Ultra-Hard Borides for Industrial Applications

January 2005

Ultra-hard materials are applied to tool surfaces for industrial operations such as cutting, grinding, chopping, drilling, and milling. Technical barriers facing high-speed, dry cutting, grinding, and turning operations involve damaging chemical reactivity and poor mechanical integrity of the tool under the severe environmental conditions encountered during use. The degradation of wear related materials contributes to shorter component lifetimes, higher energy consumption, and increased costs. Thus, materials with the combined characteristics of high hardness and good oxidation resistance at elevated temperatures are needed to realize greater efficiencies in high-speed machining operations. Hard materials based on $AlMgB_{14}$ (BAM) compositions are being developed at Iowa State University's Ames Laboratory with funding from the Industrial Technologies Program. These BAM materials are showing exceptionally promising wear resistance, superior to that of commercially available hard materials, including polycrystalline diamond!

Boron Aluminum Magnesium (BAM) Materials

A process involving the mechanical alloying of constituent materials, followed by hot consolidation of the nanophase mechanical alloyed powders was developed at Ames Laboratory. The purity and initial particle size of the precursor materials have been shown to strongly influence the hardness and wear resistance of the final product. Similarly, the type and configuration of the mechanical alloying equipment employed in the production of the nanophase powders also affects the quality of the product. Optimum hardness requires tight control over particle size and morphology, as well the ability of the processing equipment to uniformly comminute and disperse the additive particles within the BAM powder. Approaches to BAM powder consolidation, such as hot pressing or hot isostatic pressing have been examined, and most of the critical variables have been identified and examined. Since $AlMgB_{14}$ behaves as a ceramic, the powders are resistant to densification and require a reaction-sintering step during granule rearrangement. A nanophase composite of two boride phases, $AlMgB_{14} + TiB_2$, was developed and processed following these procedures. The material provides mutual strengthening for increased hardness combined with crack blunting and deflection for increased fracture resistance. The hardness (as determined by Vickers indentation with a $1Kg_f$ loading) of $AlMgB_{14}$ with varying amounts of TiB_2 additions is shown in Figure 1. A maximum hardness of just under 50 GPa is achieved in composites containing roughly equal volume fractions of $AlMgB_{14}$ and TiB_2. High resolution TEM studies are currently in progress in order to understand the nature of the deformation mechanisms in the two phases and in the grain boundary region between phases..

Of course, the impact of ultra-hard materials on industrial efficiency will be determined by performance characteristics such as wear resistance. Continued improvement in abrasion resistance of the BAM materials has been observed over the last three years of processing research. Diamond belt abrasion tests were conducted on various BAM samples as well as on commercially available hard tool materials. Figure 2 shows the wear rates of these materials at a constant belt speed with increasing load. The BAM plus TiB_2 samples exhibited lower wear rates, thus outperforming the cubic boron nitride (CBN) and WC-Co cermet samples. Figure 3 shows similar results obtained from controlled, high speed grit abrasion tests used to measure the relative wear rates.

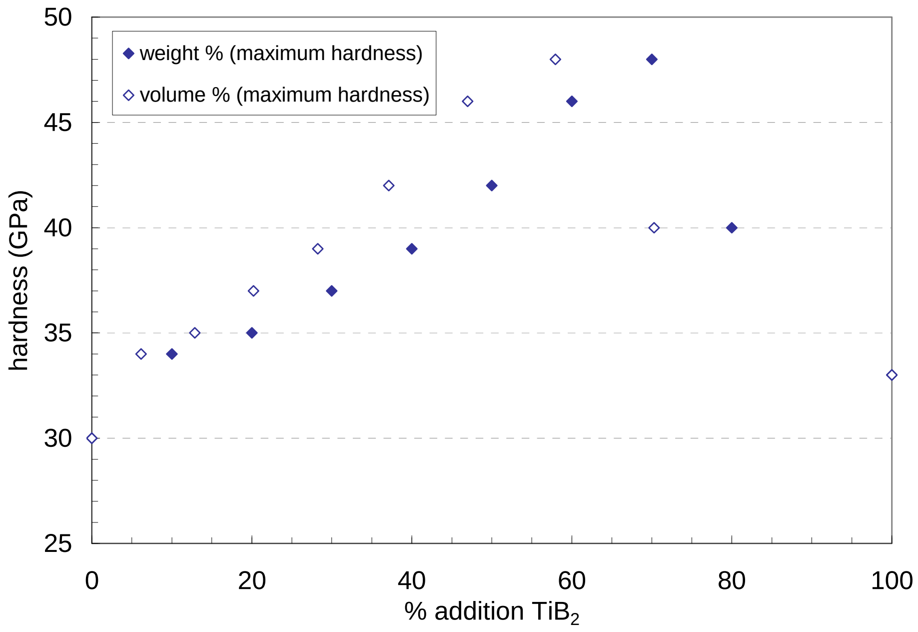

Figure 1. The hardness of $AlMgB_{14}$ samples increases with TiB_2 additions.

