Non-Destructive Inspection of Adhesive Bonds in Metal-Metal Joints

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David Moore, co-PIs
Dennis Roach
Ciji Nelson
Sandia National Laboratories

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2009 DOE Vehicle Technologies
Program Review - ALM

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Outline

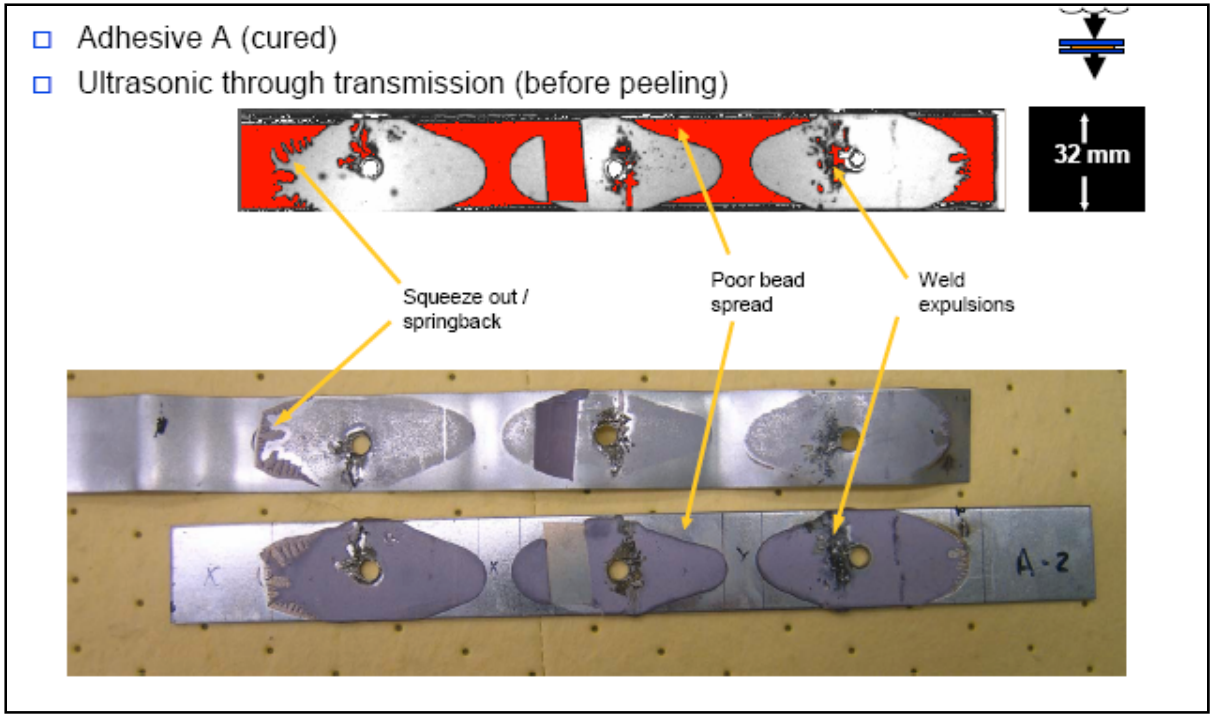
- NDE601 Objectives
- FY09 Milestones
- Technical Barriers
- Approach
- Performance Measures and Accomplishments
- Technology Transfer
- Publications/Patents
- Plans for Final Year
- Summary

NDE Objectives

- Develop nondestructive inspection (NDI) methods for adhesive bond evaluation that can be used in an automotive manufacturing environment to foster increased confidence and use of adhesive joining.
  Impetus: The wider use of adhesive joining will result in reduced vehicle weight, increased body stiffness, and improved crashworthiness. Adhesives are also a critical enabler for the joining of dissimilar materials.

- Apply NDI methods to characterize weak bonds and quantify their strengths

To accomplish the above objectives, the various attributes that determine the bond strength must be identified. A nondestructive inspection method must developed to assure the strength of the adhesive. The success of this approach will be quantitative correlations of NDI to measured bond strengths for full strength bonds and weak bonds.



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Technical Barriers

- Adhesives increasingly being used because they
  - Increase body stiffness - without significant mass increase
  - Increase body strength – without significant mass increase
  - Enable dissimilar materials, e.g. steel + Mg, or composite + steel to be used next to each other
- Reduce cost of light-weight materials.
- Adhesive bonding is a critical technology
  - Present in ~95% of the Mg Front End joints
  - Present in all the Composite Underbody joints
  - Allows less expensive sheet product to be used instead of castings or extrusions
- Spread strain for more brittle light-weight materials, especially around joints.

FY09 Milestones

- **Milestone 1: Complete**

  Finalize the ultrasonic signal processing capabilities within the Ultrasonic Phased-Array system and determine if an adhesive thickness algorithm can be applied to the USCAR production inspection equipment.

- **Milestone 2: Complete**

  Finalize and deploy an ultrasonic inspection system at one of the USCAR production plants. Develop a written procedure and provide initial training to inspection personnel.

