



## INDUSTRIAL TECHNOLOGIES PROGRAM

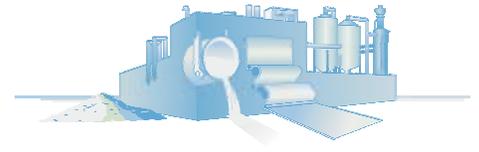
# Advanced Integration of Multiscale Mechanics and Welding Process Simulation in Weld Integrity Assessment

## New Weld Integrity Assessment Modeling Tool Will Reduce Weld Defects and Enable Cost- and Energy-Efficient Design, Fabrication, and Operation

Welding presents a number of technical challenges to the designer, manufacturer, and end-user of the welded structures. While the process of welding joins the components of a structure together, the complex thermal cycles from welding usually produce a weld joint which has microstructures and material properties different from those of the parent metal, and which may therefore not be optimum for the intended application. The thermal cycles also result in the buildup of residual stresses in the weldment. Furthermore, all welds contain imperfections. How these weld joints perform in various service environments can be the limiting factor for safe and efficient operation and the service life of many industrial components. For many such

critical structural components, an assessment of weld joint reliability is necessary and often mandatory throughout the design, fabrication and service of these structures. However, an accurate performance and reliability assessment of welded structures has been a major technical challenge.

The current effort is motivated by experimental observations that show that the macroscale response of a heterogeneous weld is intrinsically related to its microscale features. This project will develop and demonstrate an integrated computational tool to enable evaluation of integrity and design of joints in steels by combining weld-process and microstructural modeling with deterministic and probabilistic fracture and damage mechanics.

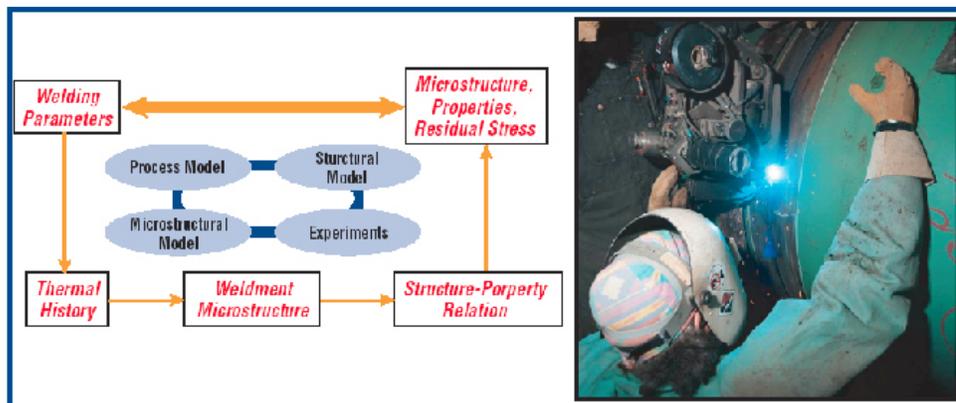


### Benefits for Our Industry and Our Nation

Use of the computational tool to better define welding process conditions will result in reduced defects, reduced costs, and energy savings in the fabrication of various components, including pipelines. Better definition of process conditions will also facilitate the replacement of low-strength steels with high-strength steels that may be otherwise difficult to weld, resulting in weight, energy, and cost savings. Temperatures and times of pre- and post-weld heat treatments can also be optimized, resulting in energy and cost savings.

### Applications in Our Nation's Industry

The results of the project will be useful in various industries, including chemicals, forest products, metal casting, mining, petroleum, and steel.



*Integrated approach for weld reliability assessment that incorporates thermal, mechanical and metallurgical characteristics of welds.*

## Project Description

The goal of the project is to develop an advanced integrated weld-integrity assessment tool by integrating fracture mechanics and damage mechanics modeling with the latest welding process modeling techniques. This technology will then be integrated into a reliability-based integrity assessment procedure targeted for joints in pipeline steels.

## Barriers

### *Major barriers to be overcome include:*

- Lack of an integrated modeling approach for weld integrity evaluation and design incorporating microstructure, thermodynamics, micromechanics, and processing for weld metals;
- Inadequacy of the traditional fracture mechanics assessment procedures;
- Difficulties in capturing the deformation process in welds using traditional meshed finite element modeling; and
- The appropriate reliability method for weld-integrity assessment that is both efficient and accurate is not known.

## Pathways

The objectives of the project will be achieved through (1) developing welding-process modeling techniques that are capable of predicting the weld's microstructural and mechanical properties from the knowledge of welding process conditions; (2) developing deterministic weld-integrity assessment methodology by incorporating the results of the welding-process modeling, micromechanics, and the latest fracture mechanics and damage mechanics analysis; and (3) expanding the deterministic procedure to a reliability-based weld-integrity assessment methodology that takes into account the natural variation of materials properties in the welds.

## Progress and Milestones

- Develop a model for weld metal thermodynamic predictions (Complete)
- Develop microstructure-prediction algorithms for weld metals (Complete)
- Develop weld-metal toughness-prediction models (Complete)
- Develop a test method for measurement of materials resistance to failure under both low and high applied strain conditions (Complete)
- Develop a multi scale mechanics approach for the description of crack driving force relations for low and high applied strain conditions (Complete)
- Develop a deterministic weld-integrity assessment procedure
- Develop a reliability-based weld-integrity assessment procedure for pipelines
- Integrate various modeling packages and provide a set of application tools

## Commercialization

The project team includes universities, a national laboratory, petroleum and chemical companies, and a consortium of pipeline companies. Initial commercialization will be through the adoption of the technology by the partner companies. Engineering Mechanics Corporation of Columbus specializes in welded structure reliability evaluations and will be able to aggressively promote the technology to its existing customers. The Pipeline Research Council International Inc. will also play a major role in the commercialization process by promoting the technology to its member companies.

## Project Partners

Engineering Mechanics Corporation of Columbus  
Columbus, OH  
(Yong-Yi Wang: ywang@emc-sq.com)

ChevronTexaco  
Richmond, CA

Massachusetts Institute of Technology  
Cambridge, MA

Northwestern University  
Evanston, IL

Oak Ridge National Laboratory  
Oak Ridge, TN

Pipeline Research Council International Inc.  
Arlington, VA

Southern California Gas Company  
Los Angeles, CA

## A Strong Energy Portfolio for a Strong America

Energy efficiency and clean, renewable energy will mean a stronger economy, a cleaner environment, and greater energy independence for America. Working with a wide array of state, community, industry, and university partners, the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy invests in a diverse portfolio of energy technologies.



U.S. Department of Energy  
**Energy Efficiency  
and Renewable Energy**  
Bringing you a prosperous future where energy  
is clean, abundant, reliable, and affordable

CPS #16945  
Ending FY07

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