

Online Weld Quality NDE & Control with IR Thermography

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Overview

Timeline

- Start: June, 2008
- End: September, 2012
- Percent complete: 30%

Budget

- Total project funding (up to FY10)
 - DOE share: \$700K
 - Industry cost-share: \$40K
- Funding received in FY09: \$0K
- Funding for FY10: \$450K

Barriers

- Barriers addressed
 - Integrity of weld joints, a critical barrier to the use of AHSS and other materials for weight reduction, safety, and performance of body and chassis structures

Partners

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

Technology Gaps that This Project Addresses

- Industry has been relying on pry-check and teardown for resistance spot weld (RSW) quality inspection and control
 - Labor intensive and expensive (rework and scraps)
 - Less effective for advanced high-strength steels, aluminum and other lightweight materials, impeding the widespread use for light-weighting
- In 2007-2008, USCAR conducted an assessment of the industry needs and state-of-the-art of NDE technologies (AMD605)
 - Industry needs: real-time inspection and postmortem (post-welding) inspection
 - Lack of viable NDE may discourage the use of lightweight materials: high strength steel and aluminum
 - “No economically reliable method exists today to inspect resistance spot welds at production rates, and the only technical needs identified in the project for further development consideration were in infrared thermography technology”

AMD 605: In-Line Resistance Spot Welding (RSW) Control and Evaluation System Assessment for Light Weight Materials

Project Objective:

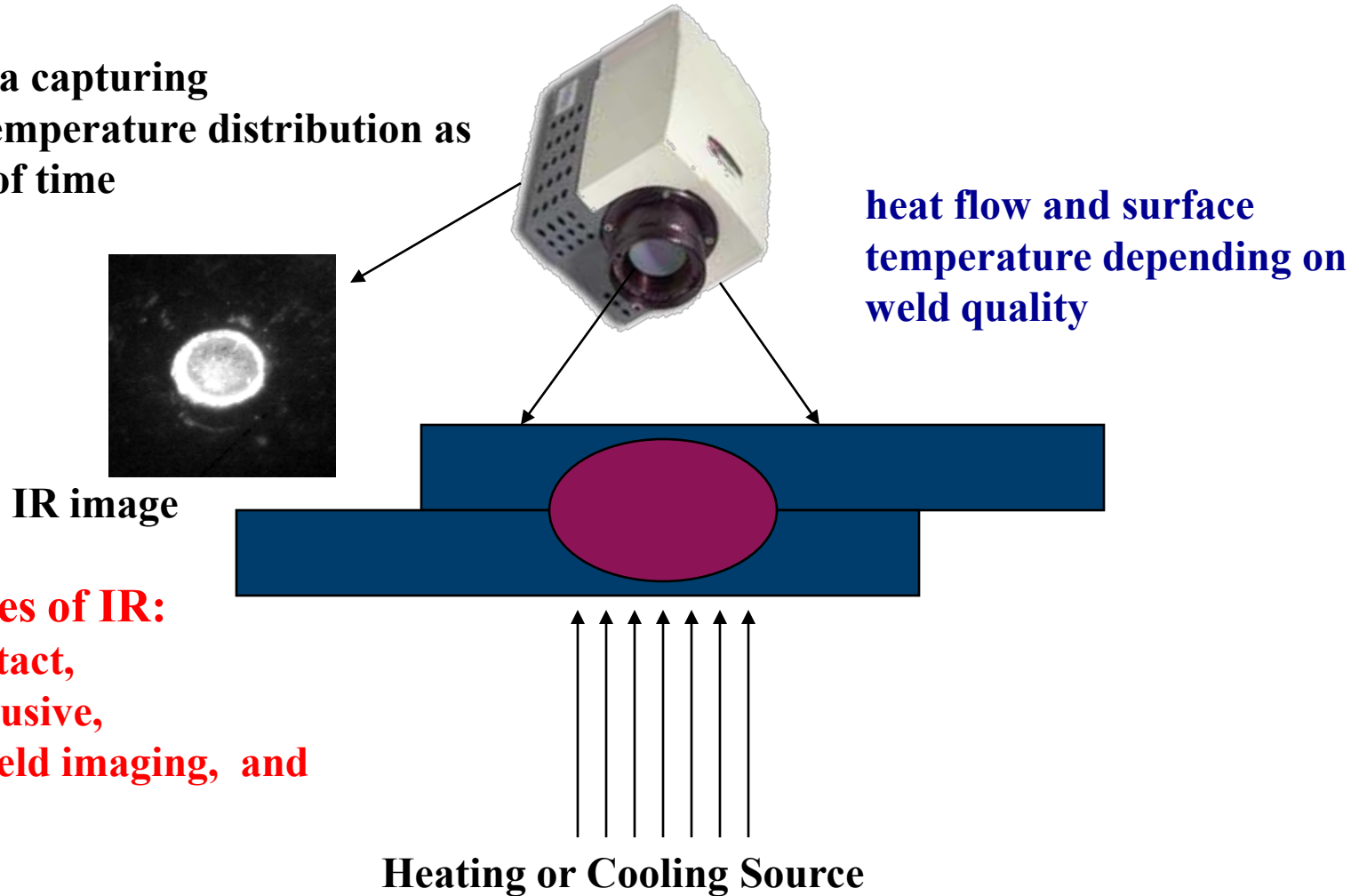
Develop an online spot weld quality monitoring technology based on infrared (IR) thermography that can be adopted reliably and cost-effectively in high-volume auto production environment for weld quality assessment