- **Milestone 3: Ongoing**

  Manufacture the weak bond samples and evaluate a wide array of candidate NDI methods. Down-select a nondestructive inspection technique that can accurately detect/assess "kissing" or weak bonds. (Final Tasks 10 – 15 of the project)

Approach

- Work with adhesive suppliers to identify key features that determine the adhesive bond strength quantitatively (complete)
- Work with NDT experts, especially from aerospace, to identify leading NDT technologies to measure these properties in vehicle structures (complete)
- Verify targeted methods on coupons (NDT prediction vs. quantitative strength measurements)
- Test performance of methods on production vehicle bodies

Partners

GM

Ford

CHRYSLER

DOW

Henkel

LORD

Inteligent Optical Systems

IOS

OLYMPUS

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Approach - Mapped to Production Requirements

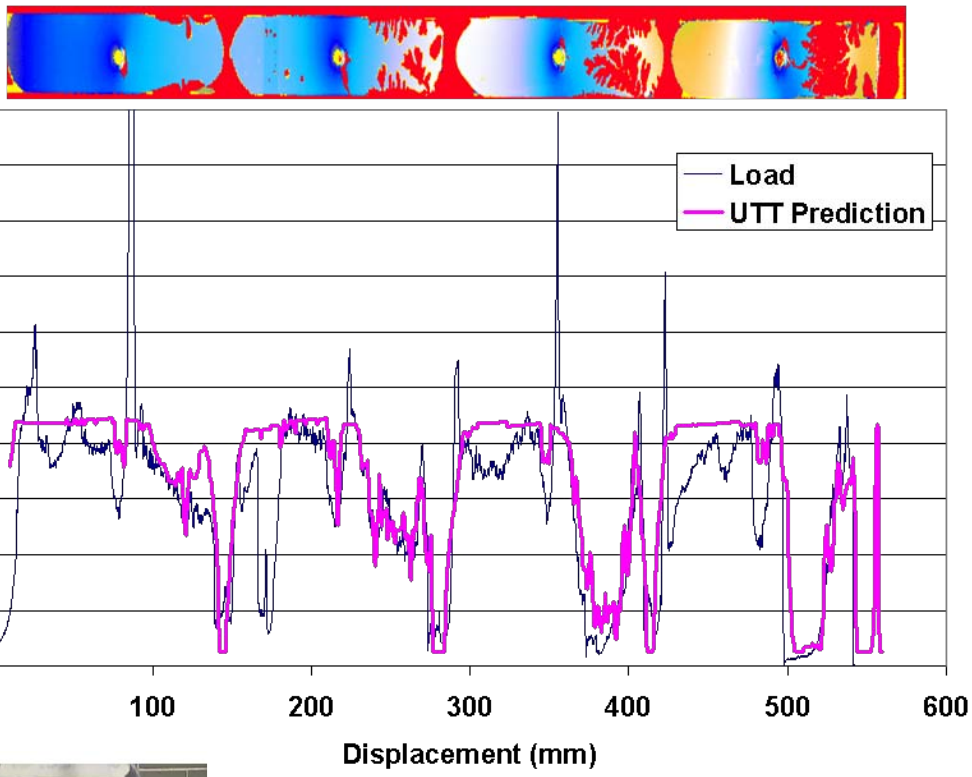
- **The method(s) must be single-side inspections that can follow a flange, navigate large changes in geometry, have spatial resolution near 1-mm and have an overall inspection speed of at least 1 m/min.**

- **The inspection method(s) must be deployed on multiple automotive bodies in white (BIW) containing adhesive joints produced by the OEMs. Complex geometries can impede the inspection strategies.**

A two-step validation process has been followed: first successfully inspect the flat engineered adhesively bonded specimens, representative of automobile flanges. Secondly, deploy the inspection method on production car bodies.

Accomplishments – Mechanical Strength Characterization of Adhesive Joints

- The wedge-peel method uses an instrumented load frame to pull a standard wedge (IS011343) through the adhesive bond. This creates a high-resolution strength map (shown at right).
- The load frame versus displacement curve was compared with NDE inspection data.
- Simple adhesive strength laws based on bond width and thickness are adequate for predicting the wedge peel strength if the bond strength varies over multi-centimeter length scales.



