## Wear-Resistant Boride Nanocomposite Coating Exhibits Low Friction

*The Pitch*

Many components experience sliding or rotating contact with other parts or with their environments. Their performance often degrades during service because their dimensions are altered by wear. Furthermore, the friction at the contact surface wastes energy. To mitigate these problems, hard coatings may be applied to contact surfaces to increase their wear resistance, and surfaces are often covered with a lubricant to reduce friction. At Ames National Laboratory, a nanocomposite boron-aluminum-magnesium ceramic alloy coating ($AlMgB_{14} + TiB_2$) has been developed that provides a superhard, wear-resistant surface that also has an exceptionally low coefficient of friction. Tests show that these boride coatings offer a combination of wear resistance and low friction unmatched by other hard materials (e.g., tungsten carbide, cubic boron nitride, or diamondlike carbon).

According to surveys carried out in different countries, the economic losses resulting from friction and wear are estimated to total 1–2% of gross domestic product (GDP). Using the World Bank's estimate of a \$54 trillion global GDP (2007), it can be estimated that friction and wear cost the better part of \$1 trillion dollars per annum. Since nearly all machinery involves sliding or rotating contact, the potential applications for a superhard, low friction coating are vast, spanning such diverse components as pump components, timing chains, cutting tools, abrasive water jet nozzles, and materials handling systems.

*The Technology*

The material that has demonstrated the best combination of wear resistance and low friction performance is a composite comprised of $AlMgB_{14}$ and $TiB_2$ with a submicron phase size. These composites can be produced in bulk form from elemental Al, B, and Mg, and then combining that powder with $TiB_2$. The blended powders are reaction-sintered to form $AlMgB_{14}$ and produce the composite. These composites can then be used in bulk form or as targets to coat components by sputtering or pulsed laser deposition.

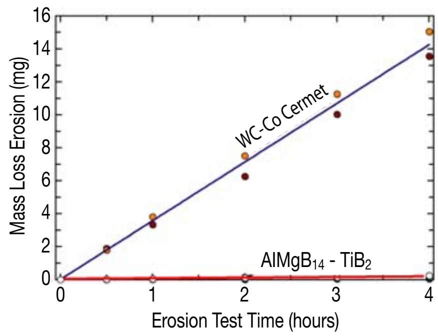


Figure 1. Mass loss from erosion by high-velocity alumina grit for commercial tungsten carbide (WC+Co binder) and $AlMgB_{14}$ (30 wt%) + $TiB_{14}$ (70 wt%).

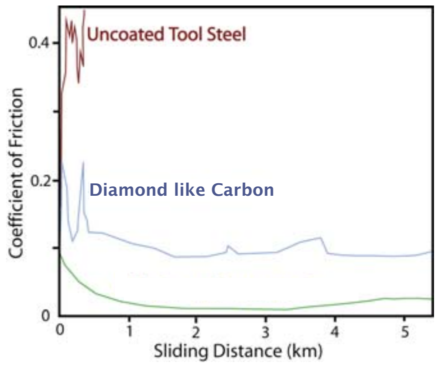


Figure 2. Coefficient of friction pin-on-disk measurements for three materials with initial lubrication with a water-based lubricant and no additional lubrication after the start of the test. The uncoated tool steel failed less than one hour after the test began. (Data courtesy of P. Blau and J. Qu, Oak Ridge National Laboratory)

Figure 1 compares the erosive wear resistance of the bulk composites to that of commercial tungsten carbide (WC)-cobalt cermet.

The boride composite microhardness varies with composition, grain size, and impurity content, but ranges between 35 GPa and 45 GPa. This is substantially higher than the microhardness of familiar hard materials such as $Si_3N_4$ (18 GPa) or WC (23 GPa), but it is lower than the hardness of diamond (70–100 GPa). Interestingly, the composite hardness is substantially higher than the hardness of either pure $AlMgB_{14}$ or pure $TiB_2$ (both near 30 GPa), behavior that is thought to result from the small phase sizes in the composite and the nearly equal surface energies of the two phases, which stymie crack propagation along phase boundaries.

As-deposited coatings of the boride material are largely amorphous, but transmission electron microscopy studies show that nanocrystals of $TiB_2$ (20–40 nm diameter) form between room temperature and ~300°C in the deposited films, and the films can be completely crystallized by annealing at 1000°C. However, microhardness values differ little between the amorphous and crystalline coatings.

Pin-on-disk (POD) testing data for friction coefficients for three materials are plotted in Figure 2. It shows that there is an initial "break-in" period for POD testing of the boride composite during which small asperities on the coating are worn smooth. This is followed by a lengthy period where the coefficient of friction remains in the range from 0.02 to 0.04. This is significantly lower than the friction coefficients of diamond and cubic boron nitride. The high B content of the boride composites is thought to promote formation of boric acid—$B(OH)_3$ at the free surface; $B(OH)_3$ is known to have a very low coefficient of friction. Unlubricated POD tests show a coefficient of friction of 0.10 for the boride composites.

Initial commercial application of these boride coatings is anticipated in 2010 for cutting tool and pump components. Additional uses are anticipated as the material becomes better characterized and more widely known.

*Opportunities*

The investigators welcome suggestions for collaborative research with other scientists and engineers in academia, industry, or federal laboratories who may wish to study particular characteristics or applications of these materials.

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