Replace the \$1 million booth with an IR Inspection Station

IR Thermography Based Weld Inspection

IR camera capturing surface temperature distribution as function of time



Advantages of IR:

- Non-contact,
- Non-intrusive,
- Whole field imaging, and
- Fast

Key Questions: Are IR signatures sufficient for weld quality inspection?
Is the technology feasible for automotive application?

Past Attempts on IR NDE


- Postmortem NDE with mostly limited to laboratory trials
 - Flash lamp heating source: pulsed heating in milli-seconds
 - Positive correlation with weld quality
 - However, minimal surface temperature change (low signal-to-noise ratio)
 - Highly sensitive to surface condition and environment interference
 - Requiring painting of weld surface – impractical in auto production line
- No successful attempts as real-time NDE



Project Approach/Strategy

- Phase I Concept Feasibility (FY08-FY09)
 - Demonstrate the feasibility of detecting various weld quality/defect attributes with sufficient resolution
 - Post-weld inspection (must overcome critical shortcomings of past attempts)
 - Real-time inspection as weld is being made (new approach)
- Phase II Technical Feasibility (FY10-FY12)
 - Develop the IR thermography based online spot weld quality monitoring technology to reliably and cost-effectively operate in high-volume auto production environment

Weld Quality Metrics for This Project

- 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
 - IR technique needs to positively identify the above weld defects/attributes
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- Most critical
- Less critical

Progress/Accomplishments

- Weld samples with controlled weld quality/defects attributes
 - Destructive examination to characterize and quantify them
- Post-weld IR inspection
 - Increasing the IR signal-to-noise ratio
 - Better heating and cooling techniques
 - Digital image processing
 - Reflection reduction/minimization
 - As-welded surface condition
 - Heating and heat transfer modeling to guide inspection and data analysis
 - Initial development of an expert system to correlate IR signal to weld quality attributes
- Real-time IR Monitoring
 - Using the heat flow during welding
 - No surface treatment

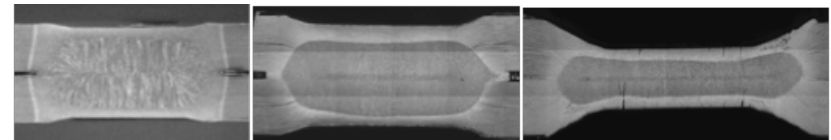


Figure 1. Cross-section view of acceptable weld (left), expulsion weld (middle) and weld with severe cracking (right).

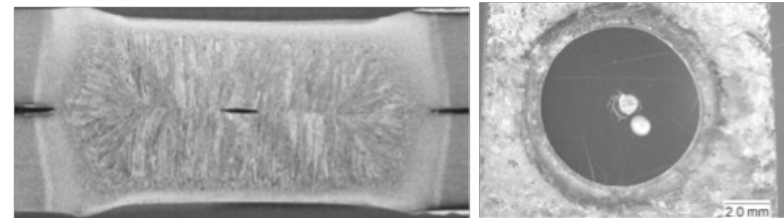


Figure 2. A weld with center voids shown (a) in cross-section view and (b) by machining off one of the steel sheets.