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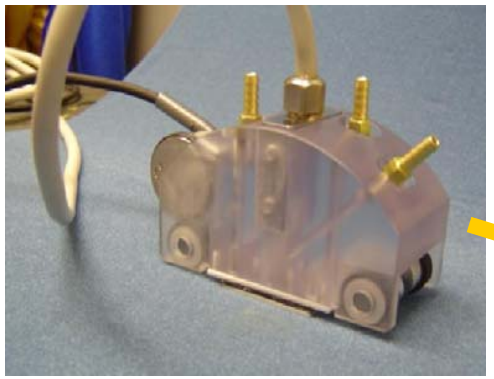
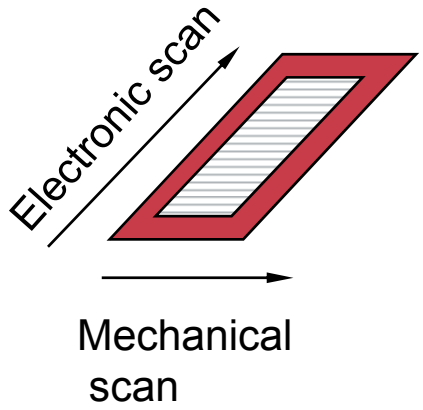
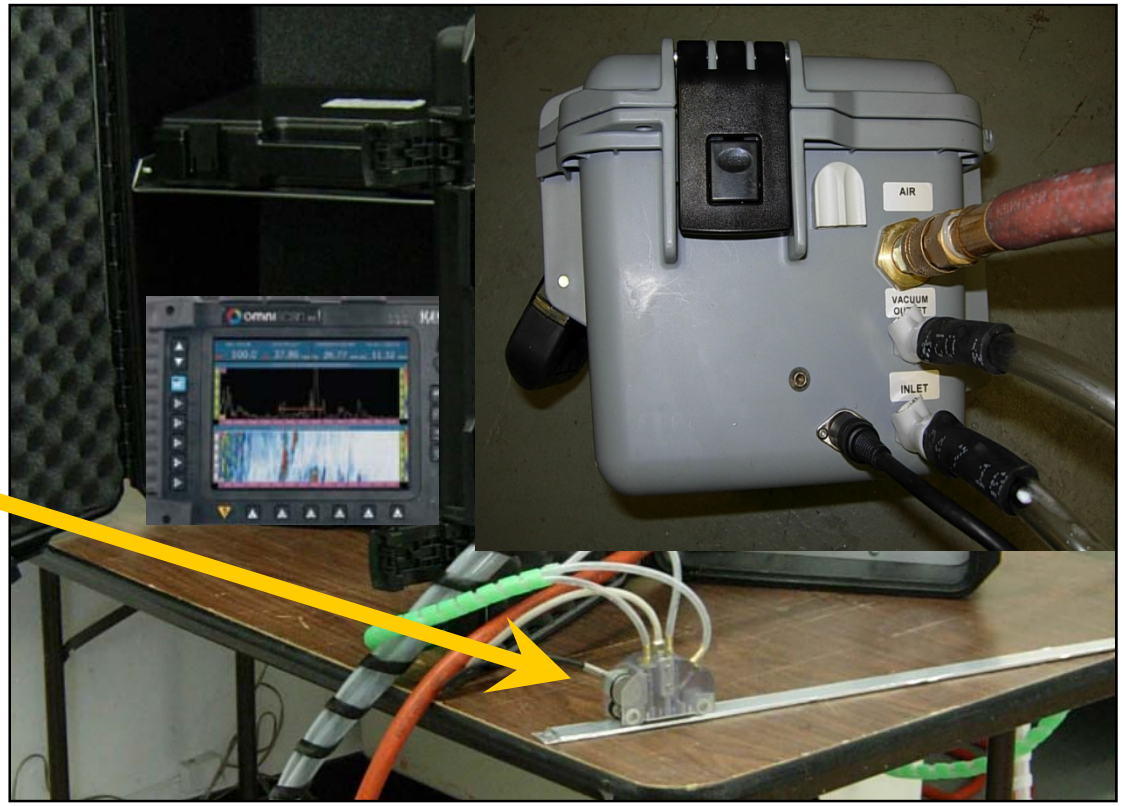
Accomplishments – Deployed a high-frequency ultrasonic phased array probe

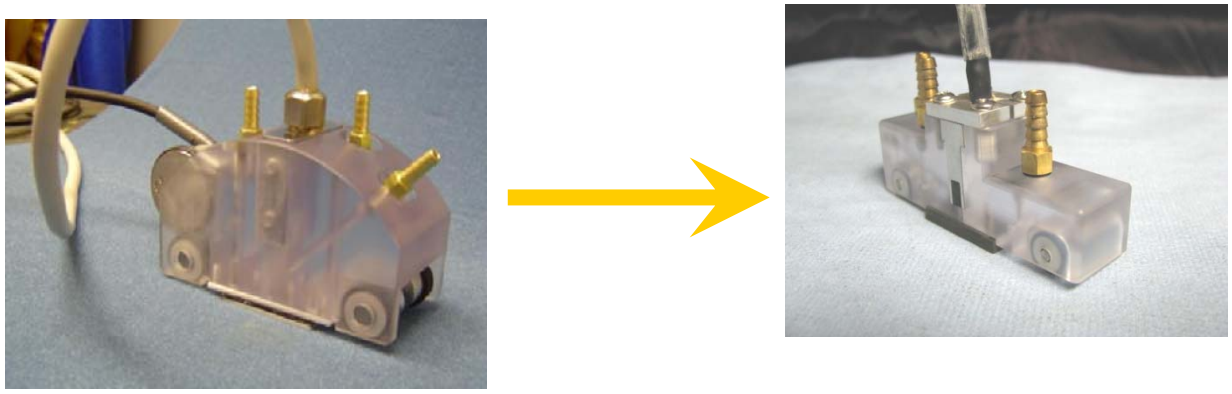
- Manual
- Portable – closed loop water COTS
- Water use: <1 cup/100 m
- Resolution: 0.5 mm
- Speed: 5 m/min



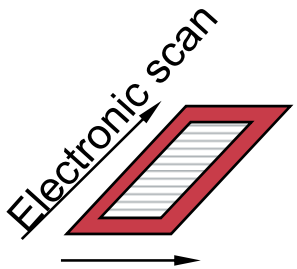




Accomplishments – Deployed a 2nd generation high-frequency ultrasonic phased array probe



- Can inspect 85% of footprint
- Can inspect more confined locations
- Can inspect virtually any convex surface
- Can inspect panels with tight concave curvature (0.3 m radius)



	Gen 1	Gen 2
Encoder type	wheel	string
Body width	37 mm	18 mm
Scan width	25 mm	15 mm
Height	50 mm	25 mm
Length	90 mm	65 mm

