

USAMP/NDE 1002 - Hybrid NDE Method for Spot Weld Quality Evaluation

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Overview

Timeline

- Development project
- Start – Jan. 2011
- Finish – Jan. 2012
- 100% Complete

Budget

- Total project funding
 - DOE \$88K
 - Contractor \$88K
- Funding received in FY11
 - \$43K
- Funding for FY12
 - \$45K

FCVT Barriers Addressed

- Cost reduction in the inspection of resistance spot welds
- Performance – provide higher sampling frequency and quicker feedback for better quality and process control

Partners

- OEMs – Chrysler, Ford, GM
- Research Partner – Oakland University

Spot Weld Inspection Background

- Resistance spot welding (RSW) is the conventional joining method for body structures. When optimized, it produces strong, robust joints with low cost. While RSW has reached its prominence in the joining of mild steels, it has been adapted to newer light-weight metals ranging from the extremely strong advanced high-strength steels (AHSS) to aluminum and magnesium. Because of the difficulties in keeping the weld process in control (weld-tip wear, weld-gun control, corrosion associated with cooling, etc.) RSW, even with mild and IF steels, requires frequent weld inspections, typically by tear downs (destructive testing). This is very expensive and has low sampling rates. Inspection of RSW in light weight materials is more critically needed because of increased weld brittleness and because of the high, variable conductivity of aluminum and magnesium.
- There have been many attempts to perform NDE on spot welds. Single-element ultrasonic inspections have been widely implemented at least in Europe but have not been successful on AHSS. An earlier AMD project developed ultrasonic phased arrays that could simultaneously image the weld surface and the faying surface. While this technology generates the most detailed, nondestructive picture of the weld, it was unsuccessful on galvanized low-carbon steels. Ultrasound was unable to differentiate between fused material in the heat-affected zones (HAZ) from the martensitic nugget that gives these welds substantial strength [AMD409 Final Report].

Project Objectives

Rationale:

- Resistance Spot Welding (RSW) is the standard joining technique used to join body panels. The current “chisel-test” is destructive, slow, and labor intensive.
- Optical shearography and similar optical techniques are nondestructive and noncontact methods that show promise in identifying nugget size, a key RSW characteristic.

Objectives:

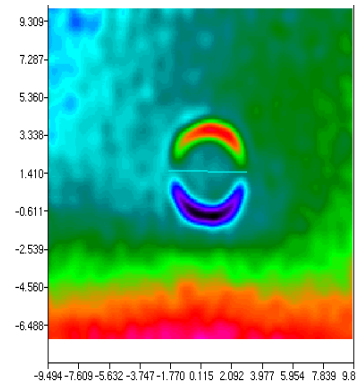
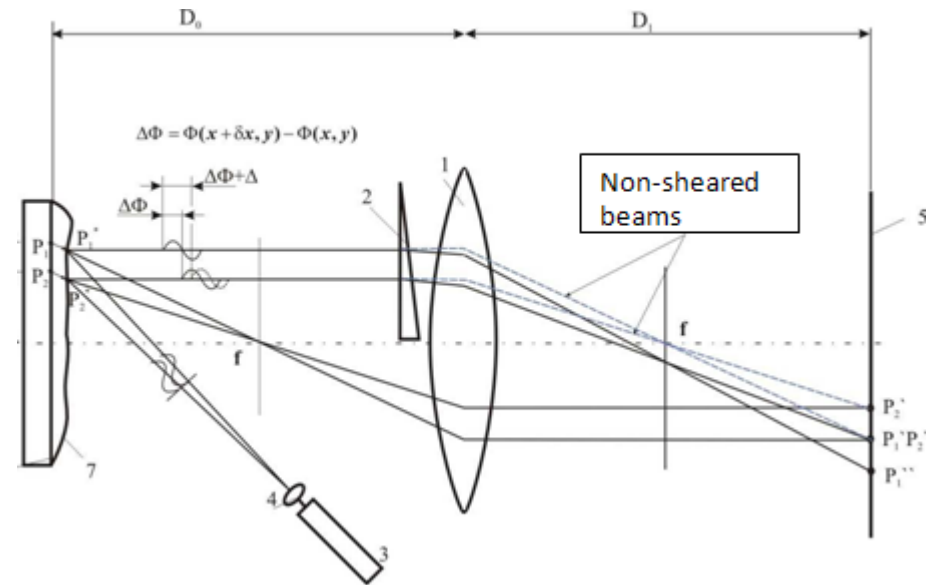
- Select a suitable candidate.
- Identify a shearography system capable for measuring surface strains and displacements with minimum sensitivity to environmental noise.
- Formulate a mathematical model that can be used to solve the problem using known boundary conditions and optical measurements.