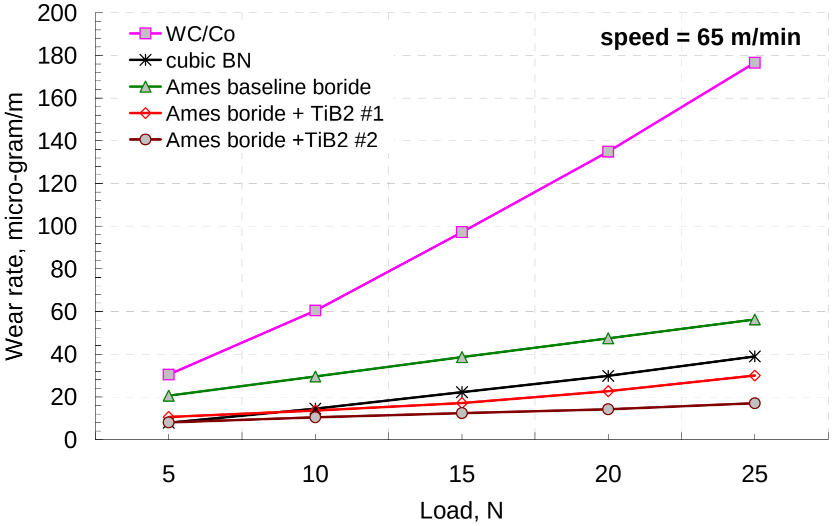

Figure 2. The abrasive wear rate for $AlMgB_{14}$ + TiB_2 samples is less than that of other hard materials.

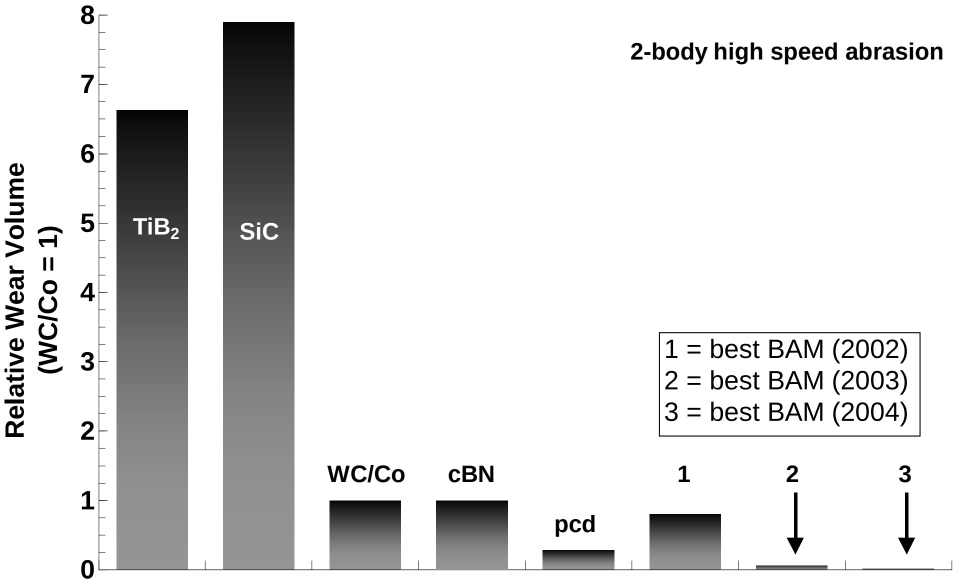

Figure 3. The wear rate of current generation BAM materials is negligible and significantly less than other ultra-hard materials such as Tungsten Carbide – Cobalt composites (WC/Co), cubic Boron Nitride (cBN), and polycrystalline diamond (pcd).

In addition to the hardness and wear data presented above, the following has also been observed for BAM materials:

- The highest hardness and wear resistance is displayed in material with the finest phase size (~100 nm).
- Elimination of residual porosity is necessary to achieve the maximum wear resistance and fracture toughness.
- Oxygen impurities lower hardness by forming Al_2MgO_4 (spinel).
- Tool life during machining of Ti and Ti alloys is extended by a considerable margin (> 60%) by the use of thin film $AlMgB_{14}$ protective coatings on cemented carbide tools.

Commercialization of all technologies developed at Iowa State University is the responsibility of the Iowa State University Research Foundation (ISURF). ISURF's commercialization roadmap for this material consists of defining the nature and scope of the license, identifying potential licensees, and initiating contact between the scientific investigators and the licensees.

For additional information about BAM materials please see the project factsheet at http://www.oit.doe.gov/imf/factsheets/ames_borides.pdf

Or contact:

Dr. Bruce A. Cook
Ames Laboratory
Materials & Engineering Physics Program
221 Metals Development
Iowa State University
Ames, IA 50011-3020
Email: cook@ameslab.gov