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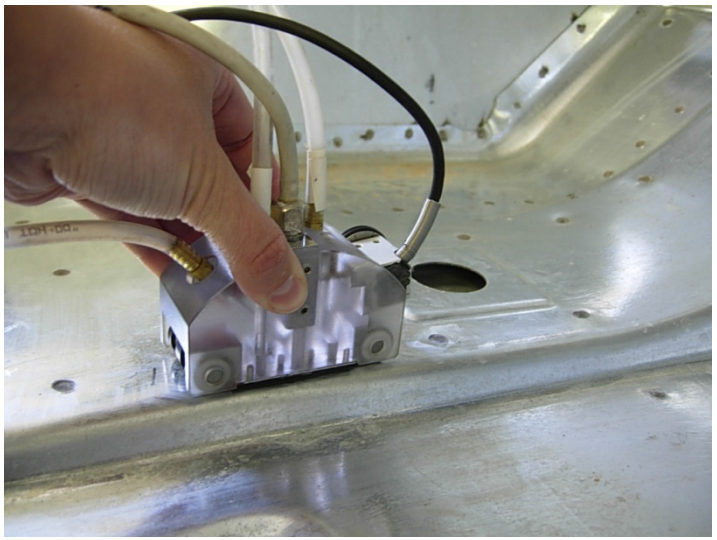
Accomplishments – Body in White Inspections

- Team completed the evaluation of the first generation array and probe holder on three body-in-white (BIW) structures
- BIW inspections covered 100 beads with a wide variety of geometries and probe orientations
- Over 80 % of the adhesive structure could be imaged at a speed of over 1 m/min
- Images showed large-scale features such as adhesive spread and the fill-factor of the flange. The 1-mm resolution also allows small features such as surface springback, air entrainment; beads dribbles, and weld expulsion damage to be imaged.



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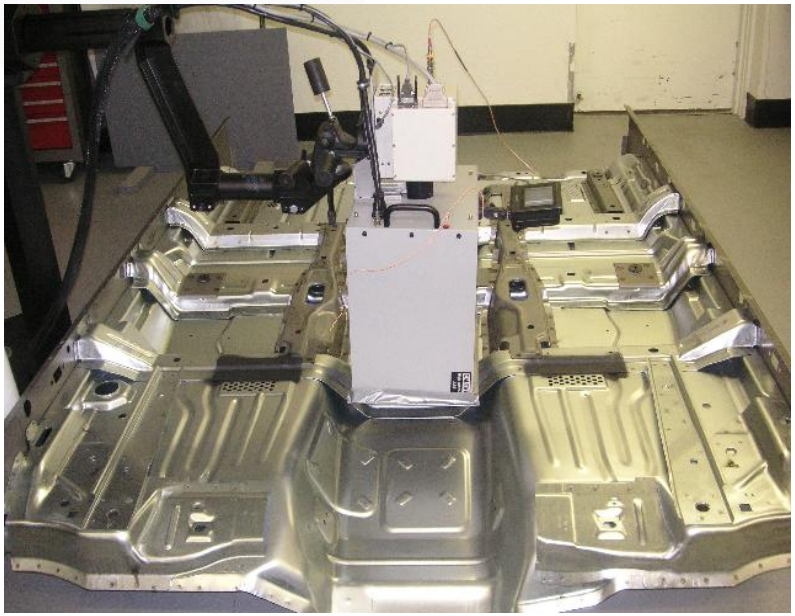
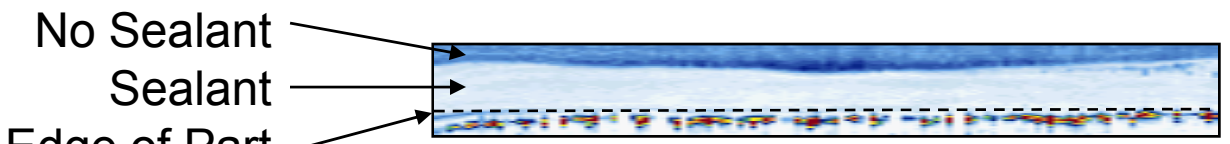
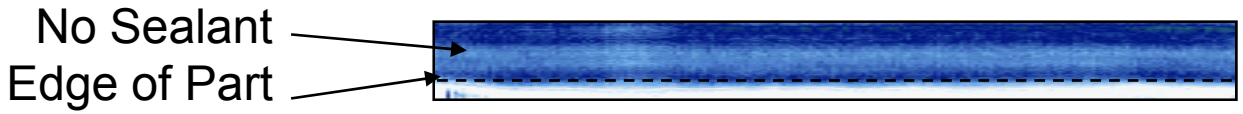
3 Bodies at Sandia/FAA NDI Validation Center



