1. **Project Name:**
Development and Demonstration of Advanced Tooling Alloys For Molds and Dies

2. **Lead Organization:**
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4. **Project Partners:**
Prof. Enrique J. Lavernia
University of California, Davis
Subcontracted to perform laboratory R&D and computer simulations

Mr. James R. Knirsch
RSP Tooling, LLC
Provides in-kind labor, materials (patterns) and coordinates die testing in forging, stamping and die casting.

Mr. Michael Greenman
Glass Manufacturing Industry Council
Provides in-kind labor and coordinates glass mold design and testing.

Mr. Donald G. Tyler
General Aluminum Manufacturing Company
Provides in-kind labor, die-casting die design and testing

5. **Date Project Initiated and FY of Effort:**
Start date was October 1, 2001 (start of FY-02). Report date is May, 2003 (mid FY-03).

6. **Expected Completion Date:**
September 30, 2005.

7. **Project Technical Milestones and Schedule:**

ID Number	Task / Milestone Description	Planned Completion	Actual Completion
1	Modify spray forming equipment	1/1/02	12/20/01
2	Model multiphase flow	4/1/02	4/1/02

ID Number	Task / Milestone Description	Planned Completion	Actual Completion
3	Produce tool steel deposits	6/1/02	6/1/02
4	Benchmark microstructure	4/1/03	4/1/03
5	Benchmark material properties	7/1/03	In progress
6	Model spray process	10/1/03	In progress
7	Evaluate properties of heat treated alloys	2/1/04	In progress
8	Modify alloy chemistry	12/1/04	
9	Design/build solid models	10/1/04	
10	Evaluate properties of modified alloys	7/1/05	
11	Produce dies from modified alloys	7/1/05	
12	Complete evaluation of modified dies	9/1/05	
13	Final Report	10/1/05	

8. **Past Project Milestones and Accomplishments:**
The main R&D activities of the project over its four-year span are summarized as:

- Select popular production alloys used in stamping, forging, die casting and glass component manufacture.
- Benchmark microstructure and material properties of production tooling processed by spray forming.
- Model heat transfer, solidification, and momentum phenomena associated with spray forming of dies.
- Tailor alloy chemistry and heat treatment to processing by spray forming.
- Perform in-service lifetime and failure mode analysis.
- Reduce energy consumption and scrap.

Tasks are progressing on schedule with no problems anticipated meeting project milestones.

The focus of activities to date included developing an understanding of how conventional ferritic tool steels, selected by industry participants, respond to processing by rapid solidification, particularly spray forming, and subsequent heat treatment. A wide variety of analytical tools have been used to assess this response including tensile testing, hardness measurement, SEM, EDS, DTA, optical microscopy, X-ray diffraction, and neutron diffraction. In addition to analytical tools, modeling tools and computational techniques have been used to help in the development of an understanding of the interplay of the characteristics of the spray plume (droplet thermo-physical properties, size distribution, velocity, heat content, flux, and spray pattern) with those of the tool pattern during tool formation. Accomplishments included modeling multiphase flow behavior of atomized droplet-laden flows within the atomization and free-jet regions; equipment modifications to a spray forming apparatus to process tooling alloys; extensive property analysis of spray-formed and heat treated tooling alloys to benchmark properties

prior to alloy development work; and the production of sample dies for in-service analysis by industry.

9. **Planned Future Milestones:**
Continuing in Year 2 of the project, alloy property response to artificial aging will be analyzed and documented. Researchers at UCD and INEEL will utilize techniques employed during Year 1 to establish microstructure/property relationship and study microstructure transformation of spray-formed tool steels during low temperature heat treatments, particularly carbide precipitation and growth. Results will be correlated with Year 1 results, and used to tailor tool steel composition to the heat transfer and solidification conditions experienced during spray deposition processing. Researchers will assess influence of alloy additions on microstructure and tooling properties. Sample material will be produced with the modified alloys and supplied to industry participants for analysis.

Structure/property assessment of modified tool steel alloys will be completed in Year 3 at UCD and INEEL and property improvements will be verified. Evaluation of alloy additions to carbide stability, size and distribution before and after heat treatment will be completed. Industry participants will supply die designs and solid models of dies to INEEL for use in casting ceramic patterns. Using modified tooling alloys, spray-formed tooling inserts will be produced and sent to industry participants for analysis and in-service evaluation of dies including lifetime studies and evaluation of failure modes. Results will be compared with commercial machined dies of the same geometry.

Sample die preparation and in-service evaluation of dies will be completed during Year 4. The turnaround time for producing spray-formed dies will be quantified and compared with conventionally processed dies. Nonproprietary results of dimensional accuracy analysis, microstructure and material property analysis, processing conditions, etc. will be documented in a final report. Project results as they relate to objectives of die life extension and energy reduction will be quantified. Technology transfer to industry will be completed.

10. **Issues/Barriers:**
No major issues to date.

11. **Intended Market and Commercialization Plans/Progress:**
Spray forming technology (Rapid Solidification Process Tooling) used in this project to manufacture molds and dies was recently licensed and commercialized with the formation of RSP Tooling, LLC. The company is located in Solon, OH at The Technology House, a rapid prototyping service bureau. A beta RSP Tooling machine has been constructed by the Specialty Equipment and Engineering Division of Belcan Engineering, and is currently in the debugging stage.

The company plans to sell machines and tools, and has received approximately 20 orders for tools. An Open House was held at Belcan in February, and was attended by about 200 people. The market potential for this technology is high because it has been demonstrated to reduce cost and turnaround time for production-quality molds and dies.

12. **Patents, publications, presentations:**

Patents:

- A U.S. patent application entitled "Rapid Solidification Processing System For Producing Molds, Dies, and Related Tooling," is under review by the U. S. patent office.

Presentations:

- An open house was conducted by RSP Tooling, LLC Feb. 4-7, 2003 in Solon, OH. Approximately 200 people attended. Presentations on RSP Tooling technology were given by INEEL and industry participants in this project.
- K. M. McHugh, "Rapid Solidification Process (RSP) Tooling for Moldmaking," presented at *Moldmaking 2003* Conference and Expo, Cleveland, OH April 29, 2003.

Publications:

- K. M. McHugh and J. E. Folkestad, "Production of Molds and Dies Using the RSP Tooling Approach," Accepted for publication in the proceedings of the *International Conference on Spray Deposition and Melt Atomization*, Bremen, Germany, June, 2003.
- Kevin M. McHugh, "Rapid Solidification Process (RSP) Tooling For Moldmaking," proceedings of *Moldmaking 2003* , Cleveland, OH, April 29 - May1, 2003, P.23 (2003).
- Kevin M. McHugh and James R. Knirsch, "Producing Production Level Tooling in Prototype Timing- An Update," Moldmaking Technology 5 (10), October 2002, P. 42.
- J. E. Folkstad, J. R. Knirsch, and K. M. McHugh, "Die Casting and Rapid Solidification Process (RSP) Tooling – An Applied Research Project," Proceedings of the 2002 NADCA Congress, Paper T02-051, NADCA, Rosemont, IL, October, 2002.
- J. R. Knirsch, K. M. McHugh, and J. E. Folkestad, "RSP Tooling – A Revolutionary New Process to Manufacture Die Cast Production Tooling in Prototype Timing," Die Casting Engineer 46 (3), May 2002, P. 56.