DEFENCE R&D DÉFENSE

Selection of Validation Parameters Suitable for Computational Weld Mechanic Simulations

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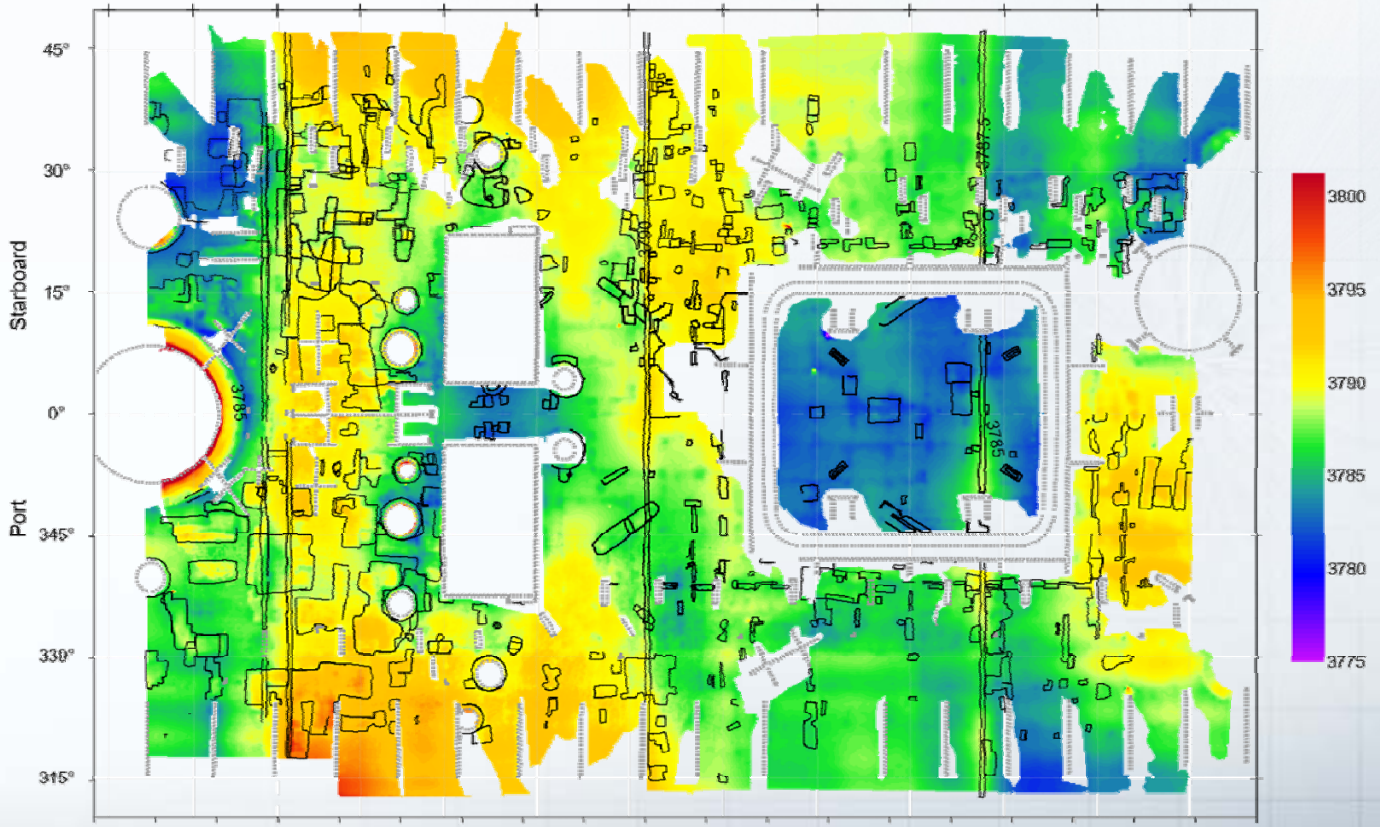
Overview

- Motivation
  - Computational Weld Mechanics
  - Overview of the Weld Overlay Program
- Defining What is Good Enough
- Examples of Validation Parameter Data
- Discussion

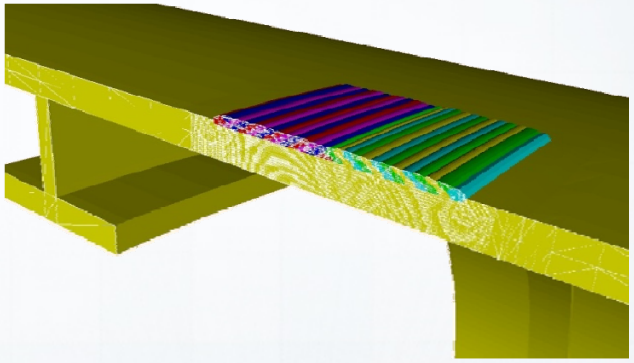
Project Motivation

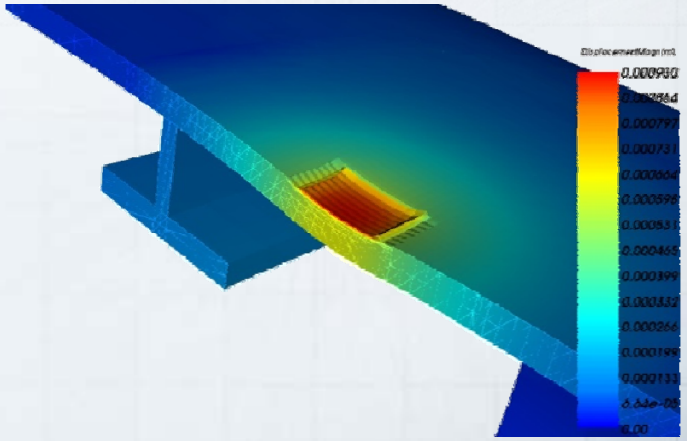
1. Develop an understanding of whether past weld repairs have influenced structural performance.
2. Development of future weld build-up standards.



Computational Welding Mechanics

- (Un) Coupled multi-physics simulations:
  - Involves temperature dependent material properties
    - Mechanical (Flow stress, Elastic Modulus, …)
    - Thermal (Conductivity, thermal expansion, …)
    - Morphology (Phase changes,)
  - Involves Heat generation
  - Are time and path dependent due to the deposition of weld metal
  - Have additional thermal boundary conditions
    - Convection and conduction must be considered.





