ADMINISTRATIVE INFORMATION

1. **Project Name:** Physical and numerical analysis of extrusion process for production of bi-metallic tubes

2. **Lead Organization:**
Institute for Metal Forming
Lehigh University
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Bethlehem, PA 18015

3. **Principal Investigator:**
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4. **Project Partners:**

Organization	Investigator	Contact Information	Responsibilities
Lehigh University	Wojciech Z. Misiolek	(610) 758 4288 Fax: 758 4244 wzm2@lehigh.edu	Project coordination, maintaining contacts between project members and organizing writing project reports
Lehigh University	Mario Epler	(610) 758 4243 Fax: 758 4244 mee3@lehigh.edu	Tube bond integrity analysis, execution of experiments and data analysis, FEM simulations
Oak Ridge National Laboratory	Vinod Sikka	(865) 574 5112 Fax: 574 4357 sikkavk@ornl.gov	Supervising the extrusion processing experiments and coordinating the simulations performed at ORNL
Lehigh University	David Williams	(610) 758 6120 dbw1@lehigh.edu	Advisor on material characterization methods
Altair Engineering	Robert N. Yancey	(614) 764 2277 Fax: 764 2122	Technical support for HyperXtrude software package
Dynamet Technology	Susan M. Abkowitz	(781) 272 6967 Fax 229 4879	Technology transfer
Energy Industries of Ohio	Robert M. Purgert	(216) 643 2925 Fax 643 5901	Technology transfer
Special Metals Corp.	Gaylerd D. Smith	(304) 526 5100 Fax 526 5643	Technology transfer
Plymouth Extruded Shapes	Tony Esposito	(270) 866 6631 Fax 855 7034	Extrusion Practice, Die Design, Lubrication, Technology transfer

5. **Date Project Initiated:** Date work began – 09/30/2001 official start of project (e.g. date cooperative agreement began)

6. **Expected Completion Date:** 09/29/2004

PROJECT RATIONALE AND STRATEGY

7. **Project Objective:** (Please provide 1-2 sentences describing the objective of this project.)

   The objective of this project is to improve modeling techniques and theory used to develop processing schedules for extruded bi-material products. Reduction of scrap through novel billet design and an understanding to extrudate quality as a result of processing parameters will come as a result of the work.

8. **Technical Barrier(s) Being Addressed:** (Please provide 1-3 sentences describing the problem(s) and/or barrier(s) limiting industrial energy efficiency which this project is addressing.)
   1-2 sentences
   During co-extrusion of materials there is often uneven flow of the materials that leads to the generation of a large amount of scrap due to out of tolerance dimensions. In addition to the poor geometric tolerances, undesirable microstructures may develop at the interface that affect service life, formability, and mechanical properties of the extrudate. This study focuses on the effect of changes in the initial billet geometry and processing parameters on the properties of the final extrudate.

9. **Project Pathway:** (Please provide a one-paragraph summary of the approach, or pathway, being used to address the barrier(s). Emphasize the overall strategic approach for the project, not individual R&D tasks.)
   A series of physical modeling experiments, finite element modeling (FEM) simulations, and industrial extrusions are being performed so that an understanding of the effect of initial billet geometry and extrusion parameters on extrudate properties can be developed. Critical properties that are being investigated include geometric tolerances, formability, and service life estimation as a result of elevated temperature environment exposure. Initial modeling was performed using modeling materials and DEFORM 3D FEM software to generate data used to understand the effect of the "shortened core length" approach to billet design. A second round of experiments was designed and performed based upon the results of the initial tests using modeling material and FEM. These industrial scale extrusions utilize stainless and plain carbon steels that were extruded using a pilot press at Oak Ridge National Lab. These extrudates were manufactured using two different sets of processing variables. They are now being characterized and measured so that conclusions can be made regarding the viability of the proposed changes to billet design and processing parameters to reduce scrap and improve service life. The results of the industrial extrusion experiments will be used to modify the theories and models developed using the simulation techniques and to predict microstructural response in the region near the interface between the different materials.