Milestones

Month/Year	Milestone or Go/No-Go Decision
Apr 2011	Weld coupon design and preparation complete. Different thicknesses and different weld qualities (nugget sizes).
May 2011	Develop a multi-shearing shearographic system
May 2011	Define FEM objective function and parameters.
Jun 2011	Define FEM objective function and parameters.
Jul 2011	Test loading methods
Aug 2011	Determine loading and system parameters due to magnetic loading.
Sep 2011	Determine loading and system parameters due to heating.
Oct 2011	Develop code to predict nugget size using experimental data.
Nov 2011	Investigate shearing amount and direction
Jan 2012	Final report complete

Strategy for Shearographic Spot Weld Inspection

- In this case, shearography is used to measure surface displacement.
- The sample (spot weld) is perturbed with heat or force which produces a displacement field on the surface.
- Strain fields experimentally obtained are used as inputs to a finite element model which is used to solve the inverse problem, i.e. how big was the nugget that produced the observed displacement field.



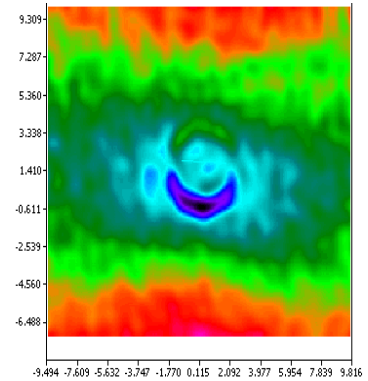
Nugget Size

Shearographic

Direct

5.0 mm

5.12 mm



2.9 mm

2.8 mm

Deliverables

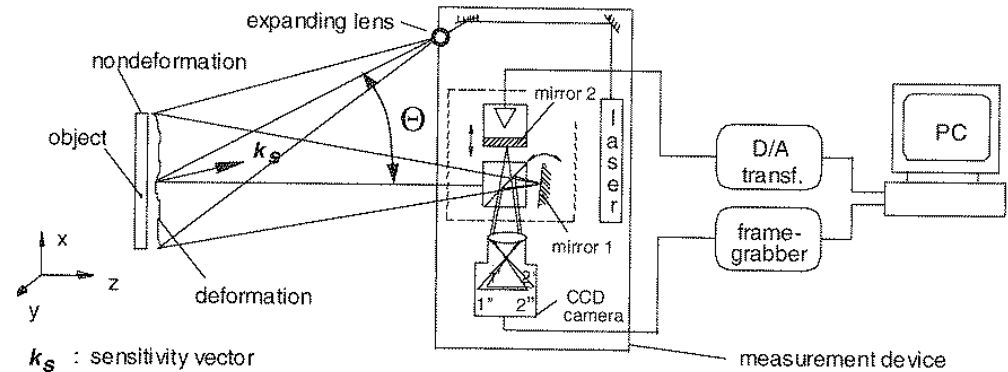
- Deliverables for the Concept Feasibility gate (completed)
 - Proposed design and configuration of optical system;
 - Description and comparison of the loading methods,
 - Mathematical formulation, and
 - Numerical algorithm description and implementation proposal.