Weld Modelling Features

- Goldak Technology Incorporated ***VrWeld***
  (www.goldaktec.com/vrweld.html)
- Involves separate thermal, microstructural and structural simulations.
- Pass-by-pass fill sequence used to capture non-symmetrical deformation.
- Material property selection tied to chemical composition.
  - Thermally dependent material properties
  - Microstructural predictions

Verification and Validation

- Verification
  - Ensuring mathematical representation of the physical phenomena is correctly implemented
  - Responsibility of the Code Developer
- Validation
  - Requires an estimate of the difference between experimentally measured parameters and a computational model.
  - Requires the selection of physically relevant criteria

Defining what is “Good Enough”

- Dependent on the modelling objectives:
    - Absolute predictions (i.e. Prediction of critical weld distortion) requires greater accuracy
    - Relative Predictions (i.e. Minimization studies associated with procedure variations) requires greater precision
- Is a transient validation required if all that is of interest is the final equilibrated state?

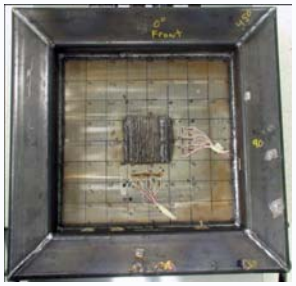
Overview of Weld Build-Up Program

	Outcome	How
Weld procedure optimization	➢ Understanding how welding influences distortion and residual stresses ➢ Serve as basis for verification and validation	CWM and Experimental
Weld procedure qualification	DefStan 02-770 Parts A&B	Experimental
Weld overlay standard development	➢ Weld area size limitations ➢ Area location limitations	CWM

Types Validation Parameters

	Transient •Single Point Measurements	Iso-Static •Multiple Point Measurements
Temperature	Thermocouple	-
Displacement	LVDT	Digital Image Correlation
Strain	Strain Gauge	Digital Image Correlation
Residual Stress	-	Diffraction (Neutron/X-ray)
Microstructure	-	Micro Hardness

