Ultratough, Thermally Stable Polycrystalline Diamond/Silicon Carbide Nanocomposites for Drill Bits

Synthesis, Characterization, and Application of Nanostructured Diamond/Silicon Carbide Composites for Improved Drill Bit Performance

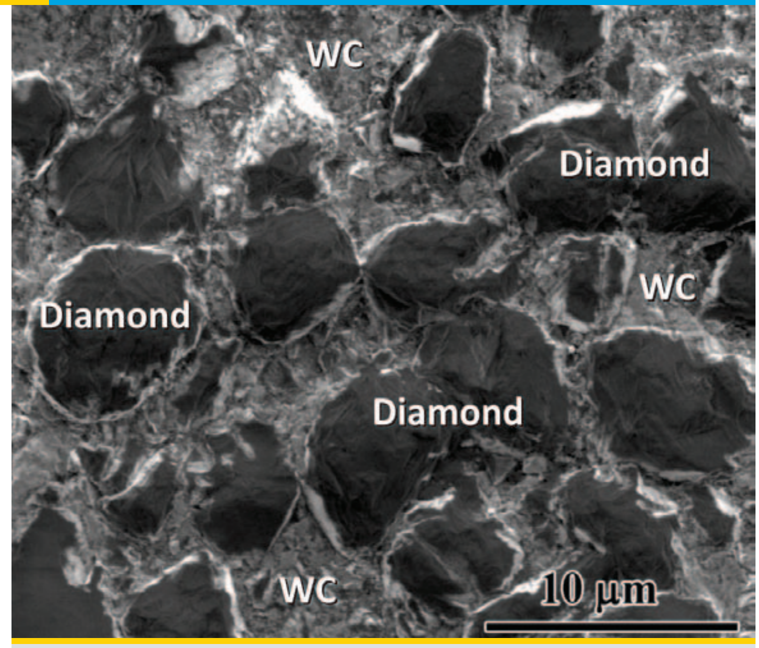
Industrial drilling, mining, cutting, and grinding make heavy use of superhard materials with superior wear resistance. In the oil and gas drilling industry, the use of polycrystalline diamond compact (PDC) drill bits has become increasingly common, with PDC drill bits accounting for a significant fraction of the worldwide rock-bit market.

Despite such widespread use, conventional PDC has several major drawbacks, including low thermal stability (failure at temperatures above 350°C) and low impact strength. The resulting blunting and shattering of drill bits greatly slows the drilling process. One attempt to improve upon conventional PDC has been the development of thermally stable polycrystalline (TSP) diamond composites using silicon carbide (SiC) binders. These composites are stable up to 1,200°C, but have reduced fracture toughness (6–8 MPa·$m^{1/2}$) due to the brittleness of the SiC and diamond.

This project is addressing this limitation by applying a novel nanosynthesis technique of high pressure and temperature (P-T) reactive sintering to synthesize diamond/SiC nanocomposites that offer superb hardness (40–60 GPa), enhanced yield strength (16 GPa, comparable to diamond), and high fracture toughness (12–15 MPa·$m^{1/2}$). The project is also strengthening the synthesized diamond composites by implanting them with carbon/silicon carbide (C/SiC) nanofibers to reinforce the composites. These strengthened nanocomposites are expected to achieve a fracture toughness of 16–20 MPa·$m^{1/2}$.

Benefits for Our Industry and Our Nation

The development and deployment of these novel diamond nanocomposites will dramatically increase drilling workload and efficiency while also reducing energy and capital costs and harmful environmental and carbon effects. In the U.S. drilling industry alone, novel diamond nanocomposites are anticipated to yield significant energy, carbon and cost savings from improved productivity (i.e., reduced total drilling time).



Scanning electron image showing nanostructured diamond/tungsten carbide (WC) nanocomposite produced under experimental pressure of 6 GPa, temperature of 1650°C, and sintering time of 10 minutes.

Photo courtesy of Los Alamos National Laboratory.

Applications in Our Nation's Industry

The superhard, superabrasive products developed in this project will greatly impact the gas, petroleum, and geothermal drilling industries. They may also have broad applications in a range of industries that require cutting, chiseling, abrading, gauging, impacting, and drilling. These applications may include the cutting and machining of rocks, nonferrous abrasive materials, aluminum alloys, reinforced plastics, and abrasive composite materials.

Project Description

The goal of this project is the development and production in quantity of novel superhard and ultratough thermally stable polycrystalline (TSP) diamond/SiC nanocomposites reinforced with SiC/C nanofibers for drill-bit applications and multiple industrial functions.

Barriers

- Prevention of crack initiation and propagation in the polycrystalline diamond compact (PDC) products
- Further development of the high P-T reactive sintering process and scale-up for drill-bit applications
- Minimization of residual stress in the PDC cutters to reduce cutter failure
- Improvement of the overall process to allow for large-scale production of nanocomposite PDCs

Pathways

This project is focusing on reducing synthesis pressure and temperature (P-T) conditions in the nanomanufacturing process with the aid of catalysts and solvents and through exploration of the hot isostatic pressing (HIP) technique. Through this development, large-scale industrial production of bulk-piece/shape-designed diamond/SiC nanocomposites will become possible. Using industrial standard facilities, systematic engineering tests are being performed on the reinforced PDC/tungsten carbide (WC) products. These tests include wear resistance, thermal stability, cutting efficiency, and impact strength in the machining of rock and ceramics. The improved PDC bit inserts for drilling, boring, and cutting are being applied in harsh environments to best assess the bits' ability to meet the demands of the mining, petroleum, and machinery industries.

Milestones

This project started in September 2008.

1. Milling of micron- and nano-diamond hybrids, polycrystalline silicon, and carbon nanofibers to mix the precursors well, make them amorphous, and disperse them (Completed)
2. High P-T synthesis and/or HIP reactive sintering of high density diamond/SiC nanocomposites (Completed)
3. Characterization of abrasive hardness, fracture toughness, thermal stability, and impact strength of the PDC products with standard industrial tests, including in situ high P-T synchrotron x-ray, abrasion tests, and neutron diffraction studies (Completed)
4. Enhancement of PDC thermomechanical performance by reducing residual stresses and eliminating impurities in the nanosynthesis process
5. Production of nanostructured PDC/WC inserts, implementation of these novel PDC/WC cone inserts in rock drill bits, and industrial field trials

Commercialization

US Synthetic Corp. is the leading supplier of polycrystalline diamond cutters used for oil and gas exploration drill bits. The project team is working closely with industrial rock drilling and boring end users such as Rockbit International, Smith International, and Baker Hughes to improve the performance of the PDC drill bits. The improved PDC drill bit inserts will be subjected to harsh environments for the ultimate downhole tests. The application and commercialization of new materials for drill bit applications will be coordinated to solve practical problems in field tests. Products that derive from this nanomanufacturing project are expected to be commercialized through the Los Alamos National Laboratory Technology Transfer program.

Project Partners

Los Alamos National Laboratory (LANL)
Los Alamos, NM
Principal Investigator: Yusheng Zhao
E-mail: yzhao@lanl.gov

US Synthetic Corp.
Orem, UT

For additional information, please contact

Gideon Varga
Technology Manager
U.S. Department of Energy
Industrial Technologies Program
Phone: (202) 586-0082
E-mail: Gideon.Varga@ee.doe.gov

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