Accomplishments – Body in White Inspections

- Floor Panels





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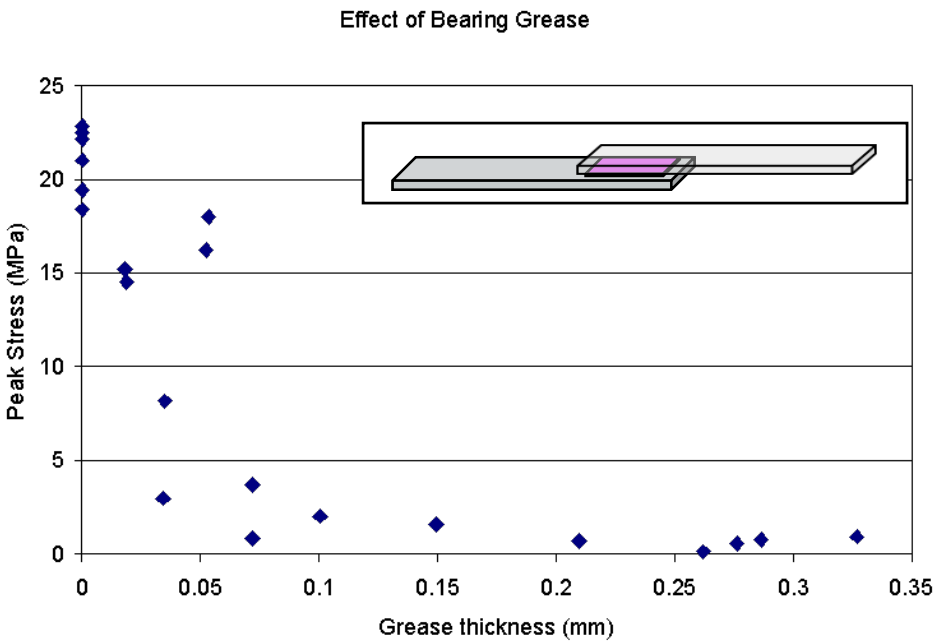
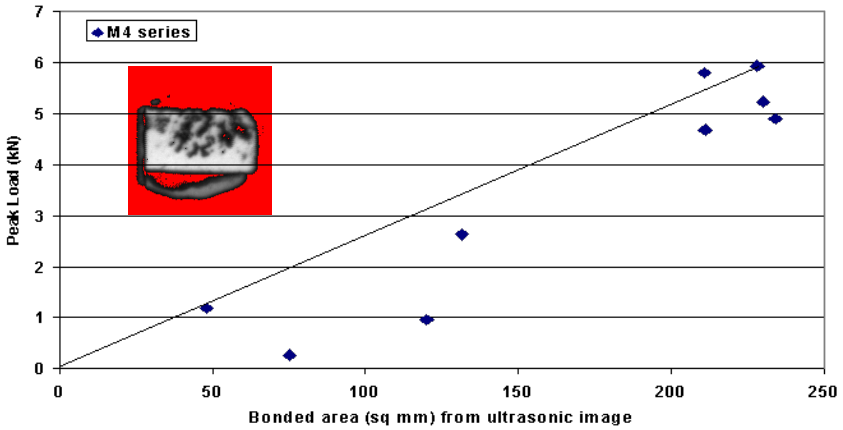
Accomplishments - Weak ("Kissing") Bond Detection

- Carefully controlled lap-shear coupons were produced with repeatable amounts of contamination.

- Extensive work was completed on bonds that have intimate contacts but are weak: so-called kissing bonds. Several new contaminates, were shown to reproducibly reduce bond strength. It was shown that grease reduces both shear and tensile strength with the same sensitivity dependence and that grease contamination can be detected with ultrasonic pulse/echo inspection.





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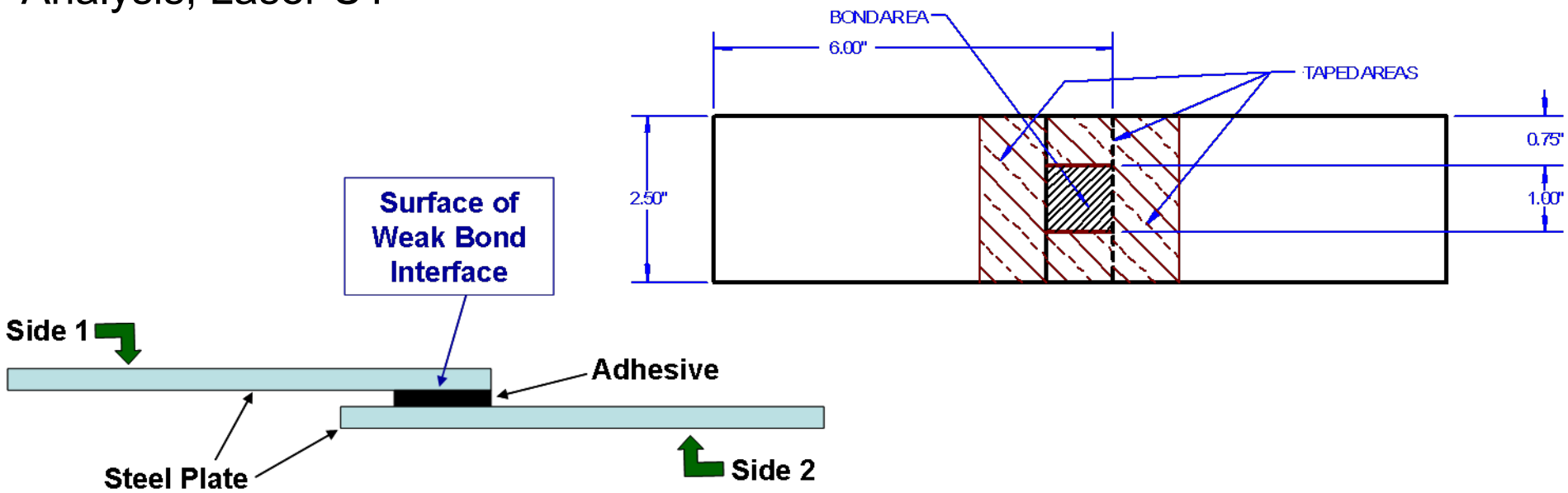
Accomplishments - Weak ("Kissing") Bond Detection

- Reliable methods developed to produce desired range of weak bonds: 10%, 30%, 50%, 70% 90%, 100%; critical to NDI studies; involved use of controlled application of contaminants and adhesive reactants