Examples of Validation Samples



Picture Frame

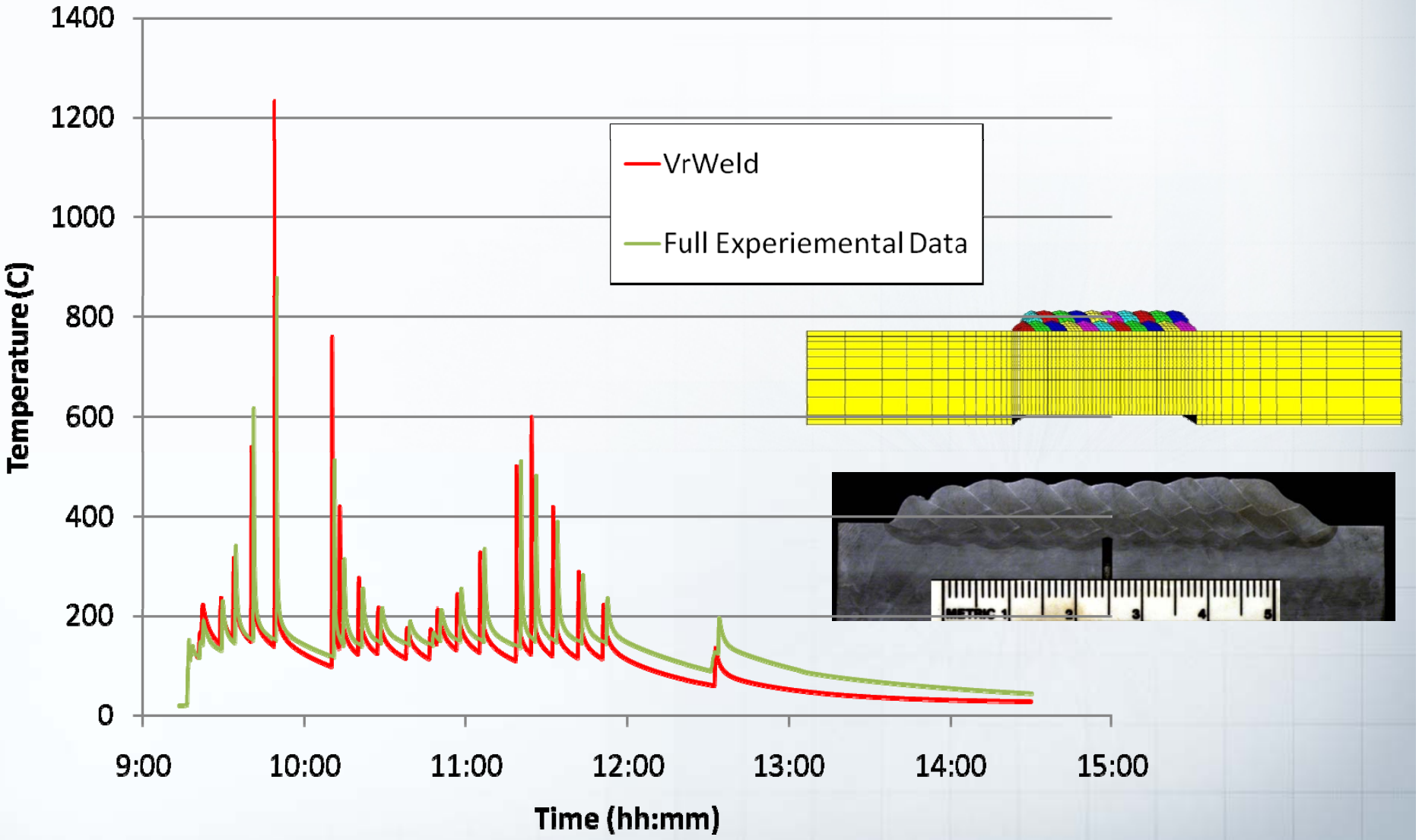
Temper Bead Study

Bead On Plate

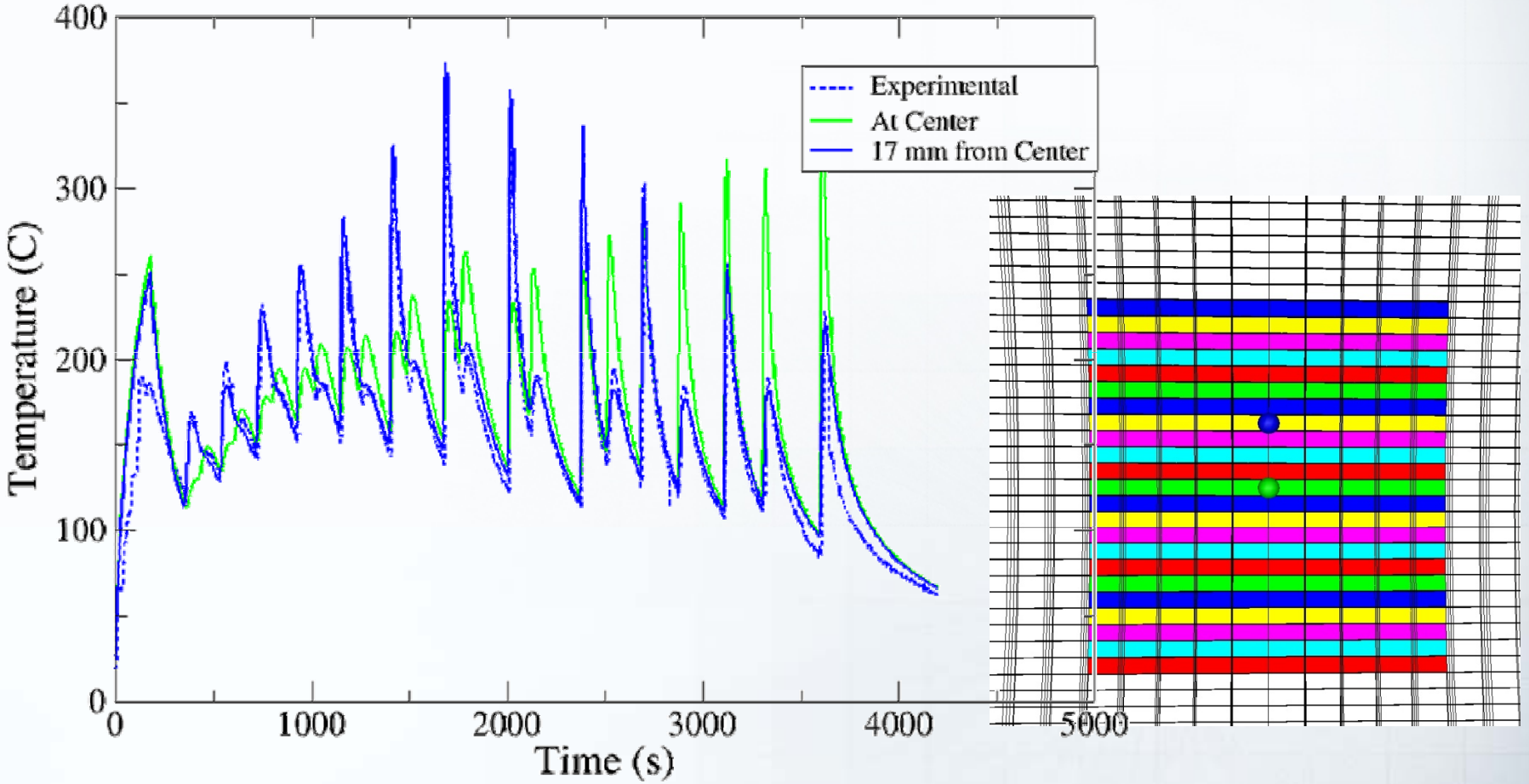
Cylinders

	# Samples	Transient Distortion	Transient Strain	Transient Temp.	Iso-Static Residual Stress	Iso-Static Micro-Structure
Picture Frame	2	No	Yes	Yes	Yes	No
Bead on Plate	4	Yes	Yes	Yes	No	No
Cylinders	8	No	Yes	Yes	No	No
Temper Bead Study	3	No	No	Yes	No	Yes

