

[PLEASE NOTE: All information you submit is public information. These forms will be posted on the materials sub-program website.]

ADMINISTRATIVE INFORMATION

1. **Project Name:** Crosscutting Applications for a New Class of Ultra-Hard Materials
2. **Lead Organization:** Ames Laboratory, Materials and Engineering Physics Program
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3. **Principal Investigator:** Dr. Bruce A. Cook
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5. **Date Project Initiated:** 10/01/04
6. **Expected Completion Date:** 09/30/06 (Phase I)

PROJECT RATIONALE AND STRATEGY

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

Research on complex ceramic composites based on $AlMgB_{14}$ has revealed that these materials possess extreme resistance to abrasive and erosive wear. When optimized for microstructure and composition, the resistance to wear of these materials surpasses cemented carbide, diamond, and cubic boron nitride, placing them among the most wear-resistant materials ever developed. Incorporation of these degradation-resistant materials in the most energy-intensive industries is expected to conserve significant amounts of energy (e.g., metalcasting (2 – 3 Tbtu/yr), forest products (1.0 Tbtu/yr), mining (6 to 7 Tbtu/yr)), thereby decreasing our dependence on non-domestic sources of energy. As an enabling step toward this goal, our research program is focussed on identifying the optimum composition and microstructure corresponding to maximum wear resistance, establishing reproducibility of the processing technology, developing cost-effective manufacturing solutions amenable to industrial scale-up, and providing technical support during the initial commercialization phase.

8. **Technical Barrier(s) Being Addressed:** (Please provide a brief paragraph describing the barrier to industrial energy efficiency that is being addressed by this project and the associated technical challenges.)

Degradation of materials resulting from wear adversely impacts energy usage, productivity, and product throughput. As critical components begin to degrade, the amount of energy required to maintain operation of the equipment increases, with more energy wasted in the form of heat. While estimates vary of the total amount of energy 'lost' to material degradation, even the most conservative figures correspond to an astounding loss each year. It is the lack of a suitable, cost-effective wear-resistant material that constrains industry to operate equipment at reduced speeds, temperatures, and differential pressures, generates added costs due to downtime, and decreases the overall energy efficiency of the process. The technology resulting from this research will be adapted to a number of industrial processing components to increase lifetime and efficiency. Field trials of best-composition materials are currently in progress, and various cost-effective manufacturing strategies such as hot isostatic pressing and magnetron sputtering are being evaluated.

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.)

The development and subsequent commercialization of the wear-resistant compositions extends beyond a traditional laboratory-scale research effort. In order to facilitate industrial implementation of the compositions developed by this project, close contact is maintained with a number of industrial partners, who recognize the potential benefits of incorporating materials with improved wear resistance. The overall strategic approach is based on an iterative field-trial philosophy, in which feedback from industrial tests is used to optimize properties of the material. As more is learned about the structure-property relationships in these complex materials, the knowledge gained is applied to refinements in composition and microstructure. By limiting the number of potential applications to a manageable number of industrial partners having similar requirements, it is possible to target specific problems within a reasonable time frame. For example, optimization of composition and microstructure in the bulk materials, suitable for abrasive nozzles and abrasive slurry conveying systems, will be resolved first, before adding the complexities associated with large-scale coating technology.

10. **Critical Metrics:** (Please describe the application-specific metric(s) (i.e., metrics in the end-use industrial process) that will be used to determine the success of the project.)

- *Identification of superior wear-resistance
(do the materials indeed possess improved wear resistance compared with other materials?)*
- *Determination of optimum range of $AlMgB_{14}/TiB_2$ ratios
(is there an optimum $AlMgB_{14} : TiB_2$ ratio that maximizes wear resistance?)*
- *Formulation of microstructure/wear resistance relationship
(how is wear resistance affected by microstructure? What is the limiting performance of the material and can this level of performance be achieved using current processing technology?)*
- *Development of cost-effective manufacturing technology
(Is the superior wear resistance maintained in materials produced by industry-accepted processing methods? Can the successful laboratory-scale technology be scaled to production levels in a cost-effective manner?)*

PROJECT PLANS AND PROGRESS

11. **Past Accomplishments:** (Please summarize the major accomplishments and key milestones achieved to date.)

1. *Discovered that hardness and fracture toughness are functions of the $AlMgB_{14}:TiB_2$ ratio*

2. *Observed higher resistance to abrasive wear in AlMgB₁₄:TiB₂ composites compared with WC/Co and cubic BN during diamond-belt abrasion tests.*
3. *Identified compositions corresponding to significantly higher resistance to erosive wear compared with diamond, cubic BN, SiC, and WC/Co.*
4. *Determined that hardness, wear resistance, and toughness depend on the microstructural arrangement of the respective phases.*
5. *Developed processing technology to incorporate nanoscale reinforcement phase in AlMgB₁₄ for improved wear resistance.*
6. *Initiated initial field trials of high-hardness compositions with industrial partners*

12. **Future Plans:** (Please describe the specific dates, milestones, deliverables, and activities of all partners (i.e., who is doing what) for the life of this project, with particular emphasis on FY06. PLEASE NOTE: This information is used by DOE throughout the year for funding actions and to respond to Congressional inquiries. Failure to provide the requested information may delay funding actions.)

