ADMINISTRATIVE INFORMATION

1. **Project Name:** Advanced Integration of Multi-Scale Mechanics and Welding Process Simulation in Weld Integrity Assessment

2. **Lead Organization:** Engineering Mechanics Corporation of Columbus (Emc^2)
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3. **Principal Investigator:** Yong-Yi Wang
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4. **Project Partners:** Industry Partners:
Pipeline Research Council International (PRCI), TransCanada Pipelines Limited, Lincoln Electric, Duke Energy, Williams Gas Pipeline, Southern California Gas Company, and ChevronTexaco
Research Partners:
Oak Ridge National Lab (ORNL),
John Vitek, (865) 574-5061, vitekjm@ornl.gov;
Massachusetts Institute of Technology (MIT),
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Northwestern University (NWU),
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5. **Date Project Initiated:** January 1, 2004

6. **Expected Completion Date:** December 31, 2007[1]

PROJECT RATIONALE AND STRATEGY

7. **Project Objective:** This project is to develop advanced weld integrity assessment procedures by integrating the advanced fracture mechanics and damage mechanics methodology with the latest welding process modeling techniques.

8. **Technical Barrier(s) Being Addressed:** The technical barriers are:
   - Inability to predict and quantify weld metal properties,
   - Lack of correlation between controllable welding process parameters and weld toughness,
   - Lack of an integrated modeling approach for weld integrity assessment, and
   - Lack of suitable fracture toughness test methods for modern high-strength and high-toughness materials.

   The lack of accurate weld integrity assessment procedures often leads to overly conservative designs of structures and components, premature shutdown of industrial operations, and even disastrous failures. All these lead to energy waste in the operation and maintenance of existing infrastructures and inefficient construction of new infrastructures.

[1] The original completion date was December 31, 2006. A one-year no-cost extension is being requested.

9. **Project Pathway:** The two basic technical building blocks of the project are welding process modeling and multi-scale mechanics (micromechanics, fracture mechanics, and damage mechanics). These two building blocks, together with their associated testing and verification processes, enable the formulation of advanced deterministic weld integrity assessment procedures. By introducing probabilistic methods, the deterministic procedures are further extended to probabilistic weld integrity assessment. The main advantage of the probabilistic weld integrity assessment procedures is that the outcome of such assessment can be applied directly to risk-based integrity management. The risk-based integrity management enables energy-efficient design, construction, and maintenance of infrastructures while maintaining high levels of structural integrity.

10. **Critical Metrics:** The baseline matrix is the adoption of the newly developed weld integrity assessment procedures in industry practice. The scale of this adoption can vary: (1) within individual companies, (2) within an industry sector, and (3) to a broad range of industries through adoption by national and international codes and standards.

PROJECT PLANS AND PROGRESS

11. **Past Accomplishments:**

The major technical accomplishments to date are:

(a) Implemented a welding simulation algorithm for the prediction of weld heat-affect zone (HAZ) hardness,
(b) Demonstrated initial success in a microstructure model to predict the softening of HAZ in modern low carbon micro-alloyed TMCP steels,
(c) Continued update of PRCI thermal analysis software for in-service welding,
(d) Developed inclusion models for welds,
(e) Implemented weld toughness prediction via neural network,
(f) Developed damage mechanics analysis procedures to predict weld failures in laboratory specimens and large scale specimens,
(g) Analyzed effects of HAZ softening on the integrity of modern low carbon micro-alloyed TMCP steels,
(h) Tested material constitutive models for anisotropic plasticity,
(i) Developed polycrystalline plasticity constitutive models that incorporate the effects of steel plate rolling texture,
(j) Conducted experimental tests to capture anisotropy in modern TMCP steels, and
(k) Performed unique low-constraint fracture toughness tests for better correlation with full-scale mechanical behaviors.

The major accomplishments in commercialization area are:

(a) Continued participation in ASME B31 code committees in updating pipeline design, construction, and maintenance codes. Drafted languages for code revisions.
(b) Drafted code language for a brand-new section in a Canadian pipeline design, construction, and maintenance code CSA Z662 for strain-based design of pipelines.
(c) Assisted a major consumable manufacturer in specifying welding consumable specifications for its product development in a new market area.
(d) Developed pipeline inspection and maintenance guidelines for a major energy company in rehabilitating several existing pipelines in the area of mine subsidence.
(e) Participated the development of hydrogen piping and pipeline standards.
(f) Published many papers in technical conferences and made presentations to industry companies, government agencies, and at code committee meetings.

12. **Future Plans:** The future plan is given in table below. Each milestone typically involves more than one research partners and at least one industrial partner. The research partners focus on technology development. The industrial partners provide overall direction for commercialization and field implementation. They donate test materials, provide field test and implementation experience, and share their test data and unique (often expensive) equipments.