Risk/challenge	Method to overcome challenge
Environmental disturbance in the shop environment will lower the signal to noise ratio	Directly measure strain instead of measuring displacements
Insufficient computer speed makes the shearographic inspection slow	Adopt efficient numerical algorithm, streamline calculation loops
Sensitivity to errors in optical measurements	Implement numerical schemes to filter unusual errors, and alleviate errors using regularization
Extract boundary data from optical measurements	Use interpolation / correlation numerical scheme

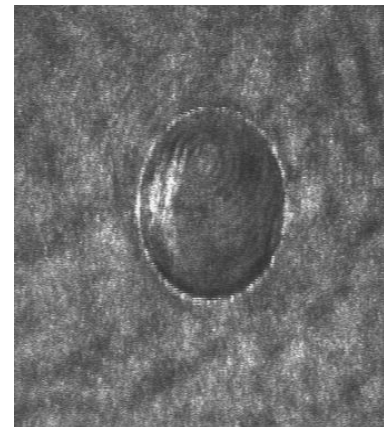
Technical Accomplishments and Progress

Experimental Accomplishments

- Holography measures displacement directly, but is sensitive to environmental vibration.
- Shearography measures the first derivative of displacement which is immune to most noise.
- Shearography was selected as the most likely optical candidate.**



Typical shearography diagram using Michelson interferometer.



Normal image of a spot weld.

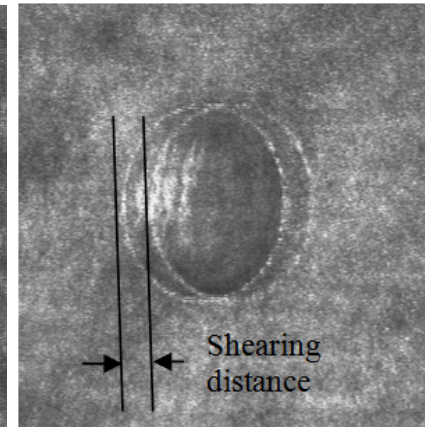
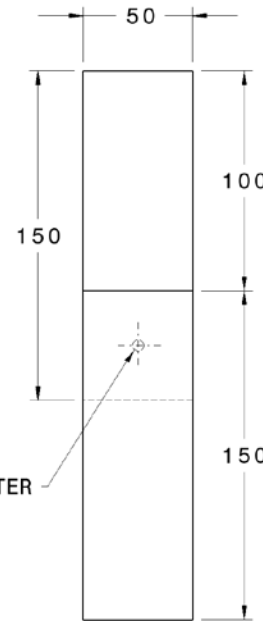


Image captured by a shearing camera.

Experimental Accomplishments

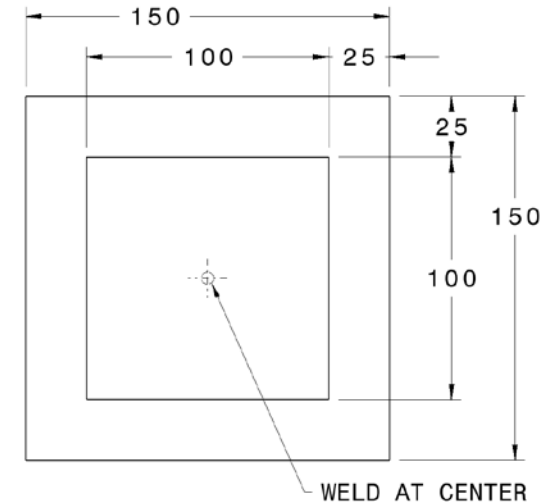
- Sample weld coupon designed and fabricated. These included samples for both shearing and center loading, different sheet thicknesses, and different weld nugget sizes.
- 280+ samples tested
- Samples torn down to verify weld nugget sizes (following testing).

