ADMINISTRATIVE INFORMATION

1. **Project Name:** Crosscutting Applications for a New Class of Ultra-Hard Materials Based on $AlMgB_{14}$

2. **Lead Organization:**
Ames Laboratory
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3. **Principal Investigator:**
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4. **Project Partners:**

University of Arkansas – Department of Mechanical Engr.	Prof. Deepak Bhat
Praxair Surface Technologies	Dr. Thomas Taylor
Kennametal Advanced Solns. Group	Dr. Dev Bannerjee
Brunner & Lay Inc.	Dr. Alan Buchanan
Michigan Technological Univ.	Dr. Marv McKimpson
Boise Cascade Corp	Dr. Perry Payne
Deere & Co. Technical Center	Dr. Bruce Boardman

5. **Date Project Initiated:** 10/1/01

6. **Expected Completion Date:** 12/31/04

PROJECT RATIONALE AND STRATEGY

7. **Project Objective:**

The objective of this project is to establish a framework for future commercialization of a new class of ultra-hard materials based on $AlMgB_{14}$. This framework is based on fundamental research into the compositional and processing variables that affect performance and efficiency in a wide range of wear-intensive applications in the mining, forest products (e.g., mechanical pulping), metalcasting, and agriculture industries. By developing improved monolithic wear-resistant tooling materials, advanced high-strength, high-ductility binder phase alloys, and related ultra-hard thin film coatings, these new materials have the potential to reduce energy usage in cutting, grinding, and drilling operations. It is estimated that a 10% market penetration of ultra-hard borides in the metalcasting, mining, forest products, and agriculture industries would result in an energy saving of 5.5 trillion BTUs per year, while reducing CO_2 emissions by at least 2 million metric tons.

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

Existing technical barriers facing metal removal, grinding, chopping, and milling operations involve deleterious chemical reactivity and poor mechanical integrity of the tool under the severe

environments encountered during normal use. The issues associated with wear contribute to high energy consumption and increased cost.

Specific technical barriers directly addressed by this project include:

- Inadequacy of existing technology for producing fully dense ceramic-based tooling materials
- Lack of a cost-effective manufacturing technology to uniformly distribute a nanophase strengthening reinforcement material (e.g., TiB_2) within a ceramic, cermet, or intermetallic matrix
- Absence of an advanced binder material to improve fracture toughness of existing tooling and grinding materials
- Difficulty in obtaining high-hardness, low friction thin film coatings for wear applications
- Lack of a material combining high hardness and good oxidation resistance at high temperatures.
- Paucity of efficient routes for scale-up

9. **Project Pathway:**

Significant increases in the efficiency of industrial machining and cutting operations are needed to reduce domestic energy consumption. The best approach to this objective is to increase machining speeds, which requires development of new materials capable of tolerating more severe environments. The specific roadmap to achieving this objective with materials based on icosahedral borides involves the following tasks, which were directly addressed by this project and its collaborators:

1. scale-up processing of high-hardness boride materials
2. optimization of production methods to reduce variability in hardness and to control deleterious oxygen contamination
3. implementation of laboratory cutting and grinding tests to quantify $AlMgB_{14}$-based cutting tool performance in controlled comparisons to other commercially available cutting tools (e.g. CBN, diamond, and WC-Co cermets) on a variety of workpiece materials
4. development of a metal binder phase to allow production of BAM cermet composite cutting tools similar to the widely used carbide cermets
5. field trials of BAM tools, coatings, and abrasive grits to be performed by cooperating industry partners
6. development and characterization of $AlMgB_{14}$ films prepared by pulsed laser deposition, including lathe cutting test comparisons with un-coated cemented carbide tools.
7. Compositional research to develop a more oxidation-resistant ultra-hard material than the baseline $AlMgB_{14}$. (There currently exists no material possessing a combination of high hardness at elevated temperature plus oxidation resistance.)

10. **Critical Technical Metrics:**

Baseline metrics:

- Current metal removal max. machining speed ~ 61 m/min
- Current annual electricity usage with existing tooling materials: 35.2 bkWh
- Current annual NO_x emission: 4.78×10^{10} metric tons

Project metrics:

- Projected metal removal max. machining speed ~ 120 m/min
- Projected annual electricity usage with 10% mkt penetration: 25.0 bkWh
- Projected annual NO_x emission (10% mkt. penetration): 3.40×10^{10} metric tons

PROJECT PLANS AND PROGRESS

11. **Past Accomplishments:**

Since the beginning of this program, the following milestones have been accomplished:

- Establishment of powder processing scale-up technology
- Incorporation of processing science advances into nanophase microstructures
- Development of a new, high-strength, high-ductility binder composition
- Preparation and characterization of high-hardness, low friction thin film coatings
- Evaluation of high-speed cutting potential of boride tools with various metal alloys
- Identification of new chemical compounds based on icosahedral borides
- Establishment of a commercialization entity and business plan
- Advancement of the science of "extrinsic" hardness

12. **Future Plans:**.