All welds were produced by ArcelorMital as in-kind contribution

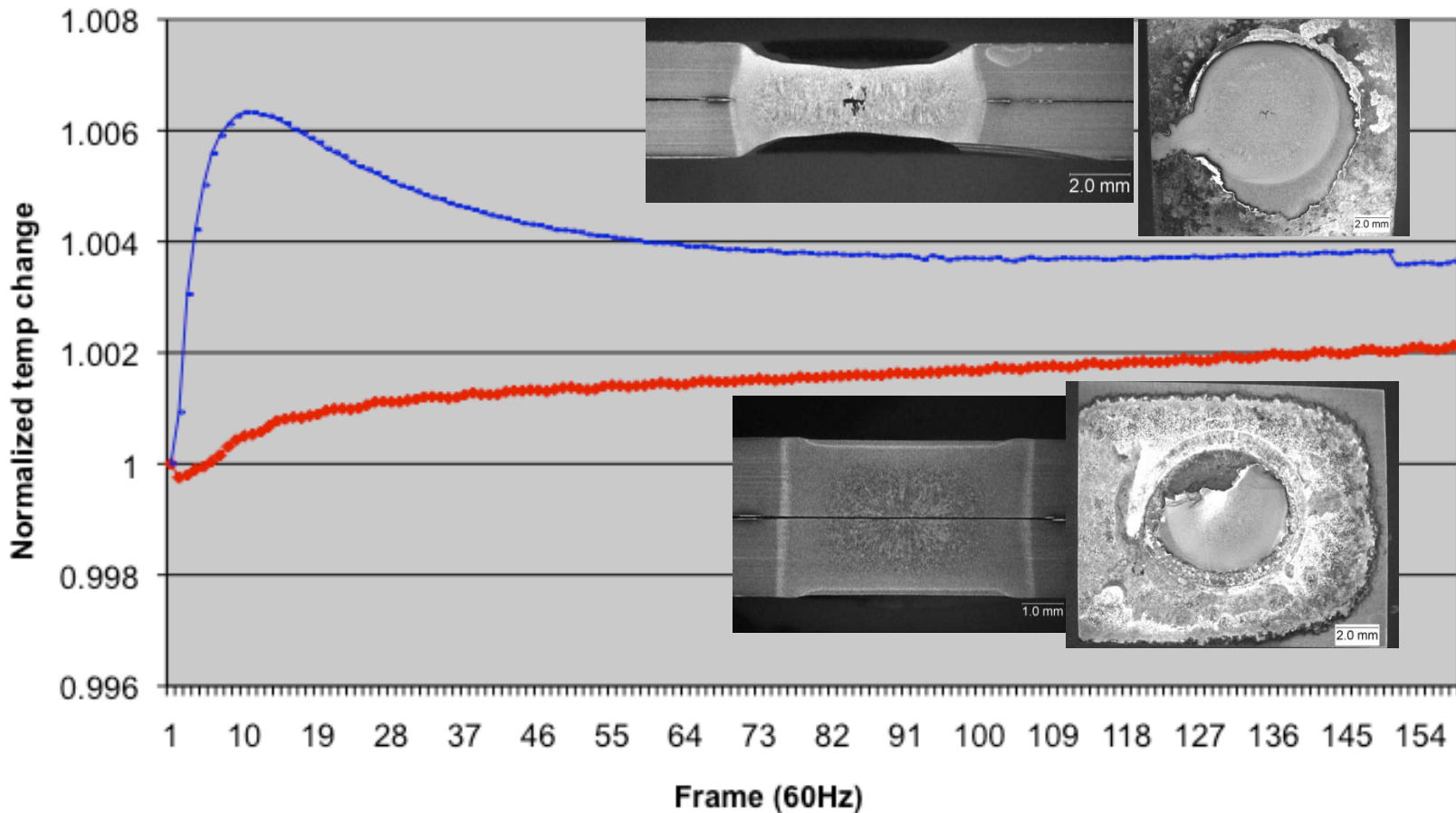
Accomplishments: Development of Heating/Cooling Methods for Post-Weld Inspection

- Xenon Flash Lamp
 - Commonly used in the past. Minimal temperature change ($dT = \sim 0.1^\circ\text{C}$), and sensitive to surface conditions & environment noise
- Ice Cubes
 - 0°C . Large temperature differential ($dT = \sim 25^\circ\text{C}$), but wet
- Vortex Tube Cold Air Gun
 - $dT = \sim 15^\circ\text{C}$, difficult to control air flow, less consistent
- Hot Air Gun
 - $dT > 30^\circ\text{C}$, less consistent
- ORNL cooling technique
 - Very consistent results allowing for relatively large distinctions between spot welds
- ORNL heating technique
 - Highly controllable and repeatable

