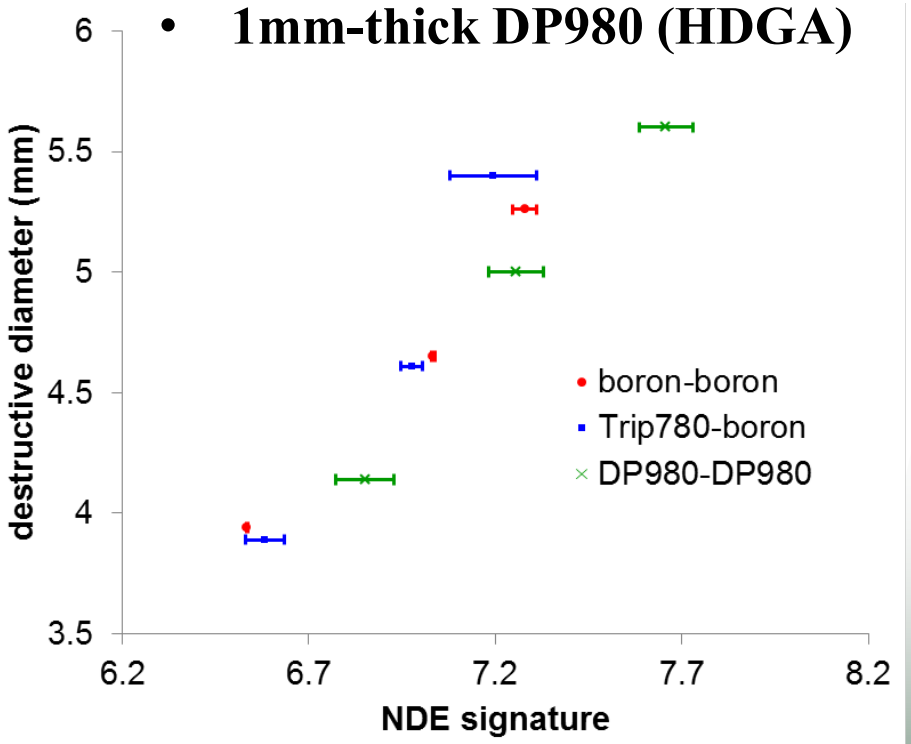
Accomplishment (Post-weld NDE): New Algorithm Quantitatively Distinguishing Weld Nugget Size

- DP980CR 1.2-1.2mm



Flash light heating

- 1mm-thick boron steel (aluminized coating)
- 1mm-thick Trip780 (HDGA)
- 1mm-thick DP980 (HDGA)

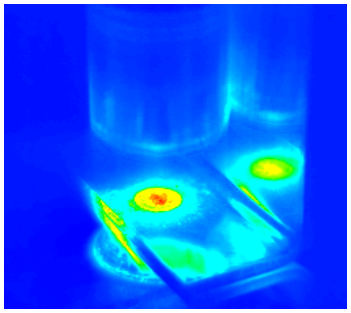


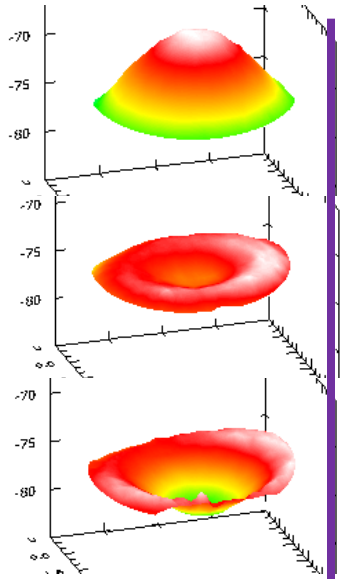
Induction heating

Accomplishment: New Algorithm for Real-time NDE Providing Reliable Detection

- A new IR image analysis algorithm has been developed (patent filing)
  - Insensitive to surface conditions