Note: FY 2004 was the last year slated for funding under the IMF program. However, because of the diversity of topics emerging as a result of this research, a number of spin-off projects and milestones are worthy of consideration for future support. These include:

- Development of improved WC alloys using the new, patented binder composition
- Incorporation of thin films of the boride into MEMS components to reduce wear
- Fundamental studies of the new compositions $AlCrB_{14}$, Mg_2B_{14}, and $LiFeB_{14}$ and examination of possible applications
- Theoretical modeling of extrinsic hardness in complex, multi-phase systems such as $AlMgB_{14}$+TiB_2

13. **Project Changes:**

As a result of the development of a very promising new binder phase alloy, some project resources were diverted toward studies of its incorporation into an $AlMgB_{14}$ matrix. In addition, at the request of our industrial partners, we embarked on a study of possible oxidation-resistant hard materials, a topic not discussed in the original proposal.

14. **Commercialization Potential, Plans, and Activities:**.

The commercialization of all technologies developed at Iowa State University falls under the jurisdiction of the Iowa State University Research Foundataion (ISURF). ISURF's commercialization roadmap for this material involved defining the nature and scope of the license, identifying potential licensees, and initiating contact between the scientific investigators and the licensees. As of May, 2004, an option agreement for an exclusive license to manufacture ultra-hard $AlMgB_{14}$-based materials was executed with Viable Technologies, LLC. Viable has been working in conjunction with the IMF industrial partners and has assumed the responsibility of providing sample material to them for evaluation. Preparation of a formal business plan is currently in progress and the final version of this document is expected to be available in the August-September, 2004 timeframe.

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

B. A. Cook, J. L. Harringa, T. L. Lewis, A. M. Russell, and Y. Lee, "Processing Studies and Selected Properties of Ultra-Hard $AlMgB_{14}$," J. Advanced Materials (in press).

A.M. Russell, B.A. Cook, J. L. Harringa, and T. L. Lewis, "Coefficient of Thermal Expansion of $AlMgB_{14}$", Scripta Materialia 46 (2002) 629 – 633.

B. A. Cook, J. L. Harringa, A. M. Russell, and S. A. Batzer, "A Proof-of-Concept Study of the Use of Complex Borides for Disassembly of Decomissioned Nuclear Reactor Containment Vessels," J. Mach. Sci & Tech. (2003), 7(1), 157-165

T. L. Lewis, A.M. Russell, B.A. Cook, and J. L. Harringa, "Al_2MgO_4, Fe_3O_4, and FeB Impurities in $AlMgB_{14}$", Mater. Sci & Engr A, 351 (2003) pp. 117-122.

J. M. Hill, D. C. Johnston, B. A. Cook, J. L. Harringa, and A. M. Russell, "Magnetic Susceptibility Study of the Ultra-hard $AlMgB_{14}$," J. Mag. Magn. Mater., 265 (2003) 23.

B. A. Cook, A. M. Russell, J. A. Harringa, A. J. Slager, and M. T. Rohe, "A New Ductile Binder Phase for use with $AlMgB_{14}$ and other Ultra-Hard Ceramics," J. Alloys & Cmpds. 366 (2004), 145-151.

Y. Tian, A. F. Bastawros, C. C. H. Lo, A. P. Constant, A. M. Russell, and B. A. Cook, "Superhard, self-lubricating $AlMgB_{14}$ films for LIGA microdevices," Appl. Phys. Lett. 83 (2003) 1 – 4.

Y. Tian, G. Li, N. L. Wang, B. A. Cook, A. P. Constant, A. M. Russell and J. E. Snyder, "Electrical transport behavior in amorphous $AlMgB_{14}$ films," submitted to Appl. Phys. Lett.

M. Stock and P. Molian, "Femtosecond pulsed laser deposition of amorphous, ultrahard thin films," J. Vacuum Sci. & Tech. A, 22 (2004) 670 – 675

Intellectual Property Disclosure and Record, filed January, 2004, "Novel Ultra-Hard Boride-Based Reinforcement of Al and Al Alloys"; B.A. Cook, J.L. Harringa, B. Biner, and I. E. Anderson. (ISURF docket number 3107, AL498).

Provisional Utility Patent Serial No. 60/422,001, "Ductile Binder Phase for Use with $AlMgB_{14}$ and Other Hard Ceramic Materials "; B.A. Cook, A.M. Russell, and J.L. Harringa (ISURF #2949, filed October 29, 2002).

U.S. Patent 6,432,855, "Superabrasive Boride and a Method of Preparing the Same by Mechanical Alloying and Hot Pressing "; (divisional patent of 6,099,605) issued August 13, 2002, B.A. Cook, J. L. Harringa, and A.M. Russell.

U. S. Patent no. 6,099,605, "Superabrasive Boride and a Method of Preparing the Same by Mechanical Alloying and Hot Pressing," issued August 8, 2000, B. A. Cook, A. M. Russell, and J. A. Harringa.

Provisional Patent Application filed: "An Ultra-hard, Low Friction Coating Based on $AlMgB_{14}$ for Reduced Wear of MEMS and other Tribological Components and Systems"; B.A. Cook, A.M. Russell, J.L. Harringa, P. Molian, A.P. Constant, and Y. Tian. (ISURF docket number 03035, AL490).

Intellectual Property Disclosure and Record, filed August, 2002, " A New, Oxidation Resistant, Ultra-hard Material, Aluminum Chromium Boride, $AlCrB_{14}$"; B.A. Cook, A.M. Russell, and J.L. Harringa. (ISURF docket number 2951, AL484).