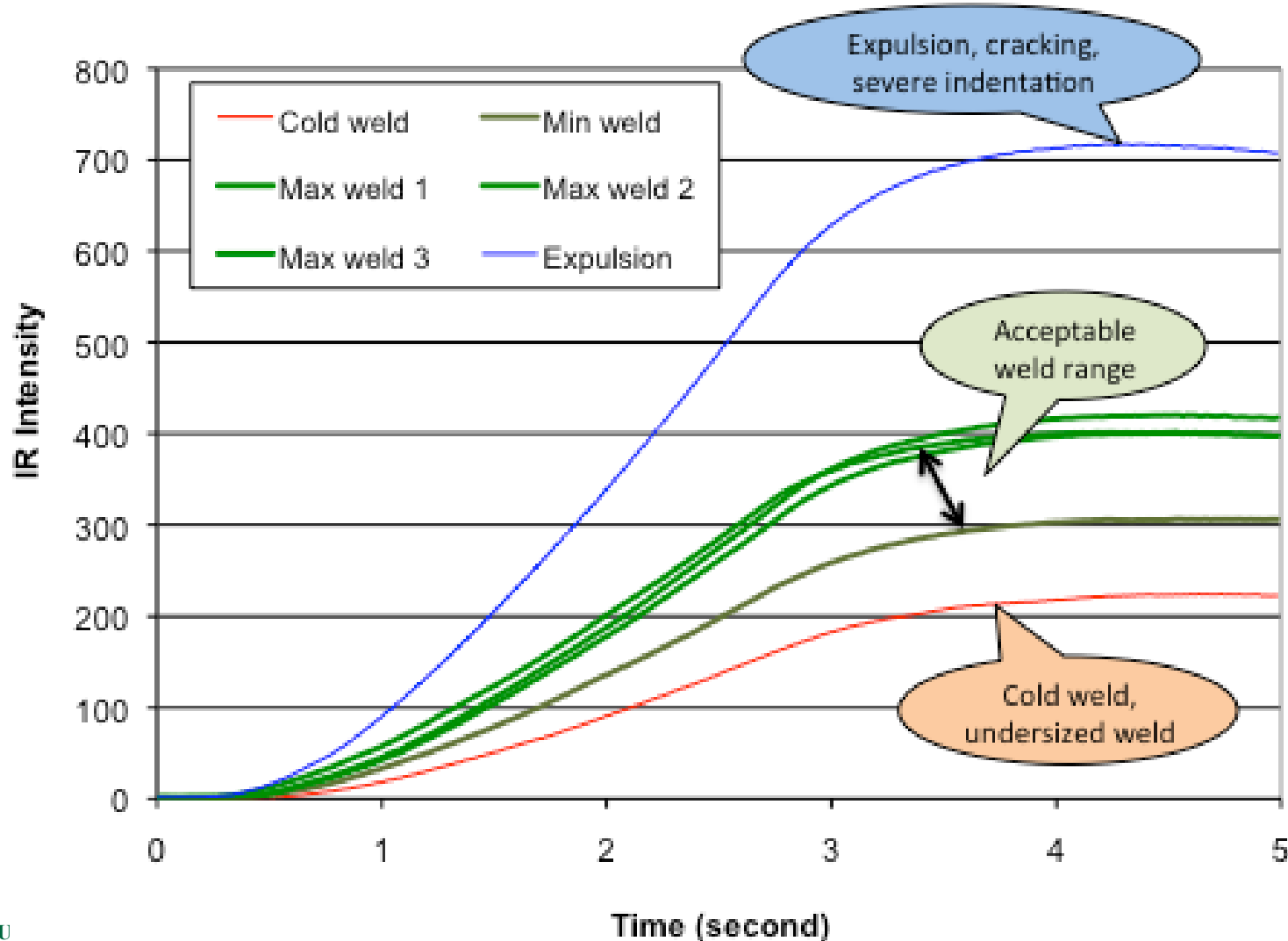


Post-Weld Inspection Accomplishment: Flash Lamp Heating (Baseline method)

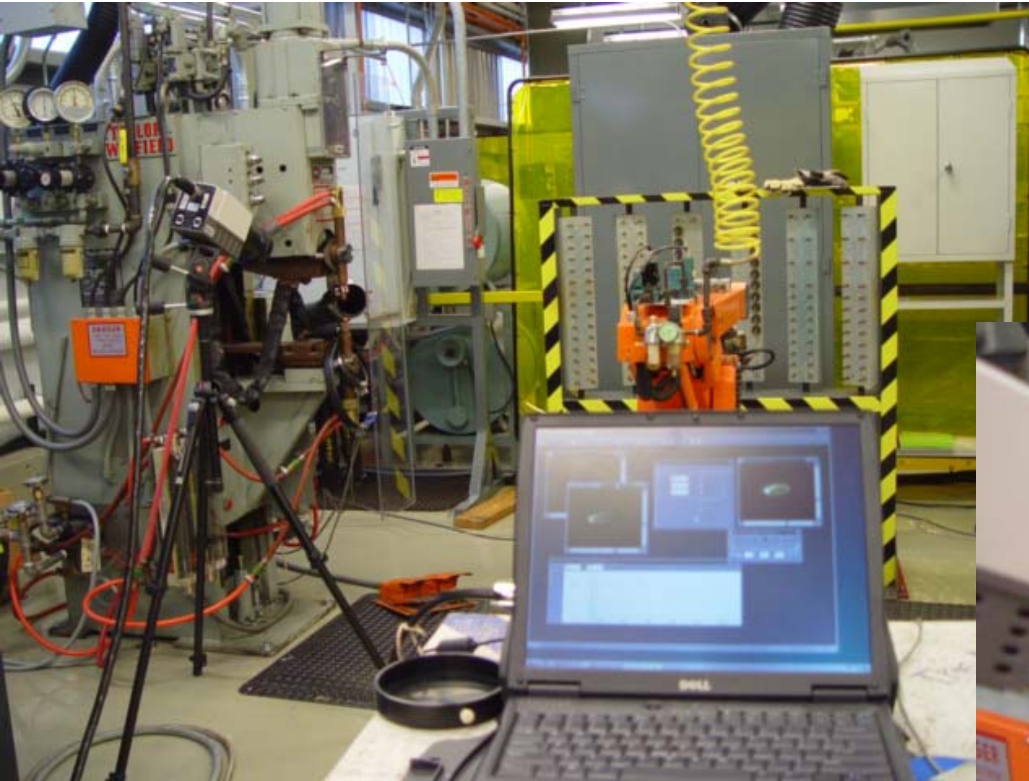
- Clear distinctions between different welds
- But the amplitude is low, prone to interferences in real-world environment (shortcomings of past attempts)



