

**ADMINISTRATIVE INFORMATION**

1. **Project Name:** Crosscutting Applications for a New Class of Ultra-Hard Materials Based on AlMgB<sub>14</sub>
2. **Lead Organization:** Ames Laboratory – Materials & Engineering Physics Program  
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3. **Principal Investigator:** Dr. Bruce Cook  
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4. **Project Partners:**

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| Carpenter Power Products, Inc.<br>Mr. David J. Novotnak<br>DNovotnak@cartech.com<br>(412) 257-5430                              | University of Missouri High-Pressure Waterjet Laboratory<br>Dr. Grzegorz Galecki<br>ggalecki@umr.edu<br>(573) 341-4938 |
| University of Alberta – Dept. of Materials Science & Engineering<br>Prof. Dongyang Li<br>dongyang@ualberta.ca<br>(780) 492-6750 | Kennametal Advanced Solutions Group<br>Dr. Dev Bannerjee<br>Dev.Banerjee@kennametal.com<br>(800) 693-2706              |

5. **Date Project Initiated:** 1 October, 2004 (wear resistance)
6. **Expected Completion Date:** 30 September, 2006

**PROJECT RATIONALE AND STRATEGY**7. **Project Objective:**

The goal of this project is to increase the operating efficiency and lifetime of wear-intensive industrial components by developing and commercializing a family of ceramic-based monolithic nanocomposites which have exhibited outstanding wear resistance in laboratory tests. Industry consumes approximately one-third of the total energy output in the United States, and losses due to degradation of materials account for an appreciable fraction of the total. Nearly 10% of our gross national product is diverted to replacement of worn components and to the resulting downtime and loss of productivity. These next-generation composite materials offer the potential to improve energy efficiency across a wide range of industrial applications, such as material conveyor systems, hydraulic drive components, abrasive fluid transport systems, and pumps.

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

At the heart of industrial energy efficiency lie the materials from which components and systems are comprised. Physical and chemical interactions between moving parts and in erosive

environments wear or degrade industrial components during normal use. As parts wear, the energy needed to operate the component or system increases; in some cases as materials enter into a “severe wear” mode, the decrease in energy efficiency can be dramatic. Development of advanced wear-resistant materials offers an opportunity to promote meaningful energy and cost savings by utilizing these improved materials across a wide range of manufacturing environments. Low-cost offshore competition and increasing energy costs challenge nearly all U.S. manufacturers. Ironically, these disadvantageous factors make it unrealistic for individual industries to bear the costs of developing the wear-resistant materials that would help tilt the competitive balance back in their favor. The crosscutting nature of this program distributes the development and implementation costs of wear-resistant materials across a broad spectrum of industries, allowing such materials to become an affordable competitive advantage for U.S. industries.

#### 9. **Project Pathway:**

The pathway to industrial implementation of advanced wear resistant materials begins by identifying the optimum combination of hardness and toughness, and continues by developing cost-effective processing methods to support crosscutting industrial evaluation and commercialization. Hard but brittle materials can degrade rapidly due to fracture, whereas highly malleable or ductile metals exhibit high wear rates due to plastic deformation. Initial studies on AlMgB<sub>14</sub>-based composites demonstrate the potential for achieving a highly wear-resistant and lightweight material through laboratory-scale powder processing and hot pressing. The objectives of this project will be achieved by a combination of laboratory studies to understand the mechanisms responsible for enhanced wear resistance in the various boride composites, evaluation of the impact of processing variables on the performance of these materials, and by evaluating materials produced by appropriate scale-up approaches under a range of industrial settings to verify properties for commercial viability.

#### 10. **Critical Metrics:**

Demonstration of manufacturing capabilities for wear-resistant AlMgB<sub>14</sub> – TiB<sub>2</sub> articles in quantities of at least 50 cm<sup>3</sup> meeting the following specifications:

*(values in parentheses indicate typical benchmarks at the beginning of project)*

- Total porosity < 1% (2 – 4%)
- Impurity phase MgAl<sub>2</sub>O<sub>4</sub> < 4% (5 – 10%)
- Impurity phase FeB < 4% (10 – 15%)
- Wear rate < 7.5x10<sup>-4</sup> mm<sup>3</sup>/g when subjected to steady-state erosion at normal incidence by 200 μm Al<sub>2</sub>O<sub>3</sub> at 77 m/s and 4.5 g/min at a standoff distance of 1 cm.

*(the following metrics correspond to anticipated performance of net-shape articles at the end of Phase IV)*

- ANSI class IV shutoff valves: < 1% leakage of full open valve capacity at service dP or 50 psid (3.4 bar differential), whichever is lower, at 50 to 125 °F. Test medium air or water at 45 to 60 psig and 10 - 52°C.
- High-pressure nozzle mixing tubes: nozzle longevity > 75 hrs of elapsed time with the maximum depth of cut 2 inches at traverse speed of 1.5 inch/min; specimen material A-108.