IR images

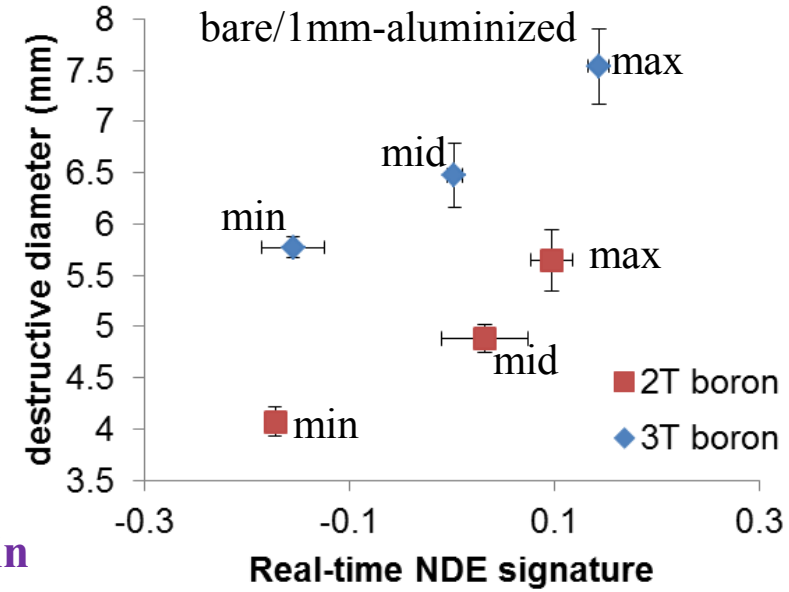




IR signature analysis

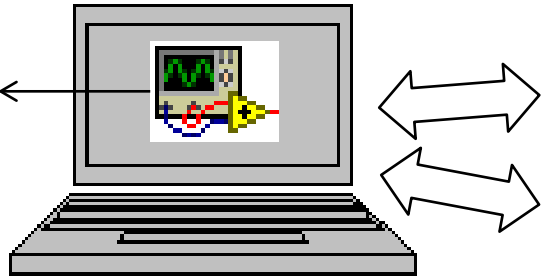
Increase in weld size

- 2T : 1mm-aluminized/1mm-aluminized
- 3T: 1mm-aluminized/2mm-bare/1mm-aluminized



Progress: Prototype of Expert System (Integration of Hardware and Software)

Fully automated software for system control, data acquisition, IR image analysis, training and decision making

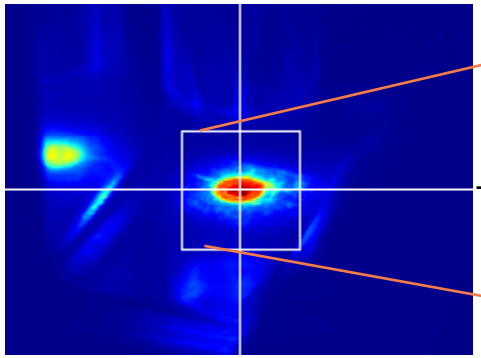


input
output

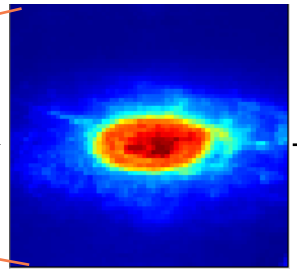
Instrument I/O

- **Production line (Real-time)**
- **Heating device (post-weld)**
- **others**

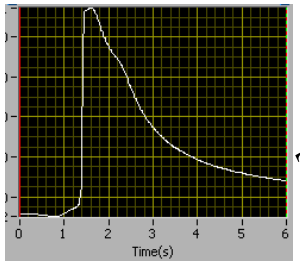
1. Acquire IR images and auto-locate weld spot