Post-Weld Inspection Accomplishment: ORNL heating method clearly distinguishes different welds

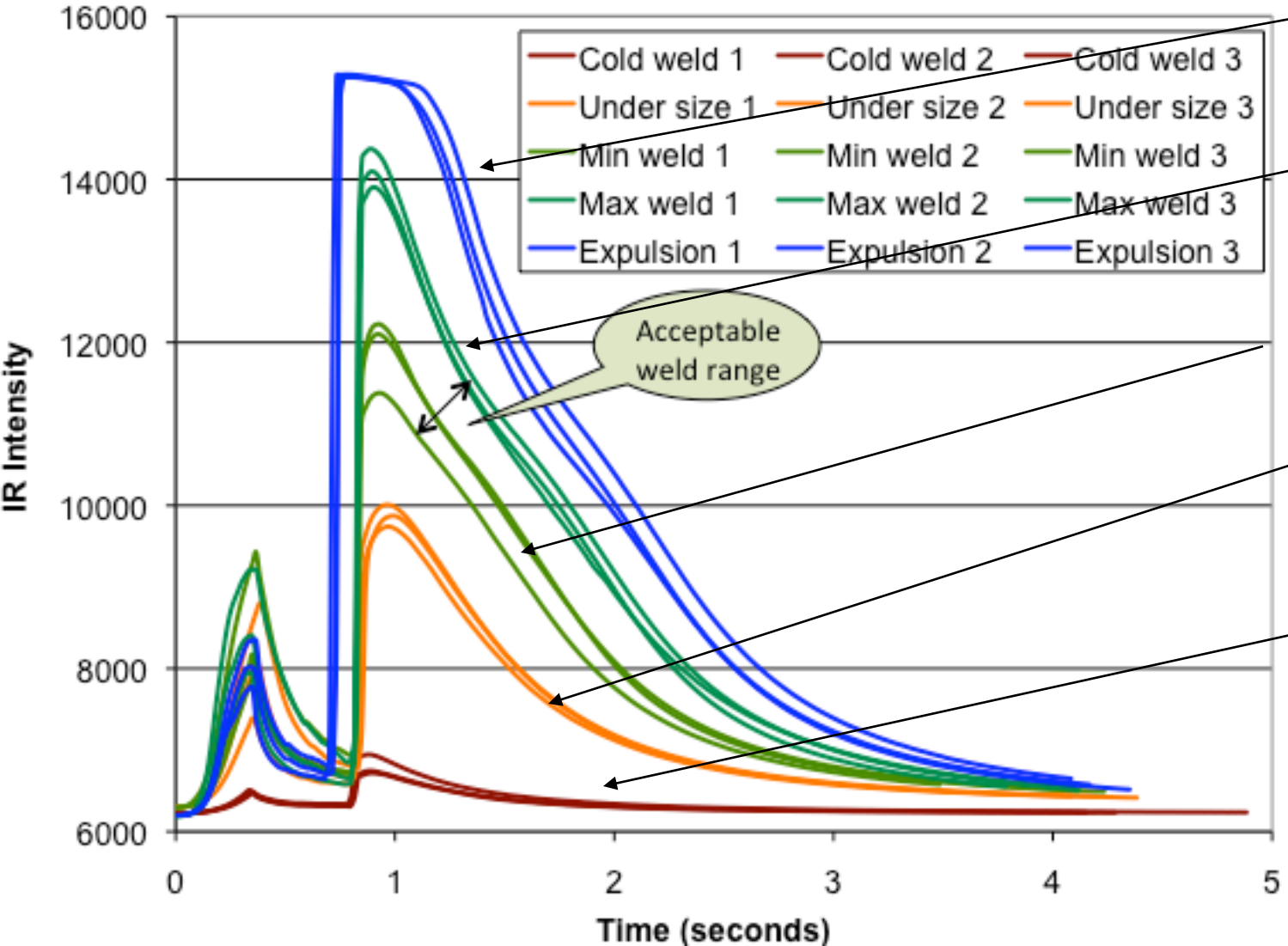
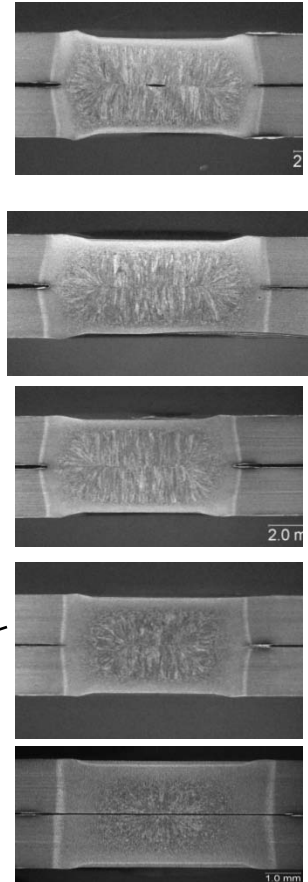


