A New Class of High-Temperature Structural Materials

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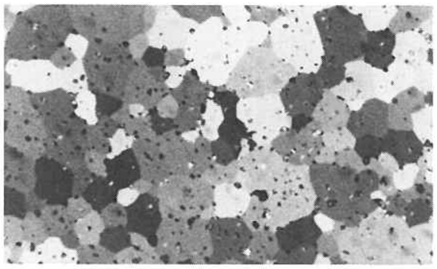

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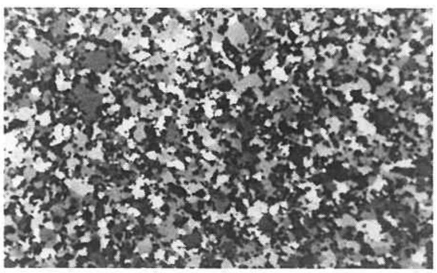

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The top two pictures are views of the micro-structure of a composite based on molybdenum disilicide. The third image demonstrates that such a composite deforms without breaking at high temperatures.

In 1986, Los Alamos National Laboratory had the only research program in the field of high-temperature structural silicides (compounds containing a metal and silicon); in 1988, there were three such programs in the United States; and now that number stands at more than thirty worldwide. This is a remarkable increase in scientific interest. Researchers have understood that the need to manufacture high-powered automobile and aircraft engines, reliable and strong parts that should be resistant to oxidation and to breaking at high temperatures, and equipment designed for generating power or controlling pollution calls for superior high-temperature structural materials.

Scientists at Los Alamos have envisioned and created a completely new class of materials, the most important breakthrough in the field since structural ceramics were introduced two decades ago. By combining molybdenum disilicide—an intermetallic (two-metal) compound whose atoms are arranged in an ordered structure—with silicon carbide—a ceramic—they have obtained composites whose performance is outstanding at temperatures above 1200 degrees Celsius. The inventors received a 1990 R&D 100 Award given by *Research and Development Magazine* to recognize the one hundred most important technical innovations each year.

The Invention—Background and Significance

When molybdenum disilicide was discovered in 1907, specialists learned that this intermetallic alloy is brittle at room temperature but ductile (capable of changing shape without breaking) at high temperatures. Limited experience in designing components made of brittle materials and insufficient knowledge of the composite approach rendered molybdenum disilicide an unattractive candidate (although it had been suggested) for high-temperature structural applications—until 1983, when hybrid materials were created at Los Alamos from molybdenum disilicide (used as a principal component or matrix) and silicon carbide (used as a ceramic reinforcement). And thus a new class of much-needed materials was born.

High-temperature structural silicides, the new materials developed at Los Alamos, are a major achievement because they are stronger, more resistant to oxidation, and far more reliable than other available materials, but most of all because they are ductile at temperatures between 1200 and 1800 degrees Celsius. Ductility in metals results from the movement of crystal defects (or dislocations) under a mechanical stress. It is the property of molybdenum disilicide to remain ductile at very high temperatures. However, a high-temperature structural material suitable for engineering applications must combine ductility and toughness (resistance to fracture) with strength (level of load a material can withstand without fracturing). And here lies the unique feature of our invention—the new materials combine the ductility of molybdenum disilicide with the strength of silicon carbide, whose main function is to stop (or "pin") the movement of the dislocations when the materials are subjected to stress. Moreover, silicon carbide does not react with molybdenum disilicide. Such a reaction could weaken the composite. The resulting material is strong enough for engineering structural applications, yet sufficiently ductile to remain resistant to fracturing. Although brittle at room temperature, at elevated temperatures (between 1200 and 1800 degrees Celsius), our composites are fifteen times stronger than superalloys (nickel- and cobalt-based metals) and forty times more ductile than structural ceramics (nonmetallic, high-temperature materials). Moreover, in highly oxidizing environments where other materials would disintegrate, our composites remain intact. This remarkable feature is due to the molybdenum disilicide, which forms a layer of silica on the surface of the composite to protect it from high-temperature oxidation.

The discovery of a totally new class of materials has far-reaching implications. Not only can the performance of all components in which the materials are used be increased dramatically, not only is the cost of these materials lower than that of traditional materials—an added but essential bonus—but also, most important, this discovery has opened up a completely new area of research that will add more materials to the class. Indeed, researchers at Los Alamos are now using molybdenum disilicide as a reinforcement in structural ceramics, thereby creating new structural materials.

For more information about high-temperature structural silicides, please contact Dr. Ronald E. Barks, Industrial Applications Office, Los Alamos National Laboratory, P.O. Box 1663, Mail Stop M899, Los Alamos, NM 87545, Telephone (505) 667-3839.

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Applications and Patents

The high-temperature structural silicides will benefit a variety of industries, from commercial aircraft and automobile manufacturers to military aircraft manufacturers and industries associated with electric power generation and pollution control.

Our composites can be used to produce advanced, very high-temperature heating elements with improved temperature capabilities and extended lifetimes for applications in industrial furnace and waste incineration. The design and operating temperatures of the waste incineration systems will be improved by the high performance of our materials.

Commercial aircraft components will be more reliable and have a longer service life. In the future, aircraft accidents caused by the fracturing of components such as turbine blades will be preventable because our materials will make the components resistant to catastrophic fracture. Better high-temperature components, such as seals, vanes, and nozzles, in the gas turbine engines of advanced aircraft will allow increased turbine inlet temperatures, which will in turn improve the performance and fuel efficiency of the engines. Composites based on molybdenum disilicide could therefore benefit one of the National Aeronautics and Space Administration projects—the high-speed civil-transport plane—which requires special engines (made of strong materials, highly resistant to oxidation) that can be run at very high temperatures and at altitudes of 75,000 feet. Although our composites are still in the early stages of their development, it is clear that they can outperform structural ceramics in high-quality glow plugs, piston faces, valves, turbocharger rotors, and many other automobile components.

Two patents on these remarkable materials have already been issued and three additional patents are pending. The invention is available for licensing.

INVENTOR John Petrovic's activity in the field of ceramics and metallurgy is at the root of his invention that received a 1990 R&D 100 Award. Petrovic obtained his B.S. (magna cum laude), M.S., and Ph.D. in metallurgy in 1967, 1970, and 1972 from Case Western Reserve University in Cleveland, Ohio. In 1975, Petrovic joined the Materials Science and Technology Division at Los Alamos as a staff member and has since been a program manager and deputy group leader. He is currently technical manager. His research interests include a variety of topics in ceramics and metallurgy. In the past twenty years, Petrovic has authored and co-authored more than seventy publications.

David Carter earned his B.S. and M.S. in materials science and engineering in 1987 and 1988 from the Massachusetts Institute of Technology while working as an intern and then graduate student at Los Alamos. In 1988, Carter became a staff member at the Laboratory. Among his research interests are high-temperature materials and composites.

After obtaining a B.S. in chemistry from the University of California, Berkeley, in 1952, Richard Honnell worked for a few years in industry. In 1968, Honnell came to Los Alamos and has since been a staff member in the Materials Science and Technology Division, specializing in ceramics processing.


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Pictured from left are Richard E. Honnell, John J. Petrovic, and David H. Carter.