Transient Instrumentation - Temperature

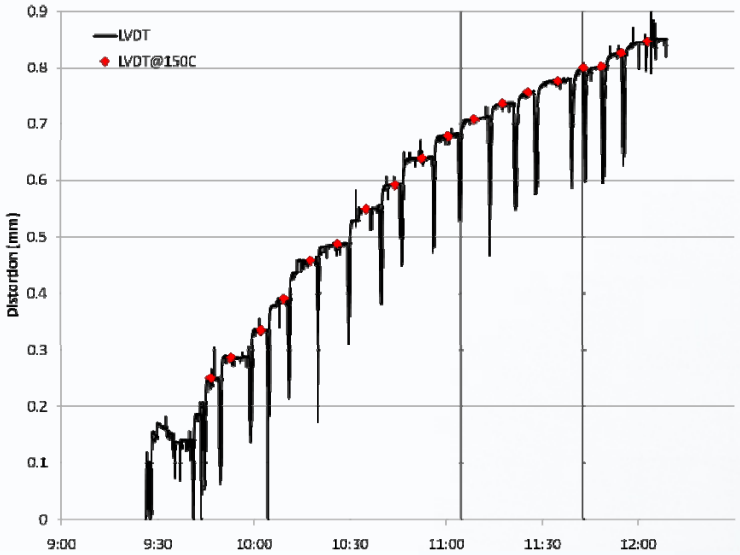


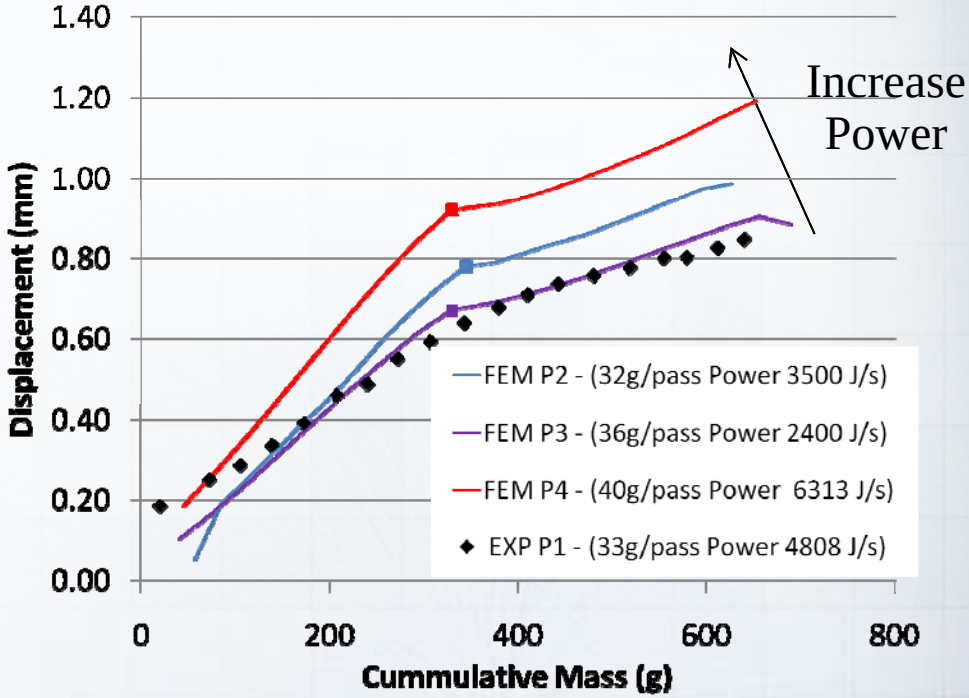
Transient Instrumentation - Temperature

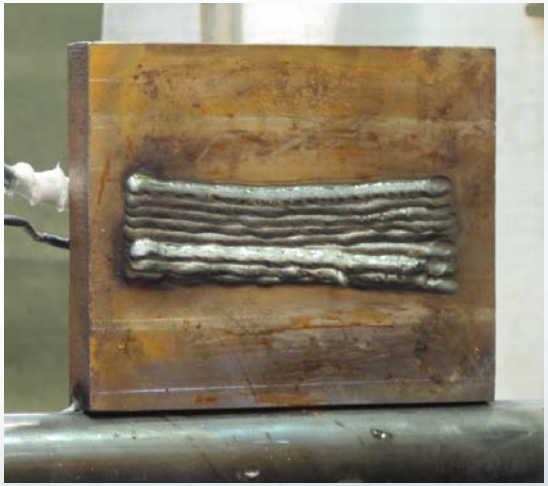


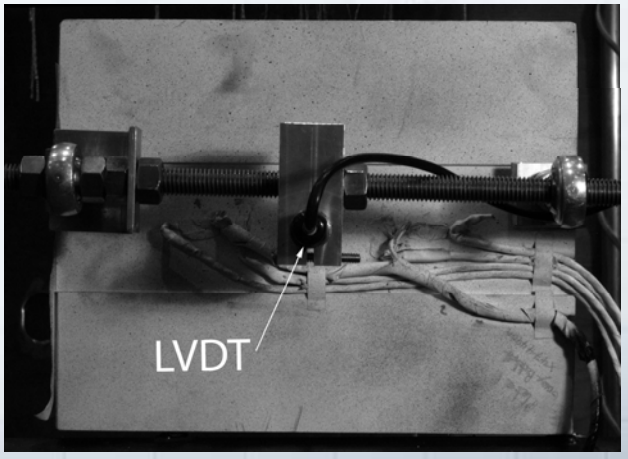
- Peak temperature is highly dependent on relative location to heat sources
- Correctly capturing measurement location as important as the data itself