Real-time IR Inspection

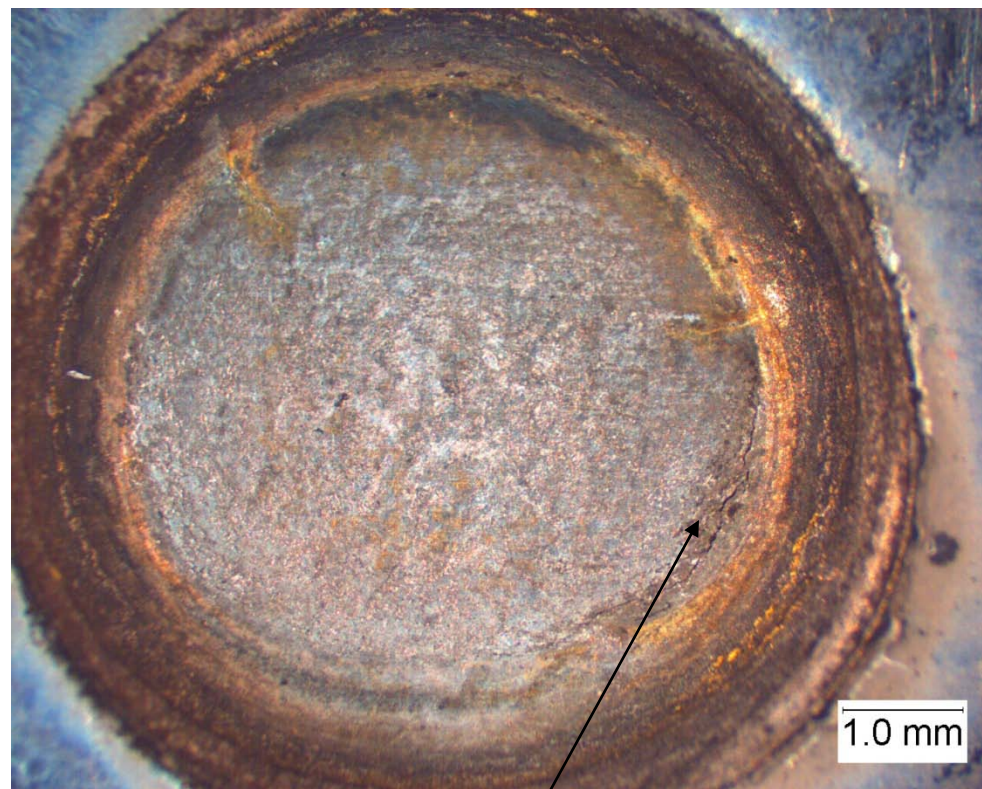
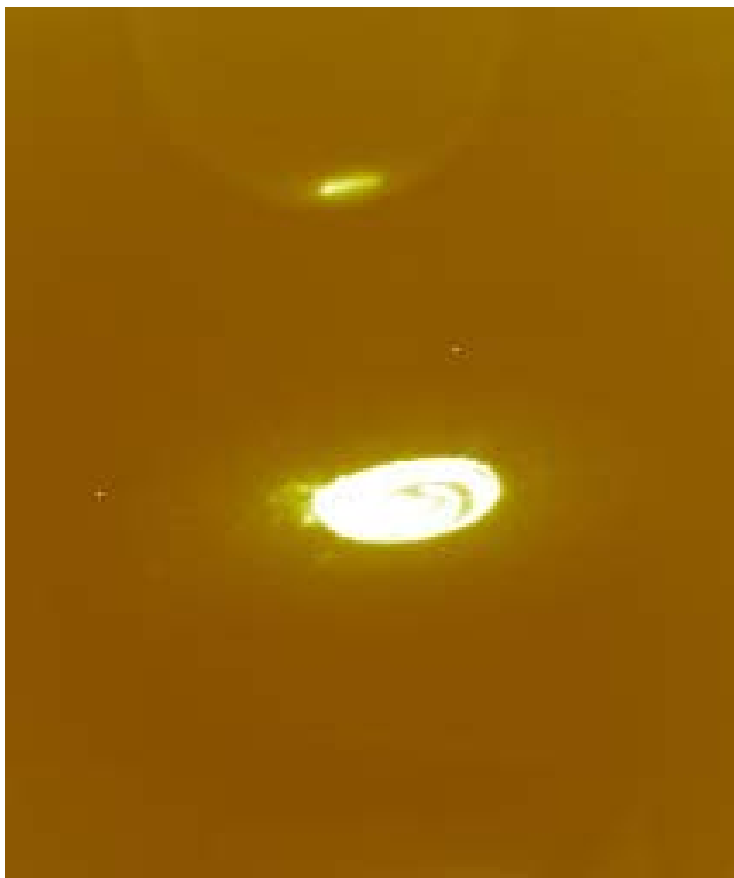


