ADMINISTRATIVE INFORMATION

1. **Project Name:** Development of Functionally Graded Material for Manufacturing Tools and Dies and Industrial Processing Equipment.

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5. **Date Project Initiated:** March 31, 2004

6. **Expected Completion Date:** September 30, 2007

PROJECT RATIONALE AND STRATEGY

7. **Project Objective:** While materials currently used for tools, dies and equipment in the hot forming industries have performed adequately for many years, they represent a weak link in regards to current day objectives of increasing manufacturing efficiency and reducing energy consumption. In many hot forming applications, the use of monolithic alloyed materials have reached the limit of their usefulness. A potential solution lies in the development of functionally graded materials (FGM) that can be designed to overcome the shortcomings of existing materials used in the hot forming industries. The project goal is to implement FGM solutions into manufacturing environments associated with hot forming applications in the forging, die casting and glass industries. Success will better enable these basic and mature U.S. industries to maintain or gain a competitive edge in a global market.

8. **Technical Barrier(s) Being Addressed:** Project technical barriers are associated with the lack of current materials that can withstand the high temperature, stress, corrosive and erosive environment of many hot shape forming applications. Issues include low strength at elevated temperatures, thermal cracking and fatigue, high energy and life cycle costs and poor erosion and chemical compatibility properties. Solving these barriers requires a new approach to materials selection and the manufacturing of these materials with advanced powder metallurgy materials and processing technology.

9. **Project Pathway:** Initially two advanced powder metallurgy forming processes will be pursued to develop functionally graded materials (FGM) to meet the rigorous environment of hot forming applications and significantly reduce energy usage and manufacturing costs. FGM materials for tools and processing equipment will be custom designed and manufactured for testing in a commercial environment. Performance, energy usage and economics will be analyzed to determine which materials and fabrication process can be successfully implemented by the project's industrial partners.

10. **Critical Metrics:** Materials currently used for tools, dies and other processing equipment in hot forming operations have been in existence for over fifty years. The cost of energy used is high and production efficiency low because of the inadequacies of these materials. The targets for success in this project are to (1) reduce energy consumption by 25 percent, (2) increase tooling lives by a minimum of five times that of current materials and (3) provide a globally competitive cost edge to U.S. forging, die casting and glass manufacturing industries.

PROJECT PLANS AND PROGRESS

11. Past Accomplishments: The majority of the milestones in Task I have been completed. A review of tooling requirements at the project's industrial partners has been completed and specific high volume applications have been selected for FGM trials. Failure analysis has shown a variety of causes for tool failures, and each will be addressed accordingly. Some modeling remains to be completed in Task I because of the lack of mechanical and physical property data on a number of FGM tooling materials. Modeling work to date has shown a variety of causes of tool failures ranging from high temperature softening, thermal fatigue, chemical reactivity, tool design or combination thereof. Results are being used to select optimum FGM tooling combinations for specific applications.

    Considerable effort with good progress has been accorded to Task II milestone during the last twelve months. The FGM consolidation process being used to manufacture tooling, Laser Process Deposition (LPD) and Solid State Dynamic Powder Consolidation (SSDPC) have been optimized and parameters established for providing full dense bi-metallic tooling and laser clad tooling. A series of FGM blanks have been prepared and forwarded to PNNL to develop the physical and mechanical property data required to complete the modeling effort in Task I. In addition, numerous FGM tools have been manufactured for preliminary testing at the project's industrial partner's plants. Results have been varied to date ranging from no improvement to significant improvements relative to our objective of increasing standard tooling life by 5X. Trials at GKN have shown no significant improvement primarily because of a tool design problem as opposed to the tooling material itself. Lives of 3X have been observed at FormTech with additional trials underway. Die segments being tested at Metaldyne's aluminum die casting plant have been running for over a year without any failures. Trials run at non-partner's plants as part of the project have shown FGM tool life improvements of 10X in an extrusion application and 20X in a hot forging application. Because of a late entry into the project, FGM tooling trials are just getting underway at our glass-forming partner, Owens-Illinois.

Task III milestone work has been initiated at Carpenter Powder Products and South Dakota School of Mines and Technology, to establish the robustness of the processes being used to manufacture FGM tooling. Both processes are being used, depending on the application, to manufacture a large number of prototype tools for testing on full scale production lines at each of our industrial partner's plants. In addition, each industrial partner is benchmarking standard tooling and costs so that a direct comparison can be made with the potential cost and energy savings associated with FGM tooling.