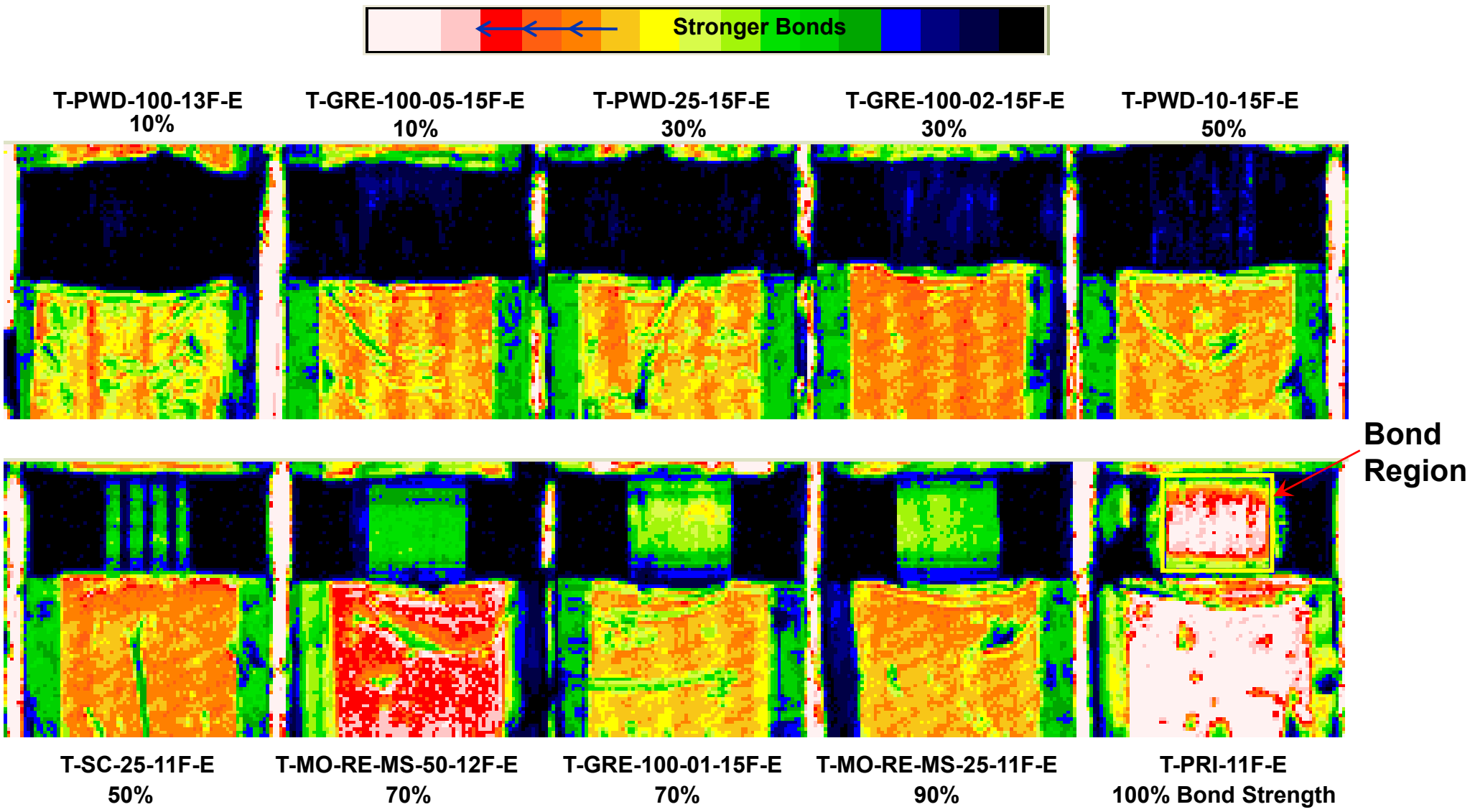
- A large suite of coupons with reduced bond strengths were built for round robin testing of advanced inspection methods.

- NDI being applied includes: Through-Transmission Ultrasonics (TTU), Pulse-Echo UT, Phased Array UT, Thermography, Laser Shot Peening, Nonlinear UT, UT Spectroscopy, Resonance, Air-Coupled UT, Modal Analysis, Laser UT



Accomplishments - Weak ("Kissing") Bond Detection

Through-Transmission Ultrasonics traces bond strength



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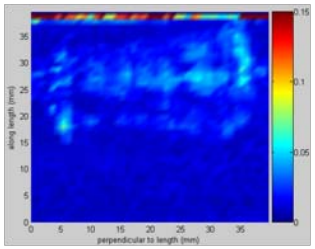
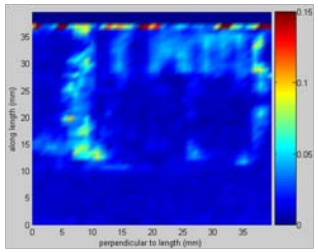
Accomplishments - Weak ("Kissing") Bond Detection

Pulse-Echo UT inspections show promise for assessing bond strength using ratio of peak amplitudes