### **PROJECT PLANS AND PROGRESS**

#### 11. **Past Accomplishments:**

1. The hardness of the AlMgB<sub>14</sub>-based materials (30 GPa and above) was found to be superior to that of other commonly used wear resistant materials, such as carburized steels (1.2 to 4 GPa), Al<sub>2</sub>O<sub>3</sub> (15 GPa), WC cermets (15 to 20 GPa), binderless WC (25 to 28 GPa), and SiC (28 GPa).
2. The erosive wear of AlMgB<sub>14</sub>-based composite materials is 10 to 40 times better than that of WC cermets and is superior even to more costly cubic-BN and diamond.
3. In the presence of liquid water or water vapor, boron-rich compounds such as AlMgB<sub>14</sub> form a layered crystal structure H<sub>3</sub>BO<sub>3</sub> thin surface film that acts as a self-lubricating coating, producing a coefficient of sliding friction with steel of 0.03 to 0.05<sup>i</sup>, far lower than that of other hard materials (0.12 to 0.80). Polymer coatings (e.g., PTFE) and some quasi-crystalline coatings (e.g., icosahedral Al<sub>64</sub>Cu<sub>23</sub>Fe<sub>13</sub>)<sup>ii</sup> rival the low coefficient of friction of the AlMgB<sub>14</sub>-based materials, but these lack the durability needed in most industrial applications.

Additional key findings include:

Most samples prepared and tested to-date contain several percent porosity, yet exhibit wear resistance comparable to or exceeding that of current-generation wear-resistant materials.

Preliminary field trials of first-generation laboratory-scale boride composites in various industrial environments have provided important guidelines for establishing the most beneficial applications in terms of energy savings, and in establishing objectives for subsequent optimization of the materials.

## 12. Future Plans:

| Date     | Milestone/Deliverable  | Partner |
|----------|--|---------|
| 09/30/06 | Synthesis of AlMgB <sub>14</sub> -based materials by alternative (i.e., non-mechanical alloying) routes with elimination of Fe contamination                                 | Ames    |
| 09/30/06 | Studies of the interface between AlMgB <sub>14</sub> and TiB <sub>2</sub> and explanation of factors responsible for the enhanced wear resistance of the two-phase composite | Ames    |
| 09/30/06 | Preliminary identification of alternate powder synthesis technologies  | ORNL    |
| 09/30/06 | Initial assessment of Dynaforge compaction technology for densification of pilot-plant scale quantities of boride composites.  | CPP     |

## 13. Project Changes:

A 3 month scheduling delay resulted from a decision by our primary supplier of boron, Atlantic Equipment Engineers, to discontinue production of their high-purity (99% metals basis) boron powder. This development resulted in an examination of the role of purity in the precursor material and of various purification steps, including dissolution of boron oxide in distilled water. Materials are now prepared from 95% B (SB Boron).

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

In February, 2006, a licensing agreement was executed between ISURF and a private entrepreneur for commercialization of the wear-resistant boride technology. The entrepreneur has a history of successful product development and considerable expertise in the area of hard materials. Any of the background technologies required for commercialization of products developed during future

research is available for sublicensing. The licensee and ISURF are equally committed to commercialization and fully support transfer of these technologies as needed to the industrial partners under the DOE program. Ames Laboratory is currently providing support to the licensee on alternate processing and densification procedures.

#### 15. Patents, Publications, Presentations:

- B. A. Cook, J. L. Harringa, J. Peters, A. M. Russell, and J. Hawk, "Wear Resistance of AlMgB<sub>14</sub> – TiB<sub>2</sub> Composites," submitted to *Wear*.
- Ahmed, S. Bahadur, B. A. Cook, and J. Peters, "Mechanical properties and scratch test studies of new ultra-hard AlMgB<sub>14</sub> modified by TiB<sub>2</sub>," *Tribology Intl.*, 39 (2006) 129-137.
- J. S. Peters, J.M. Hill, and A.M. Russell, "Direct reaction synthesis of Mg<sub>2</sub>B<sub>14</sub> from elemental precursors," [Scripta Materialia](#), 54 (2006), 813-816.
- J. Peters, B. A. Cook, J. L. Harringa, A. M. Russell, and A. Ahmed, "Improved hardness and toughness of AlMgB<sub>14</sub> composites through addition of reinforcement phases," *Advances in Powder Metallurgy & Particulate Materials* (2005), 8/21-8/30. Publisher: Metal Powder Industries Federation.
- M. Stock and P. Molian, "Femtosecond pulsed laser deposition of amorphous, ultrahard thin films," *J. Vacuum Sci. & Tech. A*, 22 (2004) 670 – 675.
- 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)
- 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, A. Bastawros, C.C. Lo, A. Constant, A.M. Russell, and B.A. Cook, "Superhard self-lubricating AlMgB<sub>14</sub> films for microelectromechanical devices," [Applied Physics Letters](#), 83 (2003) 1-3.

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<sup>i</sup> A Erdemir, c Bindal, and G Fenske, "Formation of ultralow friction surface films on boron carbide", *Applied Physics Letters*, 68(12), p. 1637 (1996).

<sup>ii</sup> AI Goldman, DJ Sordellet, PA Thiel, & JM Dubois, *New Horizons in Quasicrystals: Research and Applications*, World Scientific, Singapore (1997).