10. **Critical Technical Metrics:** (Please indicate how success or failure will be measured for this project by stating the baseline technical metric(s) and the metric(s) needed for realization of the project objectives.)
    - The baseline technical merit includes development of the understanding of the effects of initial bi-material billet geometry that is used to minimize the amount of scrap product of an extrudate. Specifically, understanding the effect of shortening the core length in the initial billet on final extrudate geometry must be completed.
    - Characterization of the interface of the co-extruded material and understanding how it develops is critical to understanding how to tailor processing parameters to promote the most favorable microstructure

- A methodology for investigating the properties of the extrudate including lifetime diffusion characteristics, formability, and other mechanical properties needs to be determined.

1-3 project metrics, including baseline, in sentence or bullet form

PROJECT PLANS AND PROGRESS

11. **Past Accomplishments:** (Please summarize the major accomplishments and **key** milestones achieved to date. Note: May not be applicable for projects initiated in FY04.)

ID Number	Task / Milestone Description	Planned Completion	Actual Completion	Comments
1.1	Literature review	04/30/02	Accomplished	
1.2	Perform deformation test	10/31/02	Accomplished	
1.2.1	Deformation tests on modeling material	10/31/02	Accomplished	
1.2.1	Deformation tests on steel	12/31/02	Accomplished	Geometry and microstructural analysis underway
1.3	Develop material model	10/31/02	Accomplished	
2.1	Analyze extrusion press characteristic	06/30/02	Accomplished	New date 08/31/02
2.2	Analyze tooling design	10/31/02	Accomplished	
3	Develop numerical co-extrusion process model	04/30/03	Accomplished	1st Generation Model
4	Perform physical modeling validation of numerical model	09/29/04	In Progress	
5	Develop powder metallurgy module for process model	09/29/04	In Progress	
6	Verify model under various conditions on a pilot press	07/31/04	In Progress	
7	Analyze tube bond integrity	07/31/04	Underway	Preparing for Detailed Chemical Analysis
8	Analyze tooling deflections and process control	07/31/04		
9	Implement model into industrial practice	09/30/04		

12. **Future Plans:** (Please summarize the **key** milestones and deliverables with dates for the life of this project. A comprehensive activities schedule is not required.)
    - Geometrical analysis of second set of industrial extrusion experiments including eccentricity and bond location – 7/31/04
    - Chemical and microstructural analysis of material near the interface between the stainless/plain carbon steel in the extrudate – 8/31/04

- Implement model into industrial practice - 09/30/04

13. **Project Changes:** (Please describe changes in scope, approach or schedule during the past year in response to any unforeseen problems/issues or successes.)

    A long delay was encountered in producing and extruding the second set of industrial experiments. Extrusion experiments were completed mid-February and the extrudates were shipped to Lehigh for analysis in early march. Currently, the best effort is being made to section and analyze the materials.

14. Commercialization Potential, Plans, and Activities:

Publications in technical, scientific, and trade journals can be used to share the information with the appropriate technical audience. Presentations at industrial conferences will also provide means to share the results. Any software that is developed by the Lehigh Team as a result of this work will be provided as free-ware or source code so that it is not prohibitive to industry.

The project has a strong industry team with the focus on implementing the technology. Plymouth Extruded Shapes is our industrial partner and currently certain metal flow analysis and die design optimization are performed for their products. It is envisioned that this work will continue for more complex solid and tubular shapes in the future.

15. **Patents, Publications, Presentations:** (Please list number and reference, if applicable. If more than 10, please list only 10 most recent.)

- Kazanowski, P., Epler, M. E., Misiolek, W. Z., **Bi-metal rod extrusion – process and product optimization,** Journal of Materials Science & Engineering A, 369, 2004, 170-180
- Misiolek W.Z., Kazanowski P., Van Geertruyden W., **Merging research with manufacturing. Making technology grow through university – industry partnership**, The Tube & Pipe Journal, Vol.13, No.7, 2002, pp.20-23
- Kazanowski P., Misiolek W. Z. **Investigation of the bi-metal tube cross-section geometrical stability after extrusion with the mandrel,** XII Scientific Conference on Production Technologies for Tubes and Pipes in Non-Ferrous Metals Industry, Zakopane, Poland, 21st November 2002
- Kazanowski P, Misiolek W.Z., Sikka V.K., **Analysis of the influence of the initial billet geometry and die design on the product geometry during bi-material tube extrusion**, THERMEC'03 International Conference on Processing and Manufacturing of Advanced Materials, Madrid, Spain, July 2003