Real-time welding trials at ArcelorMital

Accomplishments: Real Time IR Signatures of Spot Welds

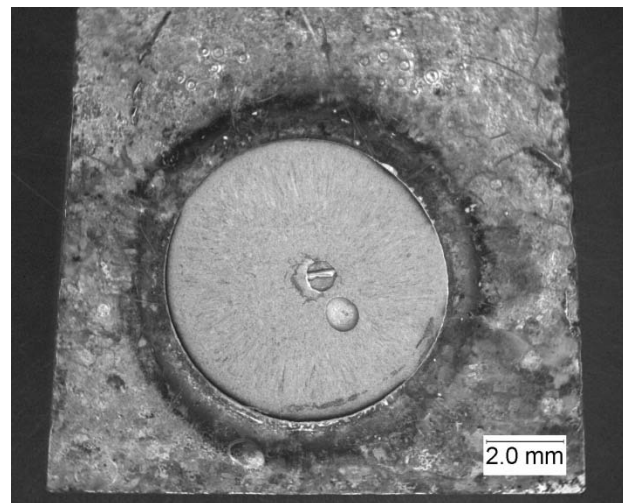
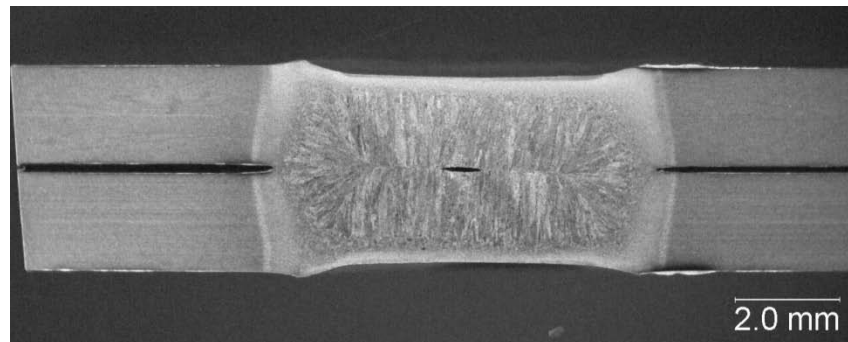


Real-Time Inspection Accomplishments: Positive identification of surface weld crack

