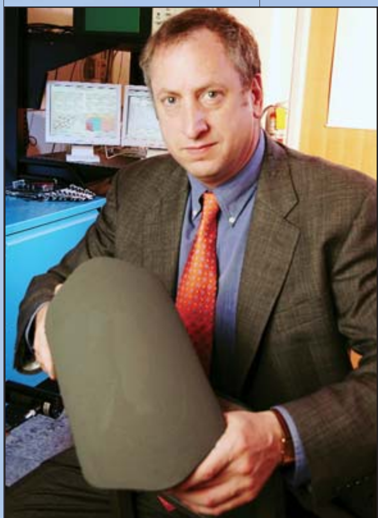
From Curiosity to Cure

Scientific quest leads to new material formation process that may save lives on the battlefield.

PHOTO BY GARY MEEK



ABOVE: Professor Robert Speyer and his research team have created a new boron carbide formation process. The method yields higher relative densities — and thus better ballistic performance — than currently available boron carbide armor. Here, he holds a prototype thigh plate.

BACKGROUND: Boron carbide materials formed by a new method developed at Georgia Tech may be used to make better protective gear for soldiers, aircraft and rotorcraft. Here, U.S. Army soldiers set up a security perimeter after landing in the desert in Iraq in September 2005.

What began simply as a desire to satisfy scientific curiosity — long before the wars in Iraq and Afghanistan — may now save the lives of soldiers on the battlefield.

The curiosity surrounded boron carbide — the U.S. Defense Department's material of choice for body armor. It is the third hardest material on earth, yet it's extremely lightweight. But it has an Achilles heel that piqued the interest of Georgia Tech Professor of Materials Science and Engineering Robert Speyer five years ago.

He knew that the boron carbide powder used to form the armor had a reputation for poor performance during sintering — a high-temperature process in which particles consolidate, without melting, to eliminate pores between them in the solid state. Poor sintering yields a more porous material that fractures more easily — not a good thing for a soldier depending on it to stop a bullet.

Determined to understand the sintering problem, Speyer built an instrument called a differential dilatometer to measure the expansion and contraction of materials during sintering heat treatments to temperatures as high as 4,300 degrees Fahrenheit.

"As a particle compact sinters, it shrinks 12 to 15 percent," Speyer explains. "There are nuances that occur in contraction, and if you monitor them accurately (with a dilatometer), it tells you what is happening at different stages in the sintering process. So we used that information in conjunction with additional materials characterization techniques to figure out the reasons why boron carbide didn't sinter well, and then found ways around them."

From these findings, Speyer and his research team have created a new boron carbide formation process — which is being commercialized — based on methodical control of thermal and atmospheric conditions during sintering. The method yields higher relative densities — and thus better ballistic performance — than currently available boron carbide armor. (Relative density is a percentage that indicates how close a material is to its theoretical density, which implies having no pores.) The current commercial process, called hot pressing, squeezes boron carbide powders together between large dies, while heating to elevated temperatures. It yields armor materials with a 98.1 percent relative density.

Speyer's pressureless sintering method yields a 98.4 percent relative density and hardness greater than hot pressing. But it can be done faster and at a lower cost than hot pressing. For the most demanding applications, post-sintering hot isostatic pressing (HIP) is used. It increases the relative density of the part to 100 percent through the hydrostatic squeezing action of a high-temperature, high-pressure gas.

"Our material made using HIP is remarkably harder than the current ceramic armor used in the Iraq and Afghanistan theaters," Speyer says. "Plus, because we're not using uni-axial hot pressing, we can make complicated, curved shapes for use in body armor and other applications. Hot pressing allows for some curvature so long as the parts can stack together, but there's no chance of making parts like a single-piece helmet."

To make such products, Speyer has formed a company called Verco Materials under the advisory support of Georgia Tech's VentureLab, which helps faculty members commercialize their research. Ceramics expert Beth Judson is the company's general manager, and Jon Goldman is the VentureLab commercialization catalyst helping Verco get started. A Georgia Tech patent on Speyer's sintering process for boron carbide is pending, and when granted,

BY JANE M. SANDERS

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Verco will have access to an exclusive license, Judson says.

The company has received two technology commercialization grants — totaling $100,000 — from the Georgia Research Alliance to fabricate prototypes for potential military and industrial customers. The Georgia Tech Rapid Prototyping and Manufacturing Institute assisted with fabrication of model armor shapes. Also, VentureLab continues to analyze the company's potential markets.

Beyond body armor, potential military applications include aircraft/rotorcraft protective components. Civilian markets include industries "that can exploit the phenomenal abrasion resistance of theoretically dense boron carbide," Speyer says. Products manufactured by these industries include bearings, blast nozzles, cutting and mining tools, and pump and turbine shafts.

The military market is growing rapidly with more than a half billion dollars worth of ceramic armor orders pending in this fiscal year, Goldman notes. That market is expected to double by 2009, according to a recent report in the publication *Ceramic Industry*. Bearings are a $27 million market with 5.7 percent annual growth expected through 2007.

Military applications — body armor, in particular — would be Verco's first target market, and its potential is promising, Speyer notes. The U.S. Army Soldier Systems Center in Natick, Mass., has conducted ballistic testing on a small boron carbide disk provided by Verco. Detailed results are classified, but the Army says they are encouraging. With a $75,000 grant from the center, Verco will produce 6- by 6-inch plates for more comprehensive military ballistic testing this fall.

Early next year, the Army Research Laboratory (ARL) at the Aberdeen Proving Ground in Maryland will be examining boron carbide materials (including complex shapes) they purchased from Verco. ARL is interested in Verco's potential ability to form complex shapes cost effectively.

Meanwhile, Verco expects to make thigh and shin plate prototypes in early 2006 for a Johnstown, Penn., company called Concurrent Technologies Corporation (CTC). The plates will be evaluated for use in CTC's Ballistic Gauntlet, a new lower-body armor product for use in military and commercial vehicles in war zones to protect against the pervasive threat of improvised explosive devices. It was the idea of CTC engineer Scott Burk, who recently served in the Persian Gulf for 21 months.

The company's current design calls for the Ballistic Gauntlet's thigh and shin plates to be made from titanium, but its cost has risen recently, and it's hard to form and heavier than boron carbide, Judson and Goldman say.

In one other effort, Verco and the Georgia Tech Research Institute (GTRI) are collaborating. GTRI has developed a composite armor "blast bucket" for the ULTRA AP, a concept vehicle designed to illustrate potential technology options for improving survivability and mobility in future military combat vehicles. Verco and GTRI hope to modify the "blast bucket" by replacing heavier ceramic spheres with lightweight boron carbide spheres in the composite structure to make it attractive for use in new helicopters, as well as in retrofitting current rotorcraft, Judson says.

If Verco gets initial defense-related contracts from the customers it is courting, the company would need a tremendous productive capacity — enough to make thousands of parts a week, Judson and Goldman say. Plans call for a highly automated manufacturing facility in Georgia that would initially hire a significant number of engineering and manufacturing employees.

@ Read more at: **gtresearchnews.gatech.edu/reshor/rhf05/boroncarbide.html**

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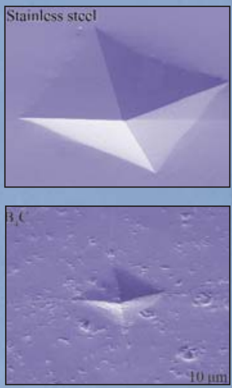

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ABOVE: At top is an indentation made in stainless steel by a Vickers indenter. At bottom is an indentation made with the same indenter and load into boron carbide.