Figure 1

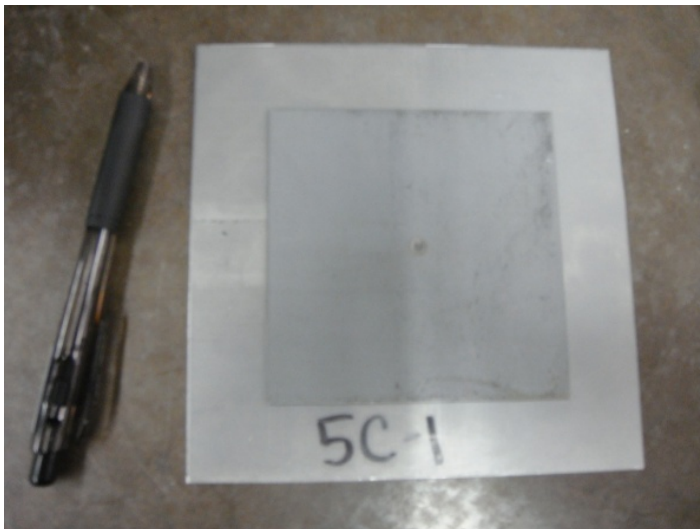


Shear coupon

Figure 2

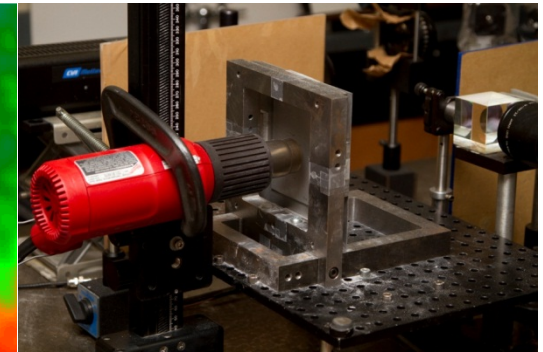
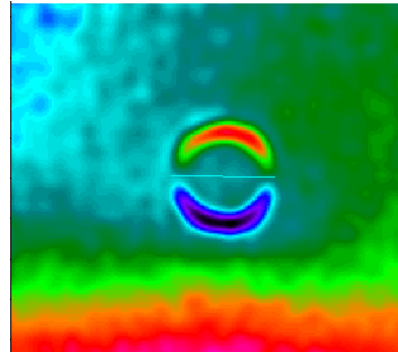
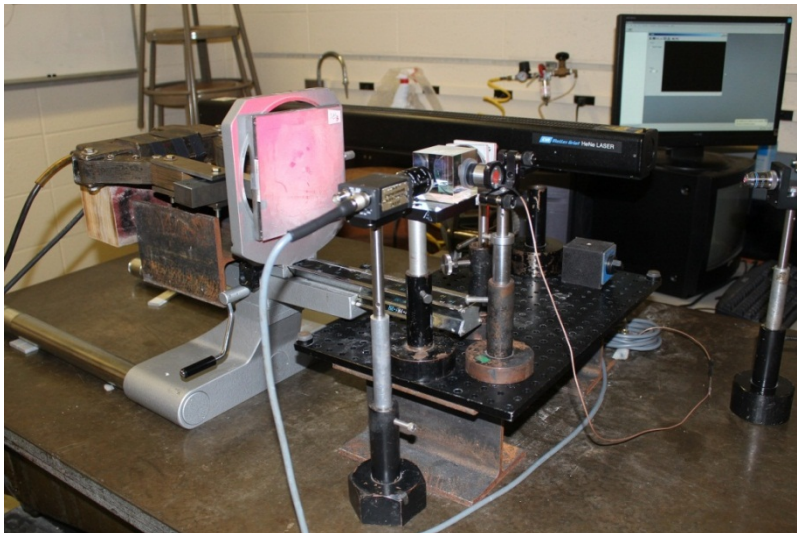
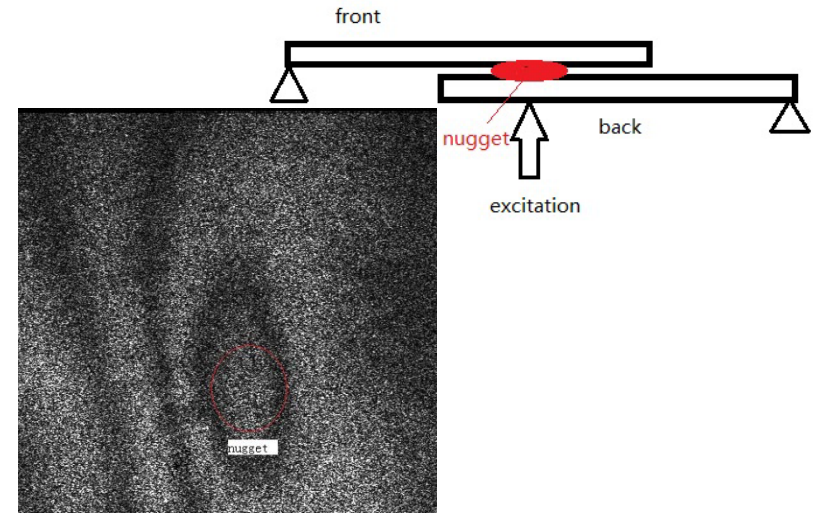


