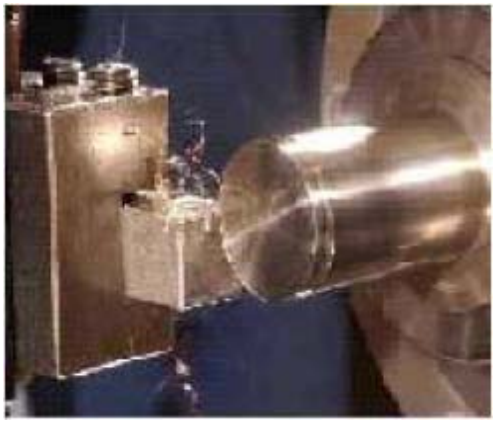
Crosscutting Industrial Applications of a New Class of Ultrahard Borides

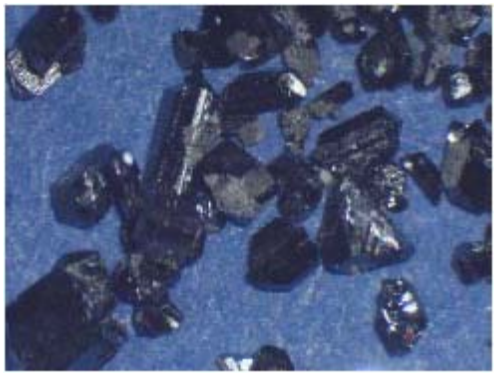
New $AlMgB_{14}$ Composites Offer Significant Improvements in Wear Resistance

Estimates of the cost to the U.S. economy of wear and degradation of materials amounted to over $100 billion annually. Wear of materials not only limits industrial productivity and economic progress the effects of wear also result in a considerable waste of energy across a broad span of industrial operations. Recent studies indicated that nanoscale $AlMgB_{14}$ composites exhibited an unprecedented resistance to wear, suggesting a new paradigm for degradation-resistant materials. In tests against a wide range of current-generation hard and ultra-hard materials, these boride composites showed superior abrasive and erosive wear resistance under severe conditions. The development of improved, wear-resistant materials and coatings was expected to benefit a wide range of industries, ranging from petrochemical to mining and metalcasting. Research into improved wear-resistant materials was also an enabling technology, fostering subsequent development of new processes and products across all industries.

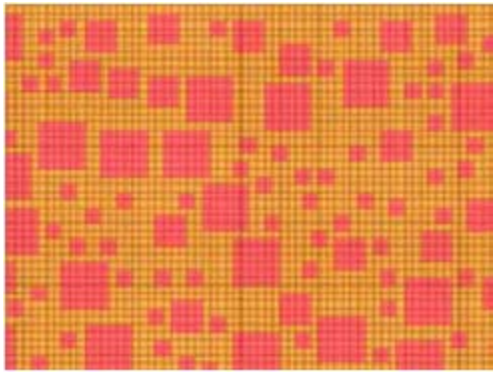
High-speed machining tests on gray cast iron

Lathe cutting tests on 304 steel





"BAM" grit



Micro-structural model

Benefits for Our Nation and Our Industry

- A 30% market in abrasive pump wear components was projected to result in total energy savings of 5 TBtu per year.
- A 10% market in the current U.S. metalcasting industry (grinding and finishing) would save an additional 5 TBtu of energy per year.
- A 10% improvement in performance in the mining industry's drilling, coring, boring, and grinding equipment would result in direct savings of $100 million per year. A more efficient grinding tool that enables a 25% increase in speed would lower energy demands by 100 billion Btu.
- A 2.5% reduction in electric power consumed for cutting operations industry-wide would result in a reduction of CO_2 emissions in the United States by 2 x 10^6 metric tons.

Applications in Our Nation's Industry

Because of the wide range of possible applications for ultrahard borides, this project described a broad-based effort to develop and transfer this technology to four key industries:

- Agriculture
- Metalcasting
- Forest Products
- Mining

Project Description

The goal of this project was to develop a new class of highly wear-resistant bulk and thin film composite materials to serve the metalcasting, mining, forest products, petrochemical, and agriculture industries.

Barriers

Barriers addressed:

- Abrasive slurry pumps were typically operated at a maximum of 1/3 to 1/2 of their rated speed in order to mitigate wear; differential pumping pressures in abrasive applications were limited to roughly 60% of non-abrasive levels, limiting throughput and decreasing energy efficiency of the pumps
- Maximum machining speed for Ti and Ti alloys was constrained by the available tooling materials as a consequence of accelerated diffusional wear. Adhesive wear between tool and workpiece decreased energy efficiency of metal removing processes
- Implementation of efficient high-pressure abrasive jet technology was limited by abrasive wear of the nozzle assembly

Pathways

The objectives were achieved through (1) study of mixing and blending technologies to achieve the distribution of reinforcement without concomitant introduction of deleterious contaminants; (2) development of a high-strength, high toughness binder phase possessing compatible surface energy and thermal expansion; (3) examination of thin film deposition technologies and properties of hardfacing boride coatings on various substrate materials; (4) collaboration with powder processing organizations to establish cost-effective large-scale processing routes; (5) development of microstructure-property models to guide processing optimization; (6) interaction with industry on evaluation of laboratory-scale materials and implementation of feedback in refinement and optimization of processing; and (7) providing ongoing technical support for commercialization.

Progress and Milestones

- Developed a novel Co-Mn binder phase alloy for boride tooling inserts
- Achieved a hardness and toughness combination of 32 GPa and 10 MPa $\sqrt{m}$ in the baseline $AlMgB_{14}$ cermet
- Obtained a microhardness of 48 GPa in $AlMgB_{14}$-TiB_2 composite
- Achieved a factor of 42 improvement over standard-grade cemented carbide during a mass loss erosive wear test
- Achieved lower abrasive wear rates than either cemented carbide or cubic BN
- Developed high-hardness $AlMgB_{14}$ thin films with a friction coefficient of 0.04
- Synthesized $AlMgB_{14}$-based materials by alternative (i.e., non-mechanical alloying) routes with elimination of Fe contamination
- Identified alternate powder synthesis technologies
- Completed initial assessment of Dynaforge compaction technology for densification of pilot-plant scale quantities of boride composites

Commercialization

Commercialization was administered through the Iowa State University Research Foundation (ISURF), which held patents to all ISU ultrahard boride compositions. Recent improvements in wear resistance increased awareness of the potential to provide improvements in productivity and energy efficiency across industry.

In 2006, a licensing agreement was reached between ISU and Innovative Materials, Inc. (IM) for development of the boride-based wear-resistant composite technologies. IM had a history of successful product development and expertise in the area of hard materials. IM explored novel processing and densification techniques for $AlMgB_{14}$. Technical assistance was provided to IM for processing development and characterization of materials via hot pressing studies, metallographic and chemical analyses, and evaluation of hardness and wear resistance.

All of the background technologies required for commercialization are available for sublicensing. IM and ISURF are equally committed to commercialization and fully support transfer of these technologies as needed to future industrial partners.

Project Partners

Ames Laboratory, Iowa State University
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The University of Arkansas
Fayetteville, AR

Praxair Surface Technologies
Indianapolis, IN

Kennametal Advanced Solns. Group
Latrobe, PA

Michigan Technical University
Houghton, MI

The University of Missouri
High-Pressure Water Jet Laboratory
Rolla, MO

A Strong Energy Portfolio for a Strong America

Energy efficiency and clean, renewable energy will mean a stronger economy, a cleaner environment, and greater energy independence for America. Working with a wide array of state, community, industry, and university partners, the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy invests in a diverse portfolio of energy technologies.

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