Original Dates	Actual or Projected Dates	Milestone/Deliverables	Sub-Milestone/Deliverables	Partner Activities
6/30/2005	9/30/2005	Develop crack driving force relations that correlate crack driving force with material tensile properties, weld geometry, and spatial distribution of material properties in and around the weld	Develop driving force relations under low strain conditions	Emc^2 develops technology. Transcanada provides materials and test data.
12/31/2005	6/30/2006		Extend driving force relations to high strain conditions	Emc^2 and MIT develop technology. Transcanada provides materials and test data. Duke Energy share test data.
6/30/2005	6/30/2006	Develop and refine welding process modeling	Refine weld metal thermodynamic predictions	Emc^2 and ORNL work on technology development. Lincoln Electric and TransCanada provides test welds and test data.
6/30/2005	6/30/2006		Develop microstructure algorithms for weld metal	
12/31/2005	6/30/2006		Explore weld metal toughness prediction algorithms	
12/31/2005	6/30/2006		Refine weld metal microstructure algorithms	
6/30/2005	6/30/2006	Develop testing procedures to characterize material's resistance to weld defects.		Emc^2 and MIT develop technology. Transcanada provides materials and test data.
12/31/2005	12/31/2006[1]	Develop deterministic assessment procedures.		Emc^2, MIT and Northwestern develop technology.
12/31/2005	3/31/2007[1]	Validate the deterministic assessment procedure by testing structural components.		Emc^2 leads on validation tests with assistance from MIT and ORNL. Transcanada, Lincoln Electric, Duke Energy, and Williams Gas Pipeline provide materials and share test data. Lincoln helps fabrication of test specimens.
12/31/2006	12/31/2007[1]	Develop reliability based assessment procedure. The output of the weld assessment procedure will be reliability index or failure probability.		Emc^2 leads. Possible field trials at TransCanada, Lincoln Electric, Duke Energy, Southern California Gas Company, and ChevronTexaco.

[1]**Refects the contract extension being requested.**

13. **Project Changes:** There was a change of PI at ORNL in the spring of 2005, which resulted in the delay of the work at ORNL for 6-9 months. The start of the initial contract was delayed for approximately 3 months. Securing test materials and testing facilities have taken longer than expected. These factors, and the slightly reduced funding level from DOE in FY2005, made the

extension of the project necessary. A request for one-year no-cost time extension is being filed. Funding from commercial partners is in line with the original budget.

14. **Commercialization Potential, Plans, and Activities:** Our commercialization plan consists of a number of venues. One of the most effective ways of bringing the weld assessment technology to the widest possible audience is through adoption in codes and standards. The project team members are continuing their work in a number of industry code committees, including API (American Petroleum Institute), ASME B31 (ASME codes for Pressure Piping), ASME Hydrogen Piping and Pipelines Project Team, and CSA (Canadian Standards Association). The second venue is field applications by industrial companies, with initial focus on members of PRCI. PRCI members include all major petroleum pipeline infrastructure companies. The project team has been actively working with some of these companies in their business and product development. These companies are also partners in code adoption of the technology. The third venue is through software development and sales. The project team is updating a piece of software for PRCI which will be available commercially in 2007.

15. **Patents, Publications, Presentations:**

Patents: None to date.

Publications:

1. Wang, Y.-Y., Liu, M., Horsley, D., and Zhou, J., "A Quantitative Approach to Tensile Strain Capacity of Pipelines," 6th International Pipeline Conference, Paper No. IPC2006-10474, September 25-29, 2006, Calgary, Alberta, Canada.
2. Wang, Y.-Y., Liu, M., Chen, Y., and Horsley, D., "Effects of Geometry, Temperature, and Test Procedure on Reported Failure Strains from Simulated Wide Plate Tests," 6th International Pipeline Conference, Paper No. IPC2006-10497, September 25-29, 2006, Calgary, Alberta, Canada.
3. Liu, M. and Wang, Y.-Y., "Applying Gurson Type of Damage Models to Low Constraint Tests of High Strength Steels and Welds," 6th International Pipeline Conference, Paper No. IPC2006-10416, September 25-29, 2006, Calgary, Alberta, Canada.
4. Chen, Y., Wang, Y.-Y., and Horsley, D., "An Updated Cooling Rate and Microstructure Model for Pipeline In-Service Hot-Tap Welds," 6th International Pipeline Conference, Paper No. IPC2006-10496, September 25-29, 2006, Calgary, Alberta, Canada.
5. Liu, M. and Wang, Y.-Y., "Modeling of Anisotropy of TMCP and UOE Linepipes," Proceedings of the Sixteenth International Offshore and Polar Engineering Conference, (ISOPE 2006), Paper No. 2006-JSC-426, San Francisco, USA, May 28 – June 2, 2006.
6. Wang, Y.-Y., "Tensile Strain Limits and Material Specifications for Strain-Based Design of Pipelines," International Forum on X100/X120 High Performance Pipe Steels, Beijing, China, July 28-29, 2005.
7. Liu, M., Wang, Y.-Y., and Horsley, D., "Significance of HAZ Softening on Strain Concentration and Crack Driving Force in Pipeline Girth Welds," OMAE 2005, June 13-17, Kalkidiki, Greece.
8. Wang, Y., Liu, M., and Horsley, D., "Some Aspects of Materials and Welding Specifications for Strain-Based Design of Pipelines," Proceedings of EPRG-PRCI-APIA 15th Joint Technical Meeting on Pipeline Research, Orlando, U.S.A., May 17-19, 2005.
9. Tang, H., Banerjee, A., and Parks, D. M., "An Investigation on the Mechanical Behavior of X100 Pipe-Steels under Monotonic Loading Conditions, Experiments and Simulation," submitted for publication.
10. Vishal, V. and Parks, D. M., "Polycrystal plasticity modeling of elastic-plastic buckling in X-100, UOE-formed line pipe." Manuscript in preparation.