Transient Instrumentation - Displacement

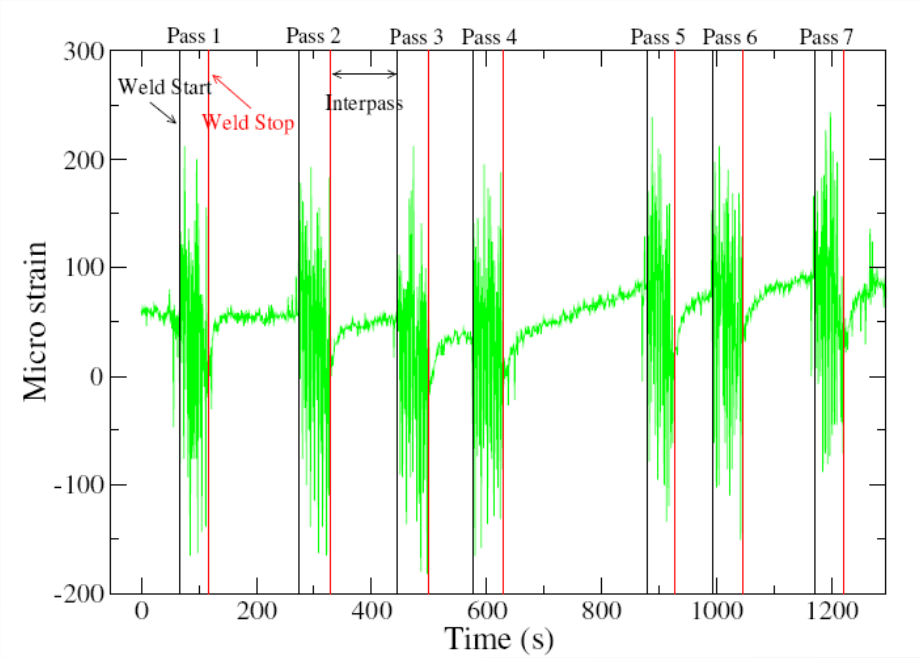


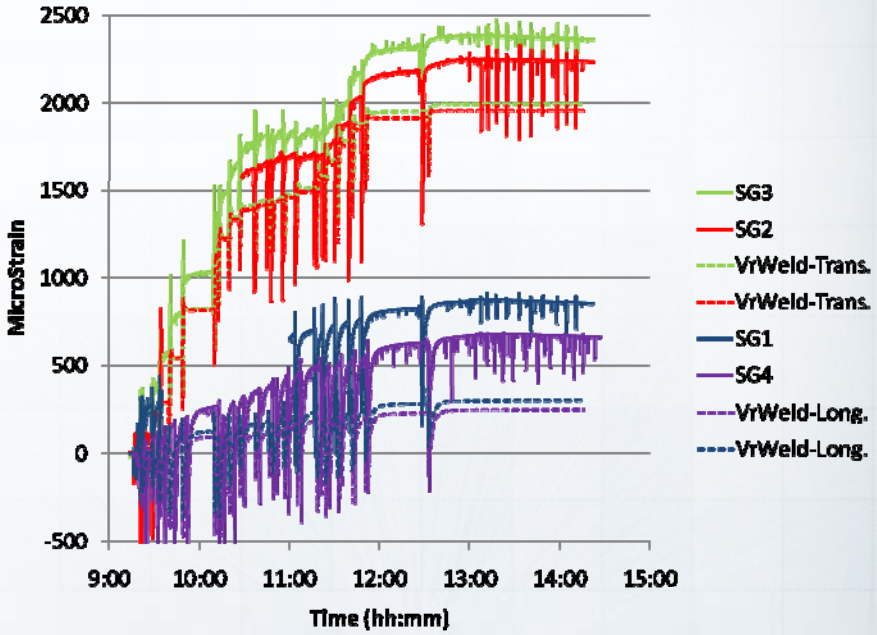






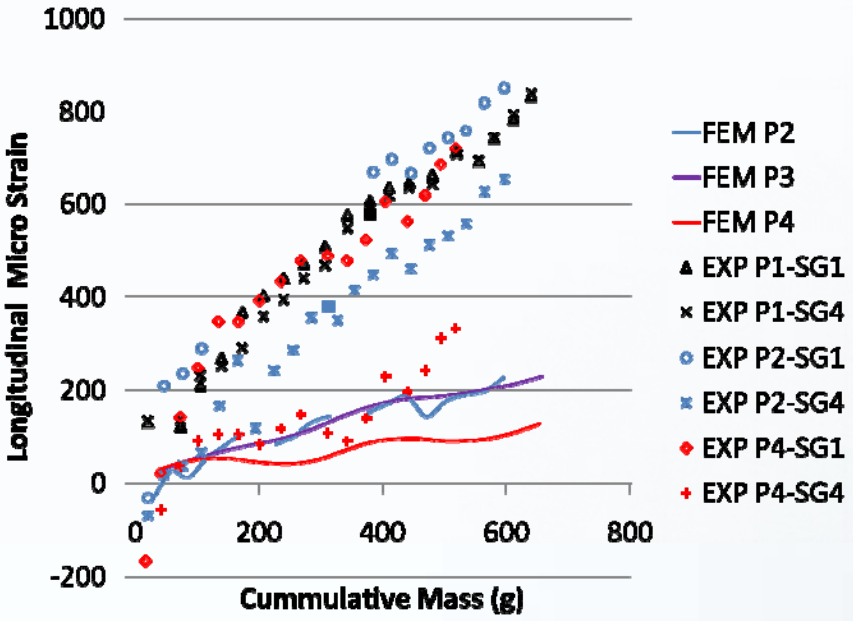
Transient Instrumentation - Strain

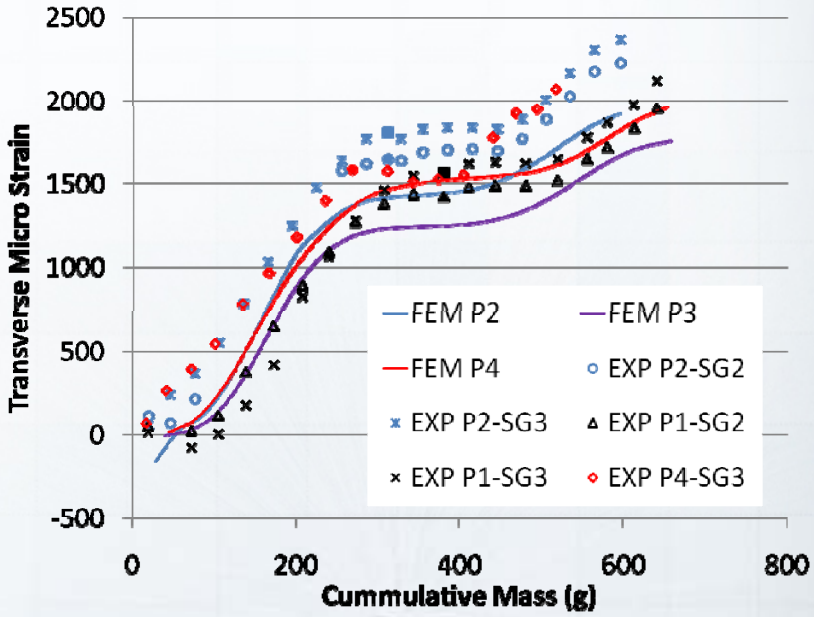


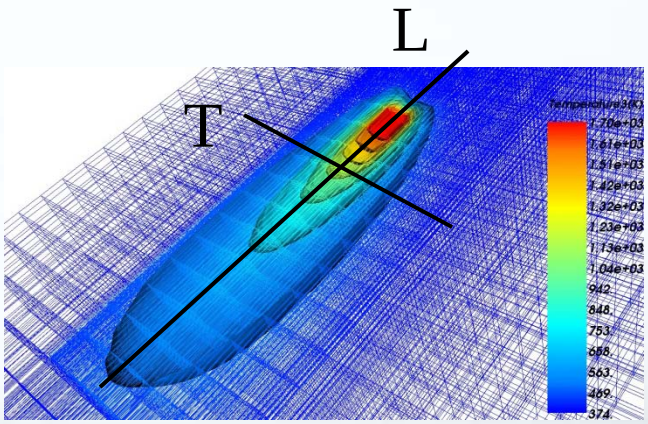


- EMF associated with welding arc marks the welding start and stop
- Convenient to mark the incremental change in strains associated with each pass