Center loaded coupon



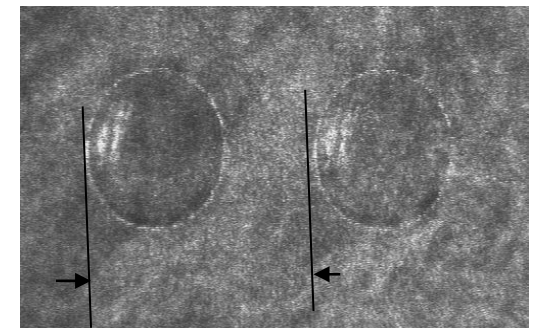
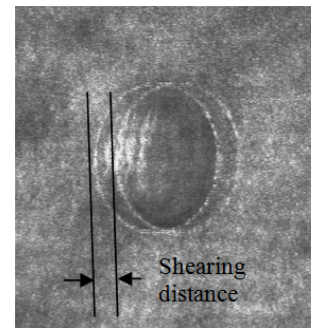
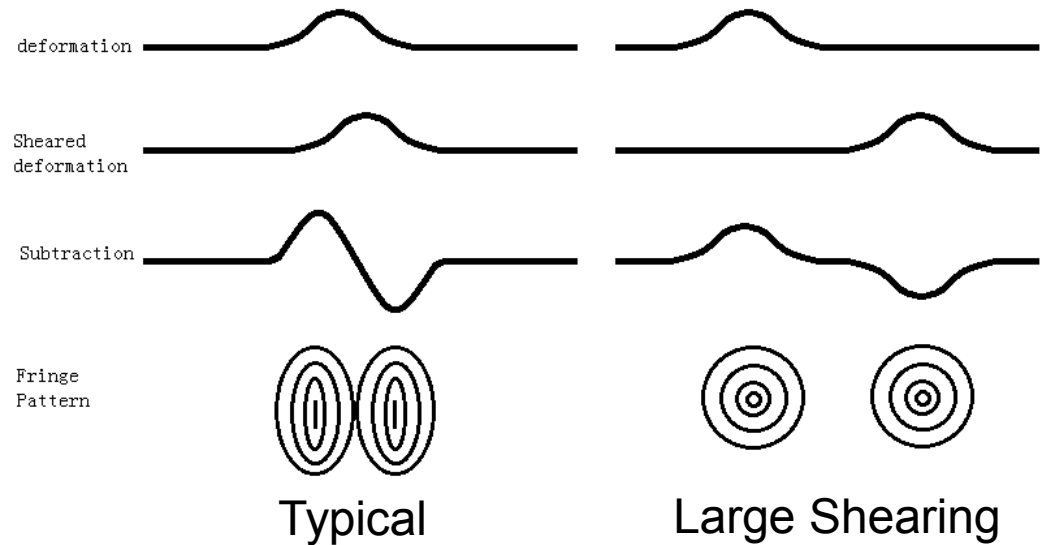
Experimental Accomplishments

