ADMINISTRATIVE INFORMATION

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

2. **Lead Organization:**
   Idaho National Engineering and Environmental Laboratory, P.O. Box 1625, Mail Stop 2050, Idaho Falls, ID 83415-2050

3. **Principal Investigator:**
   Dr. Kevin M. McHugh, E-mail: kmm4@inel.gov, Ph: 208-525-5713,

4. **Project Partners:**
   - University of California, Davis, Prof. Enrique J. Lavernia, E-mail: Lavernia@ucdavis.edu, Ph: 530-752-0554
   - RSP Tooling, LLC, Mr. James R. Knirsch, E-mail: knirsch@rsptooling.com, Ph: 440-505-6033
   - Glass Manufacturing Industry Council, Mr. Michael Greenman, E-mail: mgreenman@gmic.org, Ph: 614-818-9423
   - General Aluminum Manufacturing Company, Mr. Donald G. Tyler, E-mail: dtyler@generalaluminum.com, Ph: 440-593-6225

5. **Date Project Initiated:** October 1, 2001.

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

PROJECT RATIONALE AND STRATEGY

7. **Project Objective:**

The objectives were established in response to R&D needs for improved mold and die materials and reduced energy consumption expressed in the IOF Technology Roadmaps for steel, glass, metal casting, forging, and heat treating. These objectives include:

Objective One: Increase die life by a minimum of 20%.

Objective Two: Reduce energy consumption associated with the manufacture and heat treatment of dies by a minimum of 25%.

8. **Technical Barrier(s) Being Addressed:**

Conventional fabrication of molds and dies is very expensive and time consuming because each is custom made to the desired geometry, the materials from which they are made are difficult to machine and work with, and the dies must have high dimensional accuracy. This project involves the development of a rapid tooling technology (Rapid Solidification Process (RSP) Tooling) to manufacture molds, dies and related tooling, and the development of alloys and heat treatments tailored to the process. It is anticipated that RSP Tooling will result in a reduction in the cost, turnaround time and energy use associated with the manufacture of molds and dies by:

1. Eliminating steel mill unit operations for producing forged plate, rod, bar, etc.
2. Eliminating many of the machining, grinding, and polishing unit operations necessary to transform the forged steel into molds and dies for die casting, forging, stamping and glass manufacture.

3. Extending die life as a result of unique microstructural qualities found in rapidly solidified tool steel and the potential to develop tooling alloys tailored to the process.
4. Providing the means to heat-treat the tool steel using relatively low temperature artificial aging rather than conventional autenitization/quench/temper heat treatment.

9. **Project Pathway:**

RSP Tooling combines rapid solidification processing and net-shape materials processing in a single step. The general concept involves converting a mold design described by a CAD file to a tooling master using a suitable rapid prototyping (RP) technology such as stereolithography. A pattern transfer is made to a castable ceramic, typically alumina. This is followed by spray forming a thick deposit of tool steel (or other alloy) on the pattern to capture the desired shape, surface texture and detail. The resultant metal block is cooled to room temperature and separated from the pattern. Typically, the deposit's exterior walls are machined square, allowing it to be used as an insert in a standard mold base or holding block. The project pathway is:

- 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 and evaluate material response to artificial aging and conventional heat treatment.
- Model heat transfer, solidification, and momentum phenomena associated with spray forming of dies.
- Develop ceramic casting materials and procedures for tool patterns.
- Tailor alloy chemistry and heat treatment to processing by spray forming.
- Perform in-service lifetime and failure mode analysis.
- Demonstrate/document reduced energy consumption and scrap.
- Transfer technology to industry partners.

10. **Critical Technical Metrics:**

Baseline Metrics

- The cost and turnaround time for molds and dies depends on their complexity and size. For example, large die-casting dies for transmissions cost $750,000 with a lead time of about 40 weeks. The cost and turnaround time of experimental dies used in this study can be quoted by industry participants.
- Anticipated die life and failure modes of dies are also material and geometry dependent. For example, dies used to die casting aluminum have lifetimes ranging from about 10,000 to1 million parts. Dominant failure modes include heat checking, erosive wear, and soldering.

Project Metrics

- Reduce cost and turnaround time for production-quality dies by about 30%.
- Increase die life.
- Successfully transfer technology to industry partners.

PROJECT PLANS AND PROGRESS

11. **Past Accomplishments:**

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, responded 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.

Alloy property response to artificial aging was analyzed and documented. Researchers at UCD and INEEL utilized techniques employed during Year 1 to establish microstructure/property relationship and study microstructure transformation of spray-formed tool steels during low temperature heat treatments and conventional heat treatment, particularly carbide precipitation and growth. Results were correlated with Year 1 results, and used to tailor tool steel heat treatment to the rapid solidification conditions during spray-deposition processing. Researchers have begun to assess the influence of alloy additions on microstructure and tooling properties. Preliminary material was produced with the modified alloys and sectioned for microstructure and property analysis.

12. Future Plans:

The status of project milestones is summarized in the table below.

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
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	7/1/03
6	Model spray process	10/1/03	10/1/03
7	Evaluate properties of heat treated alloys	2/1/04	2/1/04
8	Modify alloy chemistry	12/1/04	In progress
9	Design/build solid models	10/1/04	In progress
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	

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.

13. **Project Changes:**
No changes in project scope are anticipated at this time.

14. **Commercialization Potential, Plans, and Activities:**
An important development is that the spray forming technology (Rapid Solidification Process Tooling) under development in this project to manufacture molds and dies was 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, was debugged, and is currently making and shipping tooling inserts.

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

Patents:

- The U.S. Patent Office has notified INEEL of an allowance on a patent entitled "Rapid Solidification Processing System For Producing Molds, Dies, and Related Tooling." Foreign patent applications have been filed (An allowance in Canada thus far).

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.
- Kevin M. McHugh, "Rapid Solidification Process (RSP) Tooling For Moldmaking," proceedings of *Moldmaking 2003* , Cleveland, OH, April 29 - May1, 2003, P.23 (2003).

Publications:

- Kevin M. McHugh and James E. Folkestad, "Production of Molds and Dies Using the RSP Tooling Approach," proceedings of SDMA 2003 and ICSF V, Bremen, Germany, P. 5-123, (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.