12. **Future Plans:**

Date	Milestone/Deliverable	Partner Activities
9/30/06	Task I – Identify and Model Tooling Issues in Hot Forming Processes • Model Hot Forming Applications	 PNNL,O-I, FormTech, THT, GKN
12/3/06	Task II – Optimize LPD and SSDPC Processes for Manufacturing FGM Tooling • LPD FGM Tooling • Optimize Key LPD & SSDPC Variables • SSDPC FGM Tooling • Characterize FGM Structures and Properties	 SDSMT, FormTech, O-I SDSMT, CPP CPP, Metaldyne, GKN PNNL, CPP
2/28/07	Task III – Assess FGM Tool Performance in an Industrial Environment • Select and Evaluate FGM Tooling • Manufacture Prototype Tools • Conduct Industrial Tooling Trials • Assess FGM Performance for Energy/Economic Savings	 CPP, SDSMT, PNNL CPP SDSMT Metaldyne, GKN, FormTech, O-I, THT All Partners

13. **Project Changes:** A number of project changes have occurred relative to the FGM team on this DOE Cooperative Agreement. As previously reported, the original glass manufacturing participant, Techneglas, withdrew from the project when their Japanese parent closed all U.S. manufacturing plants. After an extensive search, Owens Illinois (O-I), located in Toledo, Ohio, became an official member of the project team in the first quarter of FY'06. O-I is a major glass manufacturer with large glass container manufacturing plants throughout the world. In addition, the forging division of Metaldyne, one of the project's primary industrial partners, was sold to FormTech Industries with headquarters located in Royal Oak, Michigan. FormTech is the largest provider of automotive forgings in North America, with plants in Michigan, Indiana and Ohio. They will remain a part of the FGM project and will continue to explore the use of advanced tooling for their hot forging operations. Metaldyne, who also participated in the FGM project relative to their die casting operations, will remain with the project and continue to study new tooling materials for their aluminum die casting plants. Yet another change involves FGM partner GKN who will close their Romulus, Michigan plant, which forges powder metallurgy connecting rods and transfer all forging operations to their Pennsylvania plants. GKN will also continue to be a team member. The team is now comprised of six industrial companies involved in various types of hot forming operations along with the Pacific Northwest National Lab and the South Dakota School of Mines and Technology. No changes have occurred in respect to the scope or approach to the project. Because of the late entry of O-I into the project, changes at Metaldyne and GKN,

and the need to develop property data for the process modeling work, the schedule has slipped, and it is anticipated that a no cost extension of the project will be requested by the end of FY'06 so that all milestones can be achieved.

14. **Commercialization Potential, Plans, and Activities:** The commercialization potential for tools and dies associated with the hot forging, die casting and glass forming activities of the project's industrial partners is very large. Tool life varies as a function of the application, but all project partners agree that a 5X increase in tool life will greatly improve manufacturing efficiency and reduce energy consumption. One forging company purchases over 80,000 pounds of tooling per month, while the project's glass partner purchases over one million plungers per year, all of which could potentially be minimized with new FGM tooling. Plans include testing of FGM tooling in commercial hot forming operations at each industrial partner and comparing the results with baseline material currently being used. All of the industrial partners have committed to implement new tooling that reduces energy consumption and manufacturing costs. Successful implementation is being disseminated to like and similar U.S. manufacturing companies.

15. **Patents, Publications, Presentations:** No patents have been granted or applied for as a result of this DOE Cooperative Agreement. A number of presentations and publications by SDSMT personnel have resulted from FGM project work. The most recent include:
"Developments in Hard Metal Surfaces for Industrial Applications through Laser Powder Deposition", Sears, J.W., Costello, A., Miller, S., and Wolff, M., Presented & Published at the PowderMet 2006, the MPIF International Conference on Powder Metallurgy & Particulate Materials, San Diego, CA, June 2006.

"Improving the High Temperature Wear Characteristics of Industrial Tools, Dies and Processing Equipment using Functionally Graded Materials", Roalstad, J., Bhattacharya, S., Howard, S. M., Costello, A., and Sears, J. W., Presented & Published at the PowderMet 2006, the MPIF International Conference on Powder Metallurgy & Particulate Materials, San Diego, CA June 2006.

"Fabrication and Repair with High Temperature Materials by Laser Powder Deposition", Sears, J. W., Presented at AeroMat, Seattle, WA. 15-18 May 2006.

"Laser Applications in Additive Manufacturing: Spanning Microns to Meters", Sears, J. (Invited Plenary Talk) Presented and Published at the 2nd Pacific International Conference on Lasers and Optics, (PICALO), Melbourne, Australia, 5 April 2006.

"Investigating Functionally Graded Materials to Improve the High Temperature Operating Characteristics of Industrial Tools and Dies and Processing Equipment' 2006 TMS Annual Meeting, San Antonio, Texas, March 12-16, 2006.

"Thermal Stability of Various Alloys Clad on H13 Tool Steel by Laser Powder Deposition" 2006 TMS Annual Meeting, San Antonio, Texas, March 12-16, 2006.

"Improving the High Temperature Wear Characteristics of Industrial Tools and Die Using Functionally Graded Refractory Metals" 2006 International Conference on Tungsten, Refractory and Hardmetals VI, Orlando, Florida, February 8, 2006.