- Static loading (perturbing) schemes tested.
 - 3-point bend
 - Thermal (non-contact)
 - **Magnetic (non-contact)**



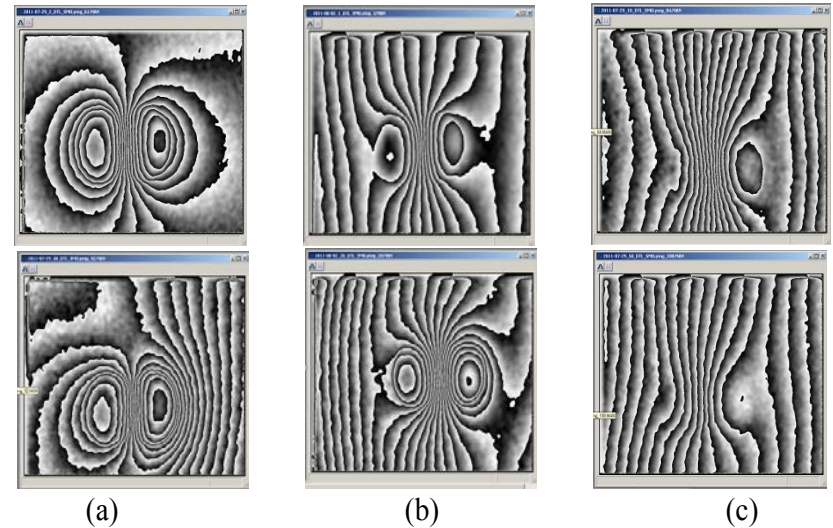
Experimental Accomplishments

- Large shearing shearography tested
 - Works with RSW
 - Fringe patterns are distortion itself instead of first derivative as in typical shearography.



Experimental Accomplishments

- Roughly, the larger the nugget is, the more circular the fringes will appear at both ends of the ellipse.
- Multiple tests on multiple samples shows the technique is extremely repeatable.
- Based on the fringe pattern, a series of criteria can be built up to make it possible to classify the samples with different nugget sizes. This criterion is closely related to the sample and system parameters, such as the heating time, sample dimension, constraint position or the thickness of the metal sheets. Changes in these parameters will not alter the trend of change in the fringe pattern.



Results from Shearogram; (a) sample with 6-mm nugget, (b) sample with 4-mm nugget; (c) sample with 2-mm nugget.



Nugget areas indicated by red ellipses.