Transient Instrumentation - Strain Orientation

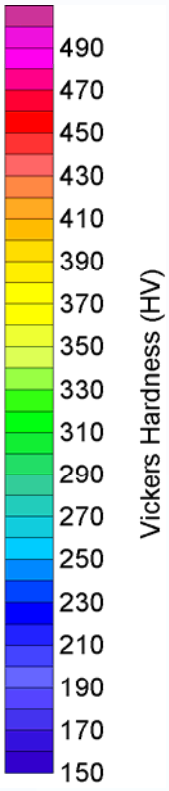




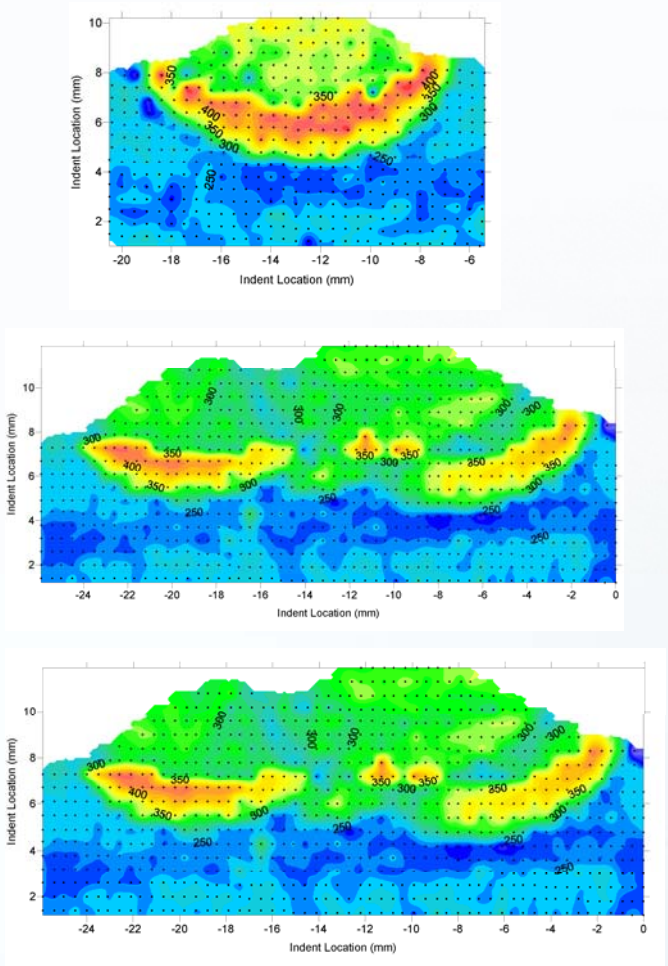


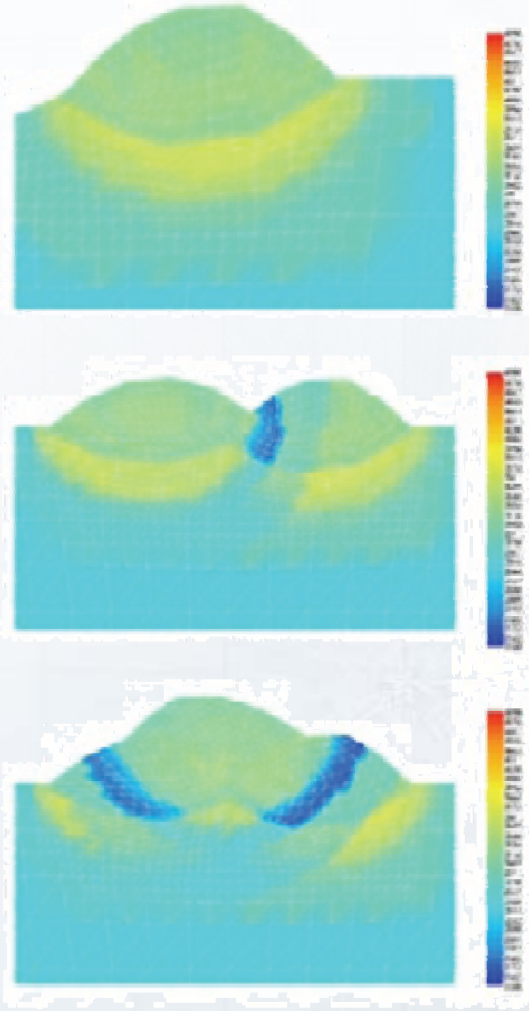
- Strain sensitive to relative distance between sensor and heat source
- Monitoring strain more sensitive than displacement

Iso-Static - Microstructural Predictions



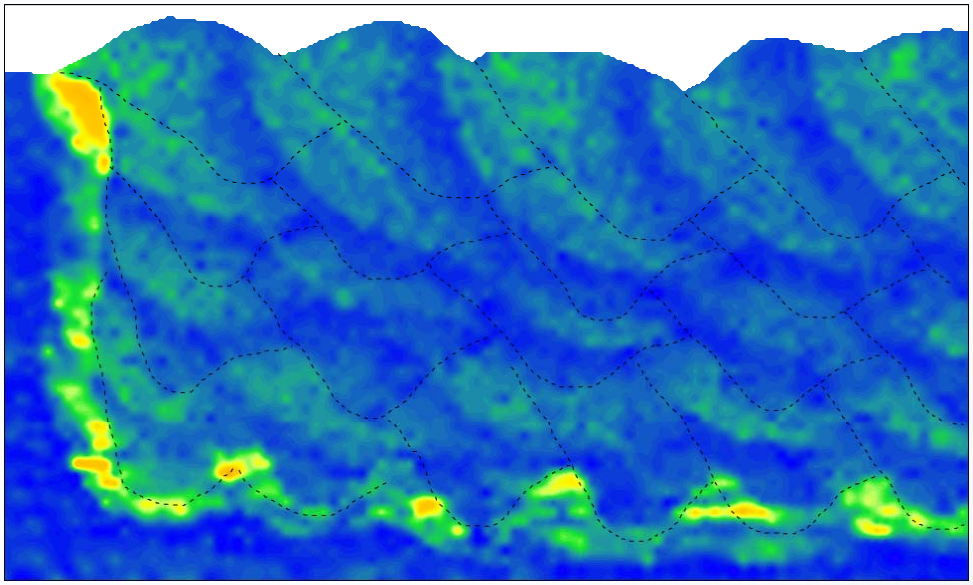
Vickers Hardness (HV)