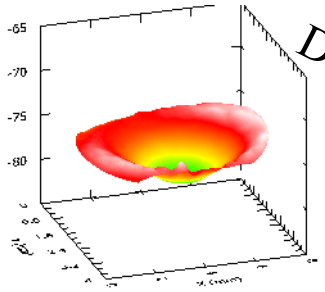


2. Process data only **near** weld for fast analysis



3. Calculated NDE signatures





Training mode

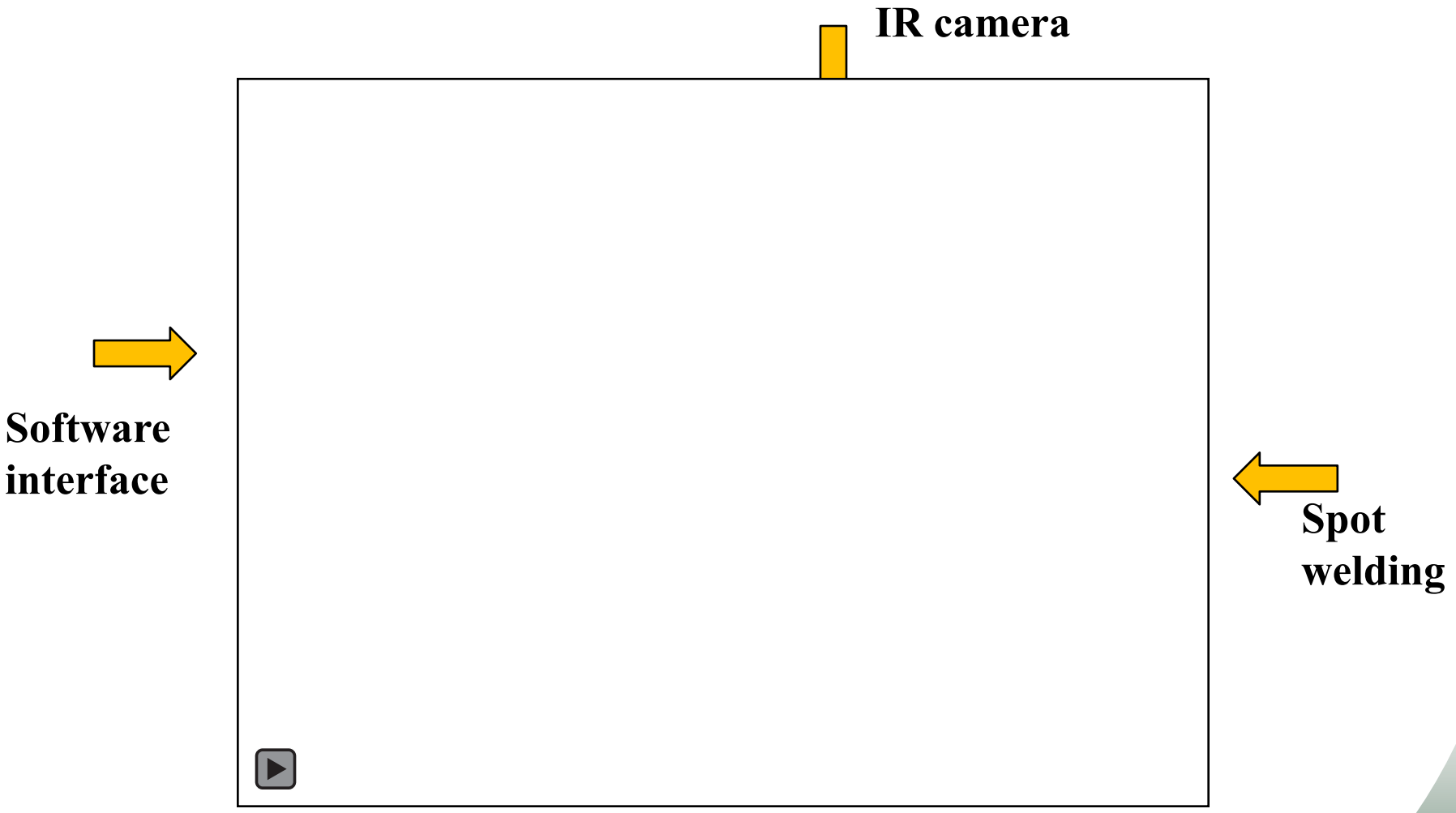
Decision making

Material, welding condition, etc.

Expand database of the expert system

Accept/reject weld

Movie Showing the Prototype IR NDE System in Operation



- Click the above picture to play the movie
- Or click this link to open the Windows Media File (wmv)

Future Plan

- FY2012
  - Produce additional testing welds made with other materials commonly used in auto-body structures
  - Perform more IR inspections to expand the weld quality database covering wide range of weld configurations (materials, thickness, locations)
  - Continue to refine and optimize the automated IR image analysis algorithms to reliably and quickly detect major weld qualities.
  - Continue on the development of software and the system integration of the hardware
- FY2013
  - Complete the development of the prototype system
  - Perform field demonstration
  - Seek industry partnership for technology transfer and eventual commercialization

Summary

- Successfully demonstrated the feasibility to detect major weld quality and defects commonly encountered in resistance spot welds made using industry practices
- Confirmed the adequacy of low-cost IR camera for IR NDE
- Developed efficient IR image analysis algorithms for both post-weld and real-time inspection
  - Time duration for entire detection and decision can be less than 2 seconds
  - Further refinement/optimization underway
- Developed a prototype of automated software for system control, data acquisition, IR image analysis, deciding on weld quality, etc.