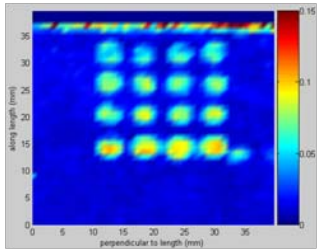
T-GRE-100-05-21F-G
10%



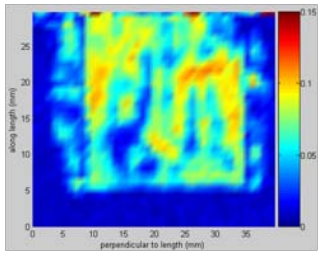
T-GRE-100-02-21F-G
30%



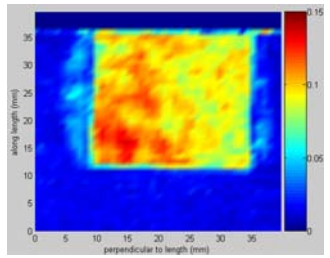
T-SC-25-17F-G
50%

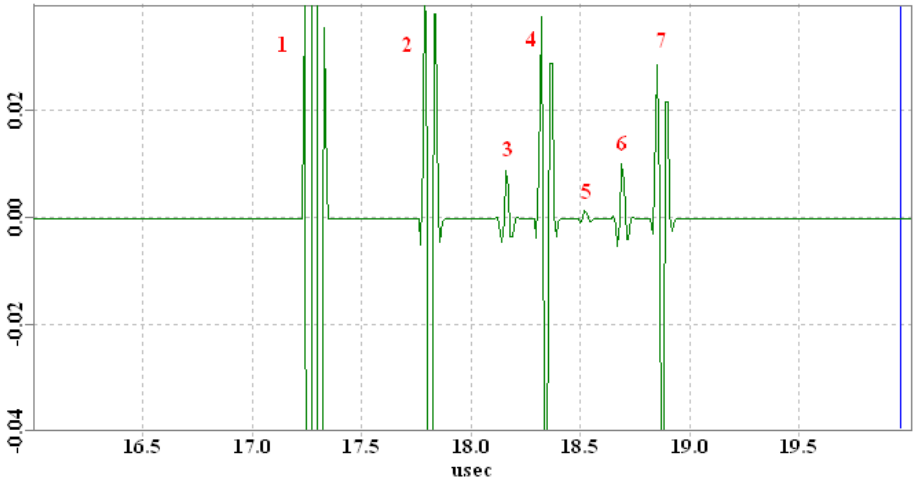


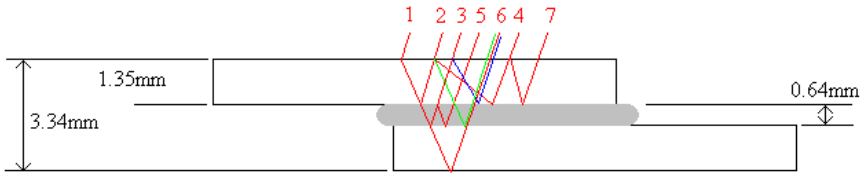
T-GRE-100-01-21F-G
70%



T-PRI-7F-G
100% Bond Strength







Peak 3 interrogates the bond line and is critical to producing sensitive assessments

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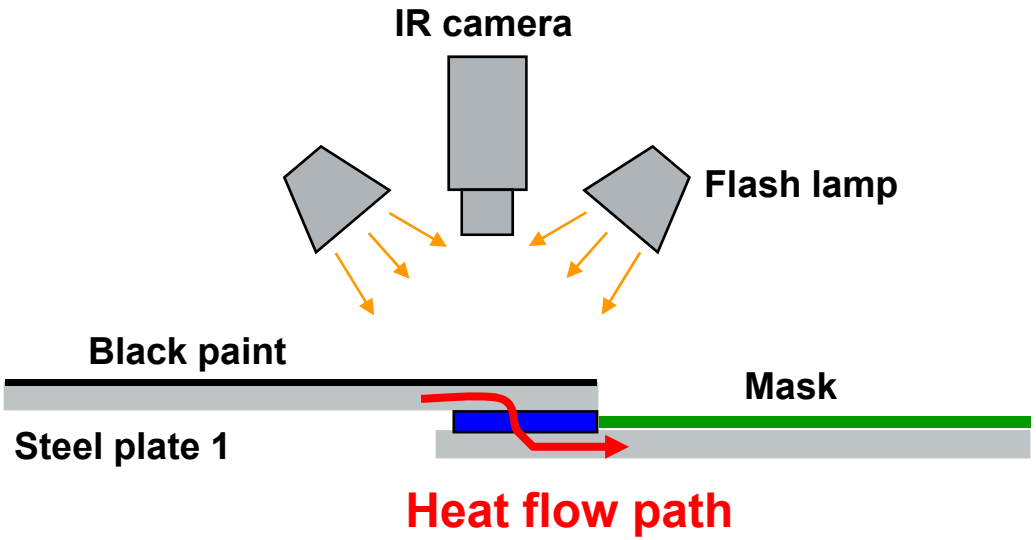
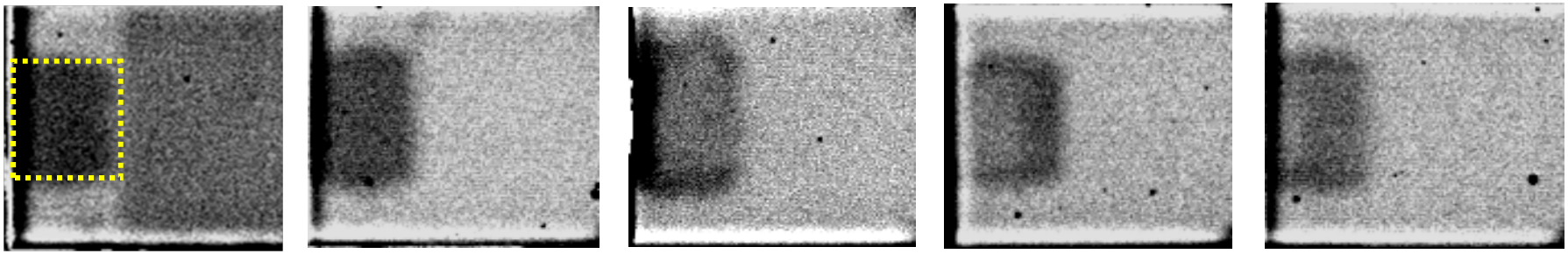
Accomplishments - Weak ("Kissing") Bond Detection