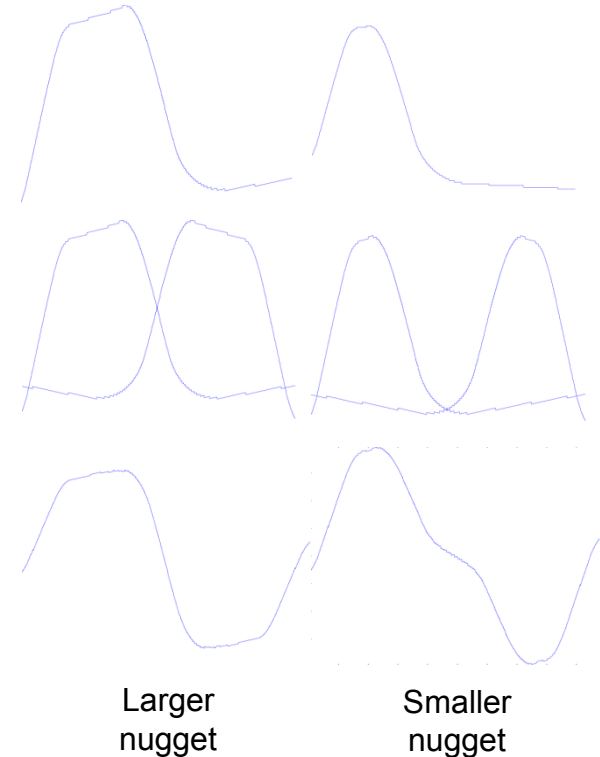
Simulation Accomplishments

- Fringe patterns can be predicted, i.e. there will be a series of vertical straight fringes in the middle between two circular fringes area.
 - Larger nuggets will have two similar circular fringe areas, and the fringes will be quite close to each other.
 - Smaller nuggets will have smaller circular fringe areas which will be farther apart.

Deformation
cross section at
center of nugget

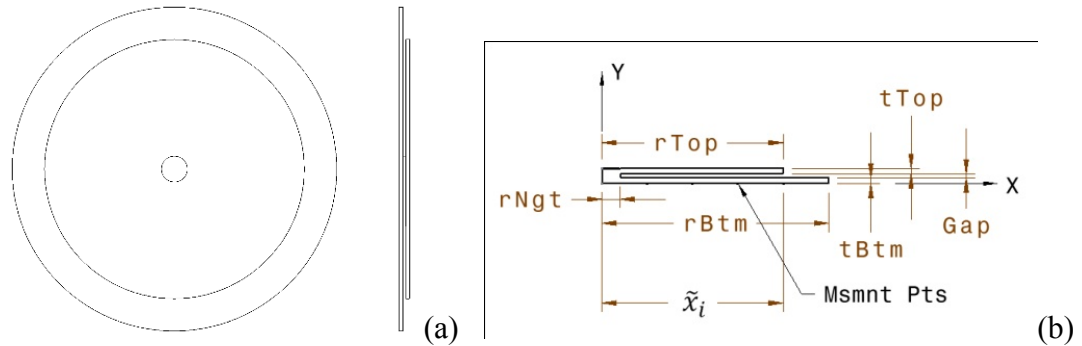
Cross section of
image from
shearing camera

Difference of
shearing images

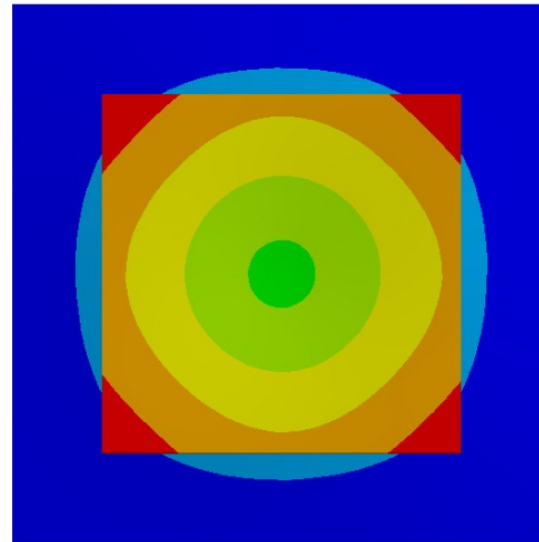


Simulation Accomplishments

- The spot weld plates (center loading design) are simulated as a 2D axisymmetric system.
- FE simulation of weld coupon with small plate pulled away from the larger along the edges (by magnetic force).



Projection views of the weld sample, (b) Axisymmetric model with geometric parameters and locations of measurement points \tilde{x}_i .