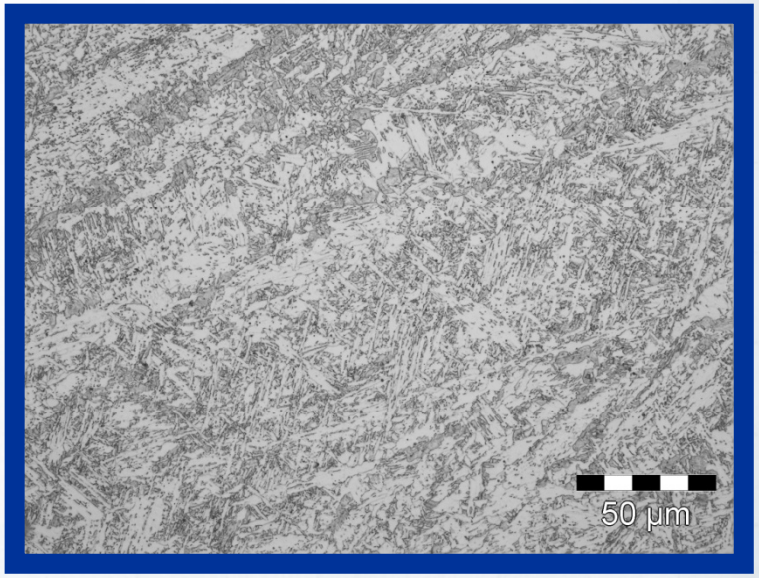


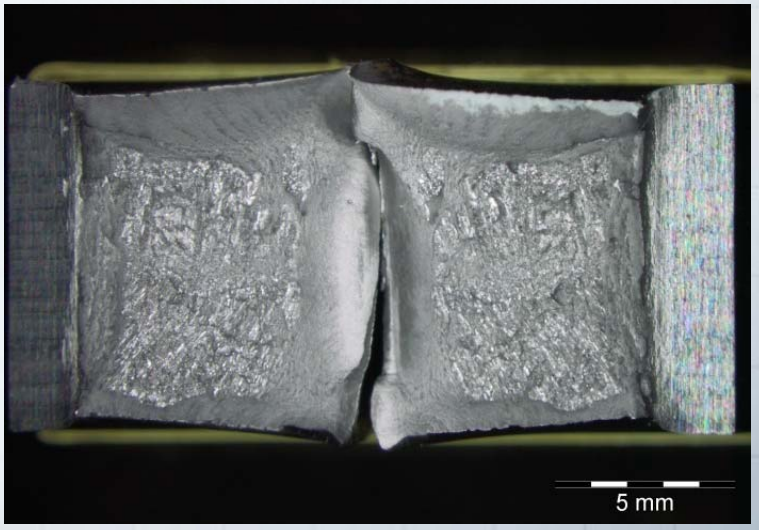


- Temper Bead Study 0.8 kJ/mm, AWS 9016 Consumable

Relevance of Microstructural Predictions



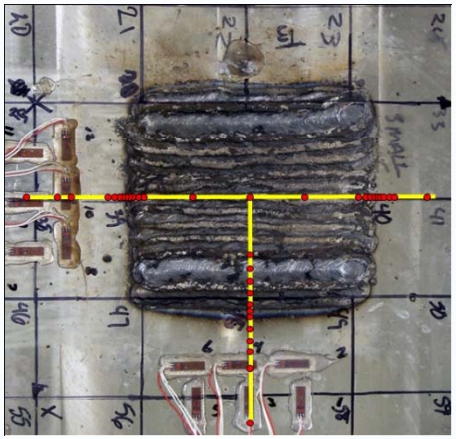




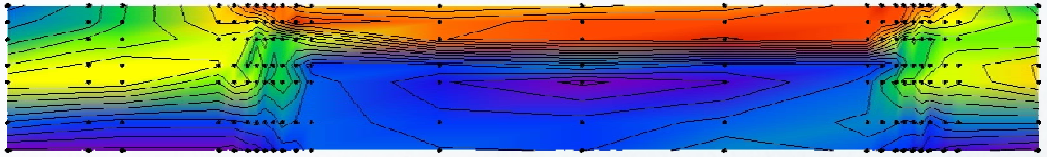
EB Specimen slow-1 (HI~1.3 kJ/mm)

Iso Static - Residual Stress Predictions

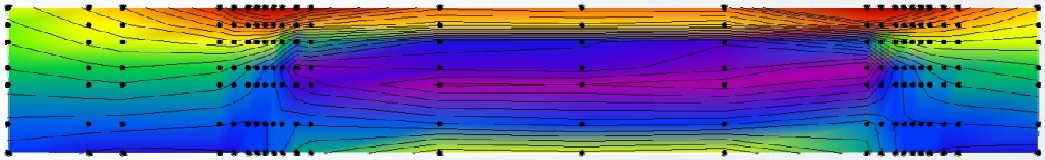
Longitudinal Stress Component Along Weld