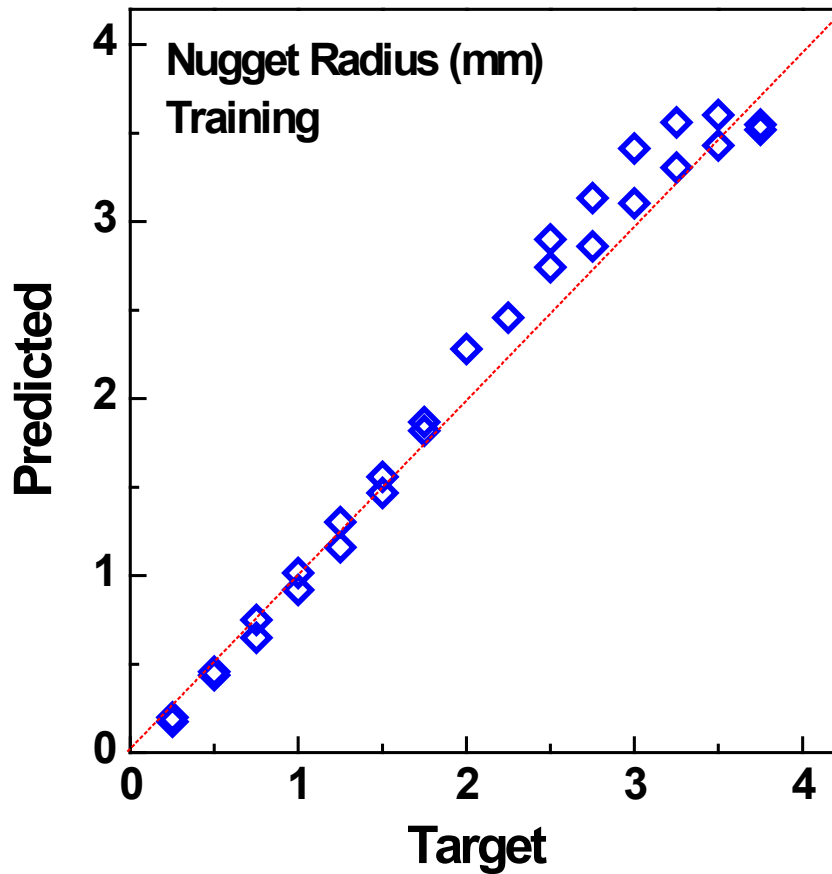


Surface Crack

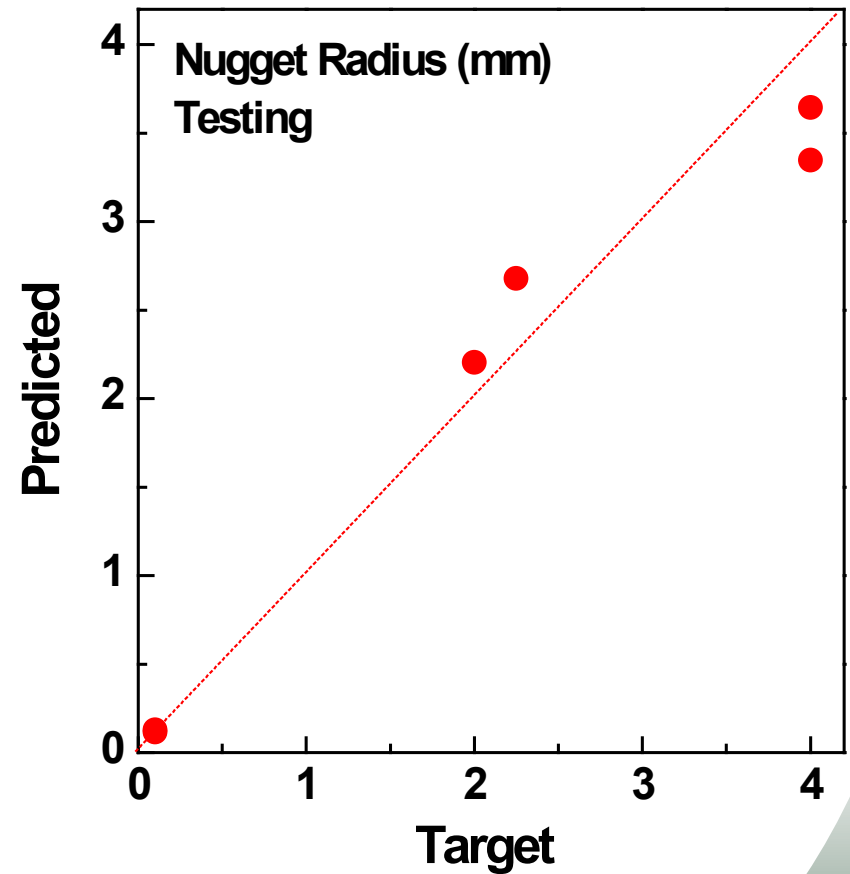
Real-Time Inspection Accomplishments: Positive identification of weld porosity



Accomplishments: Initial development of expert system for IR thermal signature analysis of weld nugget size



Data used in training expert system



Verification of expert system prediction

Accomplishments: Demonstration of Feasibility

Weld Defect	Real-time	Post-weld
Fusion/No Fusion	Yes	Yes
Nugget Size	Yes	Yes
Stuck weld	Yes	Yes
Indentation	Yes	Yes
Expulsion	Yes	Yes
Porosity	> 0.2 mm	TBD
Cracking	> 1 mm	TBD

The IR inspection system can operate in both modes!

Summary

- We have successfully demonstrated the followings in Phase I of the project
 - Feasible to detect major weld quality and defects commonly encountered in resistance spot welds made using industry practices.
 - Feasible for both postmortem and real-time IR measurements to be performed online, and within 1-2 seconds
 - Potential to develop an IR image analysis expert software based on the artificial intelligence principle to determine the weld quality in real-time and without relying on operator's skill and experience.
- Passed Phase I decision gate
- Phase II worked started in FY10

Future Work

- Refine and optimize the field-deployable IR measurement techniques both in real time and in postmortem online inspection, including
 - Design and build simple and cost-effective heating/cooling device for on-line post-mortem inspection
 - Single-side inspection and double-side inspection
 - Range of materials, thickness, surface coating and stacking configurations commonly used for auto bodies
- Develop the robust IR image analysis software that, in real-time, can provide quantitative measure of the quality and the level of defect (if any) of spot welds of *both steel and Al alloys*,
- Identify cost-effective IR imaging camera system that meets the online weld quality inspection needs,
- Develop a prototype IR weld quality monitoring expert system (hardware and software) for field demonstration, and
- Develop industry partnership for technology transfer and eventual commercialization.