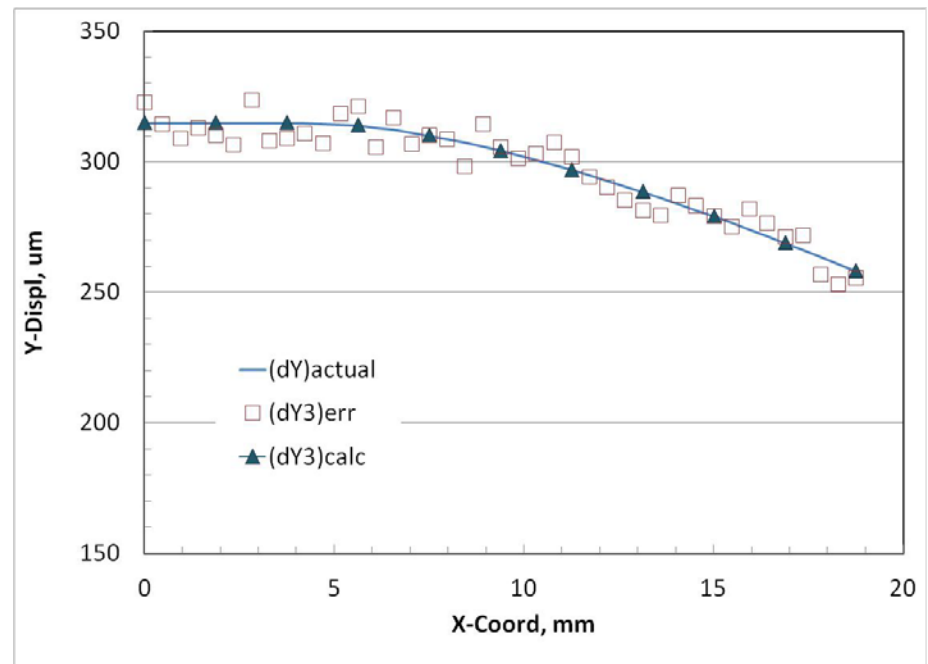
Computed deformation of coupon.

Simulation Accomplishments

- A genetic algorithm is used to solve the inverse problem. This is a minimization of the error in the measured and predicted displacements as a function of nugget size.
- The genetic solver is relative immune to the accuracy of the initial size guess.
- The solver converges to an accurate nugget size.

The calculated weld nugget size with two initial guesses from five measurement points.

No.	Nugget Size, mm		
	Guessed	Calculated	Actual
1	3.0	3.9995	4.0
2	5.0	4.0003	4.0



Computed performance of displacement prediction in the presence of noise.

Collaboration, Summary, Future

Project Collaborators

Chrysler LLC (CLLC)
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Ford Motor Company (Ford)
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General Motors Company (GM)
Leonid Lev (Chairman)
Daniel Simon

Oakland University
Lianxiang Yang
Randy Gu
Nan Xu
Xin Xie

Future Work

- Project work completed Jan 2012.

Summary

- The nugget size of the spot weld is difficult to measure. Using the Shearography technique on heated spot welded sheet metal gives a very promising result in classifying them. Fringes will have a clear difference proportional to the nugget size. If several “perfect” welded samples are used as training data, this method can easily classify the samples into 3 groups: large, medium, or small. Hundreds of experiments were conducted on 30 samples and the repeatability of this testing is good.
- The inverse problem of determining the weld nugget size from known conditions and shearographic surface measurements was formulated as a minimization problem solved using a genetic algorithm. The proposed algorithm was tested using a number of examples with simulated experimental data. It was found that:
 - The initial guess of the weld nugget size has little influence on the proposed numerical algorithm;

Summary

- Analogous to other numerical schemes for ill-posed inverse problems, use of excessive experimental measurements hampers the performance of the numerical algorithm;
- For an evenly inflated experimental data (Type I Error), the proposed algorithm predicts the correct trend for the weld nugget size – larger deflection with smaller weld nugget size;
- For the experimental data containing random noise (Type II Error), the algorithm correctly predicts the trend;
- When the experimental data contains a mild level of random noise (Type II Error) centered around the theoretical experimental measurements, the algorithm accurately predicts the weld nugget size.
- From the current study, it is shown that it has great potential to integrate the shearographic and the numerical methods to form a powerful tool for determining weld quality.