Date	Milestone/Deliverable	Partner Activities
3/06	High-speed lathe cutting tests (Ti-6Al-4V)	U. of Arkansas will conduct these tests using inserts supplied by Ames Laboratory
12/05	Initial field trials of abrasion-resistant compositions	Kennametal will evaluate improved compositions against their state-of-the-art material
12/05	High-temperature reactivity studies and rub testing of baseline boride compositions	Praxair Surface Technologies will perform high-temperature rub tests using their proprietary turbine simulation equipment
6/06	Commercial-scale processing technology	Ames Laboratory will develop cost-effective processing methods to produce nanoscale reinforcement distribution
9/06	Wear-resistant coatings	ECI will apply magnetron sputtering technology to best compositions in order to produce wear-resistant coatings
9/06	Commercialization start-up	Pilot-plant-scale manufacturing of best compositions with technical support from Ames Laboratory.

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

Early attempts to develop a cost-effective processing scale-up technology revealed complications in preventing oxygen pick-up by fine powders during operation and discharging from the Zoz attritor and also in obtaining the same degree of alloying/comminution as obtained in the laboratory-scale Spex vibratory mills. Oxygen contamination of the pre-consolidated powder results in formation of spinel (MgAl₂O₄), the presence of which severely degrades hardness in the composite. In addition, "defect" regions of incompletely-alloyed material, combined with microporosity, were also observed in consolidated compacts. It is known that the microhardness in microstructurally-optimized composites can exceed 45 GPa, however, the presence of these defects can decrease this by as much as 40 percent! Consequently, we are currently researching improved alloying and compacting methods such as micromilling, cryomilling, addition of surfactants, and glass frit encapsulation to improve process reproducibility, uniformity, and yield.

The discovery of extreme wear resistance during FY 2005 in mixed composites of AlMgB₁₄-TiB₂ has shifted research focus from hardness as a primary metric per se, to the more industrially-useful metrics of abrasion and erosion resistance. As a consequence, we have begun researching compositions that exhibit a higher

degree of wear resistance than the original 20 to 30 vol% TiB₂, and have also implemented new testing protocols for determination of erosive and abrasive wear resistance.

14. **Commercialization Potential, Plans, and Activities:** (Describe the end-use application and market potential for the project, and the plans, progress, and partners for commercial application/adoption, where appropriate; identify the product of the project and how this product will be introduced and disseminated to industry.)

The technology developed under this program will have as its primary application the replacement of existing wear-intensive components in industrial manufacturing, machining, and material delivery (e.g., piping) systems. Technology option rights are currently being re-negotiated by Iowa State University Research Foundation in response to a shift in emphasis toward the highly wear-resistant compositions. Commercial integration is being addressed through a series of industrial field trials.

15. **Patents, Publications, Presentations:** (Please list number and reference, if applicable. If more than 10, please list only 10 most recent.)
- Intellectual Property Disclosure and Record filed, "Novel Ultra-Hard Boride-Based Reinforcement for Al and Al Alloys," B. A. Cook, J. L. Harringa, A. M. Russell, I. E. Anderson, and B. Biner, ISURF docket number 03107, Ames Lab docket number AL498.
 - Intellectual Property Disclosure and Record filed, "Wear-Resistant Boride Composites," B. A. Cook, J. L. Harringa, A. M. Russell, A. Ahmed, and J. Peters, ISURF docket number 03269, Ames Lab number AL505.
 - Intellectual Property Disclosure and Record filed, "AlMgB₁₄ and Related Icosahedral Boride Semiconducting Materials for Neutron Sensing Applications," J. E. Snyder, B. A. Cook, and A. P. Constant, ISURF docket number 03277, Ames Lab number AL506.
 - A. Ahmed, S. Bahadur, B.A. Cook, and J. Peters, "Mechanical Properties and Scratch Test Studies of New Ultra-Hard Aluminum Magnesium Boride Modified by Titanium Diboride," Tribology International, (submitted)
 - A. Ahmed, S. Bahadur, A. Russell, and B.A. Cook, "Belt Abrasion Resistance and Cutting Tool Wear Studies on New Ultra-Hard Boride Materials," Tribology International (submitted).
 - Y. Tian, G. Li, N. L. Wang, B. A. Cook, A. P. Constant, A. M. Russell and J. E. Snyder, "Electrical transport in amorphous semiconducting AlMgB₁₄ films," *Appl. Phys. Lett.*, 85 (2004) 967.
 - M. Stock and P. Molian, "Femtosecond pulsed laser deposition of amorphous, ultrahard thin films," *J. Vacuum Sci. & Tech. A*, 22 (2004) 670 – 675.
 - B. A. Cook, A. M. Russell, J. A. Harringa, A. J. Slager, and M. T. Rohe, "A New Ductile Binder Phase for use with AlMgB₁₄ and other Ultra-Hard Ceramics," *J. Alloys & Cmpds.* 366 (2004), 145-151.

PLEASE NOTE: Items one through 15 should not exceed four pages in total length.