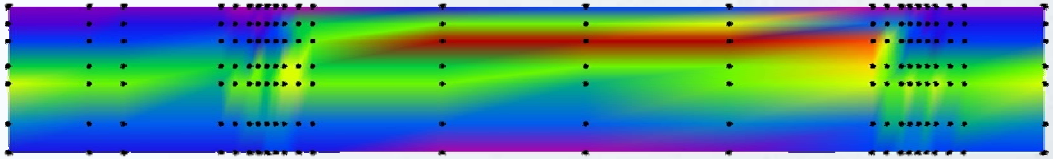
Measured Neutron Diffraction

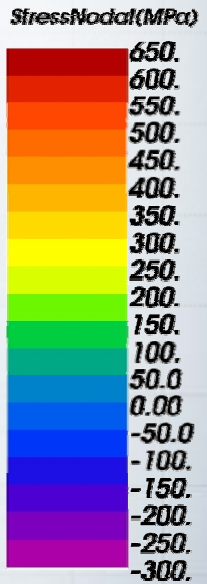


Predicted

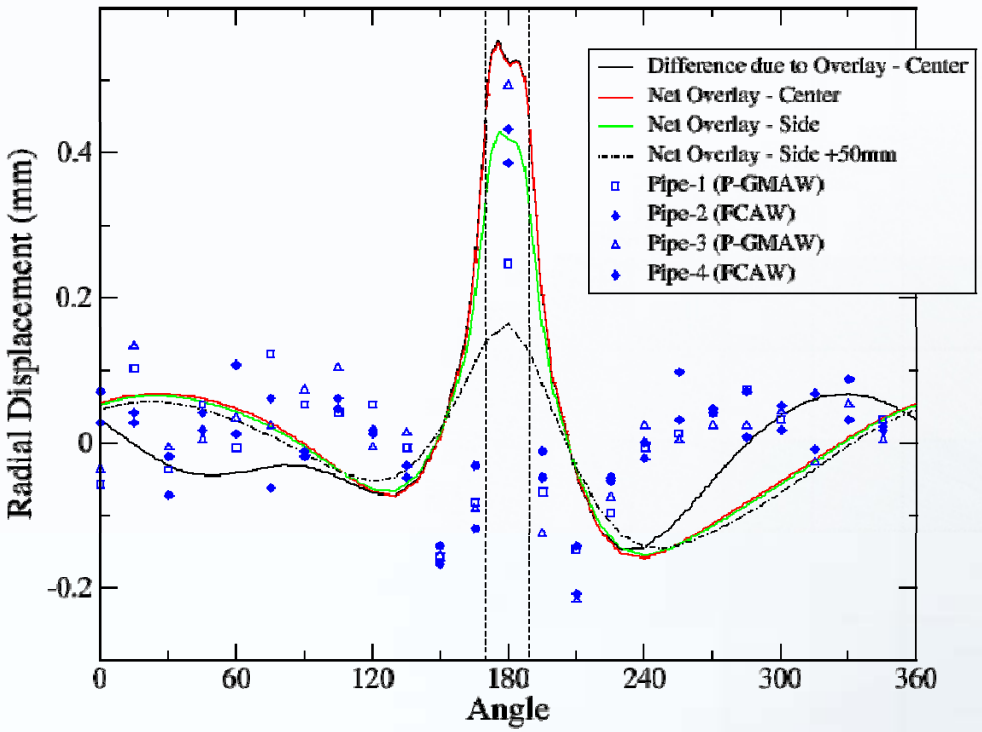


Difference





Iso-Static – Out of Circularity



Comparison of Validation Parameters

- **Transient Thermal Data**
  - ☺ Ensures that the thermal boundary conditions, weld start & stop, interpass time, heat input are satisfactorily captured
  - ☹ Located within steep gradient
- **Transient Strain Gauge Data**
  - ☺ Sensitive to transient variations in local strain and thermal expansion and contraction associated with each welding pass.
  - ☺ Robust method for marking the weld start and stop
  - ☹ Located within steep strain gradient,
  - ☹ Errors compound over measurement timespan
  - ☹ Difficult to infer global behaviour for localized measurement

Comparison of Validation Parameters

- **Transient Displacement Data**
  - ☺ Single point data provides global response due to localized effects
  - ☺ Multi-point data from Digital Image Correlation superior
  - ☺ Applicable to structural performance
- **Iso-Static Residual Stresses**
  - ☹ Provides an absolute stress measurement not relative difference due to welding
  - ☹ Experimental challenges (sampling volume, sample preparation)
  - ☹ Time, availability and cost

Comparison of Validation Parameters

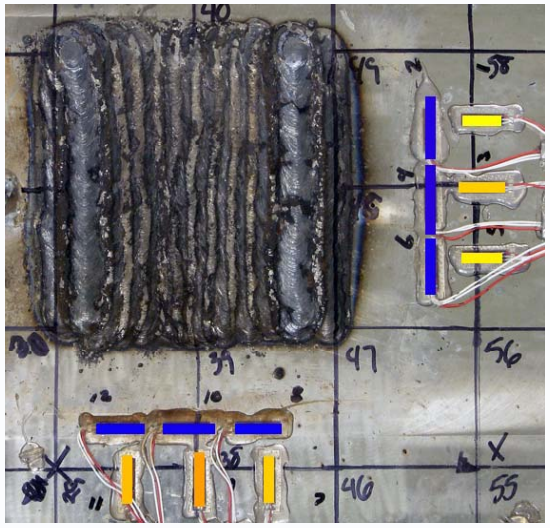
- **Iso Static Microstructural Hardness**
  - ☺Required input for process optimization
  - ☺Validation for weld process parameters (Heat Input)
- **Iso Static - Net Shape**
  - ☺Path independent
  - ☺Applicable to structural performance
  - ☹No knowledge of when/why/where problems arose

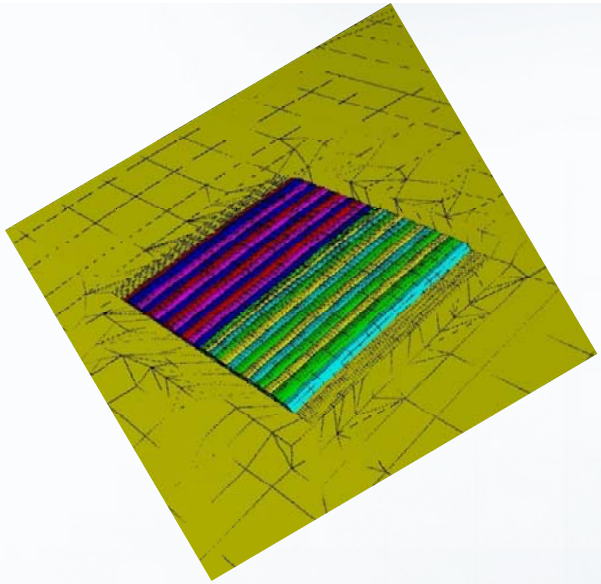
Summary

- Validation
  - Requires an estimate of the difference between experimentally measured parameters and a computational model.
  - Selection of parameters is application dependent, but should include as many “outputs” as possible
  - Transient validations help confirm that solutions not fortuitous.
  - Determination of “Good Enough” dependent on application.

Summary

- Weld Overlay Distortion – Not Intuitive
  - Welding induced strain and displacement not intuitively related.
  - Comparison between different configurations, weld areas, and boundary conditions not intuitive
  - Compounds difficulty in class wide area/location limitations as local boundary conditions influence distortion.
- Cylinder Collapse Simulations
  - Not adversely affected by Weld Overlay
  - Girth welds have a significant influence
  - Minor influence of weld metal composition





Thank You