Thermography, coupled with Signal-to-Noise optimization schemes, can differentiate bond strengths





T-PRI-11F-H (100%) | T-GRE-100-01-15F-H (70%) | T-PWD-10-15F-H (50%) | T-GRE-100-02-15F-H (30%) | T-GRE-100-05-15F-H (10%)

Thus far, weak bond assessment results have shown abilities of NDI to clearly identify bond strengths below the 50% threshold; actual quantification of bond strength is more difficult but promising results have been obtained.

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Technology Transfer

- Ultrasonic phased array has been used to answer engineering questions on OEM pre-production and production vehicles. A procedure is now available to USCAR partners.
- Working with NDE vendors to commercialize the phased array and laser ultrasonics technology. The water delivery system is now commercially-off-the-shelf (COTS).
- Working with Automotive Composites Consortium (ACC)
  - Ultrasonic through transmission has been used by ACC Energy, Focal Projects 3 & 4 to verify plaques and components
- Working with AMD 603/604 Mg Front End
  - Apply to Mg Front End joints as they become available (riv/bond)
  - Applied to corrosion tests of Mg bonded lap joints

Publications, Presentations, Patents

- Patent has been submitted for the: Ultrasonic Probe Deployment Device for Increased Wave Transmission and Rapid Area Scan Inspections

- Presentations/extended abstracts/reports
  - K. Lazarz, C. Dasch, and R. Agarwal, “Correlating adhesive bond strength with non-destructive test methods”, The Adhesive Society Annual Meeting, Austin TX, Feb. 2008.
  - NDE601-FY2008 Mid-year Progress Report for DOE ALM, David G. Moore and Ciji L. Nelson Sandia National Laboratories Cameron J. Dasch General Motors Research & Development, May 15, 2008
  - C. Dasch, K. Lazarz, and R. Agarwal,“Inferring Adhesive Bond Strength for Automotive Applications from Quantitative Nondestructive Testing”, The Adhesive Society Annual Meeting, Austin TX, Feb. 2008.
  - C. Dasch, K. Lazarz, and R. Agarwal, “Using Quantitative Ultrasonic NDE to Accurately Predict Adhesive Bond Strengths”, Review of Progress in Quantitative Nondestructive Evaluations”, Chicago IL, July 2008.
  - .“Draft Engineering Report on NDI of Adhesively Bonded Flat, Aluminum Coupons for USCAR /USAMP Project NDE 601 – NDI of Adhesive Metal Bonds”, Cameron Dasch, Joe DiMambro, Ciji Nelson, John Fickes, Jessica Schroeder, Kim Lazarz, Dan Ondrus, Dave Biernat, Raj Agarwal, Ray Bis, Andy Terry, and Dave Sigler, August 14, 2008.
  - “Final Report Phase 1: Developing Ultrasonic Signal Analysis Tools for Metal/Metal Adhesive Bonded Joints”, Steven Neal, September 15, 2008
  - D. Roach and J. DiMambro, “Enhanced Inspection Methods to Characterize Bonded Joints: Moving Beyond Flaw Detection to Quantify Adhesive Strength,” Air Transport Association NDT Forum, September 2008
  - M. Drewry, D. Roach, R. Smith, “Potential Advanced Ultrasonic Methods for Detection of Weak Adhesion,” Journal of Materials Evaluation”, May 2009

Activities for the last fiscal year

- Miniaturize / productionize phased array **(In progress)**
  - Reduce size by 50%, articulated
    - 18 mm flanges, smaller confines
    - 95% of vehicle should be accessible
  - Use commercial circulation system **(complete)**
- Ultrasonic signal processing – adhesive thickness **(In progress)**
- Weak “Kissing” bond evaluations **(In progress)**
  - Phased array performance on grease bonds
  - Access requirements of other kissing bonds
    - Dry lube

Summary

- Adhesives (with good bonding) are a light weight material enabler
  - Allow reduced gauges and reduced # of welds or rivets – reduced costs
  - Adhesives are critical technology for composites, Mg, AHSS where brittleness is a limit
  - Adhesives provide corrosion barrier in dissimilar metal structures

- Dec. 2007-Dec. 2008: Tasks 1-9 completed on time; Tasks 10 -15 will be completed by the end of this FY. Passed Gates 1 and 2. Gate 3 will be decided by end of FY. FY09 Milestones 1 and 2 are complete, Milestone 3 is well underway.
  - Demonstrated that strength (when adhesion is good) can be predicted quantitatively from NDE bond width and thickness measurements
  - Demonstration of NDE performance using commercial technology on steel and aluminum flat coupons
  - Demonstration of NDE performance on production bodies-in-white
  - Completed all bodies-in-white inspections
  - Demonstration of weak bond sample preparation
  - Demonstration of weak bond detection; quantification activities are underway

- Technology transfer is well in hand
  - Commercial vendors involved in development
  - Engaged in production and related USAMP Mg and composite problems

- Plans for Next Year - N/A, program is in final year