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BY ROGER BOLLIER, DIAMOND TOOL COATING

Crystal Clear

Crystalline-diamond coatings can make tool performance sparkle.

Government mandates, customer demands for greater efficiency and the need for lighter-weight products are driving the increased use of advanced materials in manufacturing. As such, many manufacturing engineers are specifying nonferrous materials for automotive components and aircraft structures, such as aluminum-silicon alloys, metal-matrix and carbon composites, and fiberglass-reinforced plastics.

Although these materials are lightweight, the hard, abrasive particles added to strengthen them makes them extremely difficult to machine and are a primary cause of premature tool wear and excessive heat generation. Tool wear is attributable to both the abrasiveness of the hard particles and chemical wear caused by corrosive acids created from the friction and heat during machining.

In response, many tool engineers have specified coating their tools with diamond, which is an ideal material for machining abrasive, nonferrous metals and nonmetallic composites. Of the available tool coatings, superhard crystalline diamond protects a tool's cutting edge best when cutting difficult-to-machine nonferrous metals and composites, and it's virtually impervious to chemical wear.

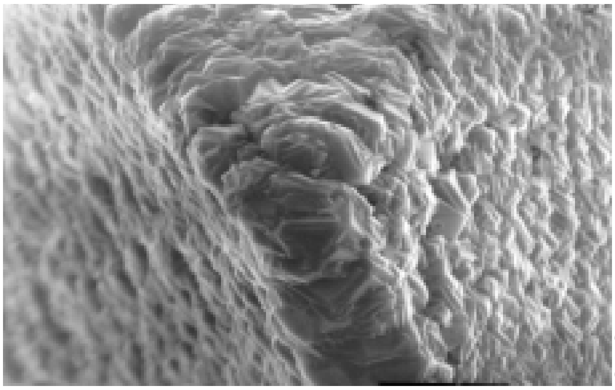
Diamond vs. Other Coatings

Crystalline diamond is grown via the chemical-vapor-deposition process onto the surface of an indexable insert or a round tool. Only solid-carbide tools are suitable for the CVD process because the 1,400° F temperature required for the process destroys brazed carbide-tipped and HSS tools.

Coatings applied via the physical-vapor-deposition process with metal-nitride compositions, such as titanium aluminum nitride, have a microhardness value equal to one-third of crystalline diamond's value. And although some PVD carbon coatings are called "diamond-like coatings," they do not have the hardness properties of crystalline diamond. Instead, these amorphous carbon coatings have microhardness values that are, at best, only 50 percent of crystalline diamond's value.

The advantage of crystalline-diamond coatings for carbide cutting tools is that they combine the hardness of natural diamond with the strength and relative fracture toughness of carbide. In addition, the diamond coating completely covers and protects the complex, 3-D shapes found on the cutting edges of round tools, as well as the multiple cutting edges of inserts with complex chipbreaker geometries.

End users pay a premium for diamond-coated tools. But these coatings can extend tool life by 10 to 20 times—or more—compared to uncoated carbide tools when cutting nonmetallic composites and plastics. And, diamond-coated tools allow increased material-removal rates when machining nonferrous metals and composites. The most impressive performance advantages of diamond-coated tools are in applications that demand lubricity and abrasion- and corro-



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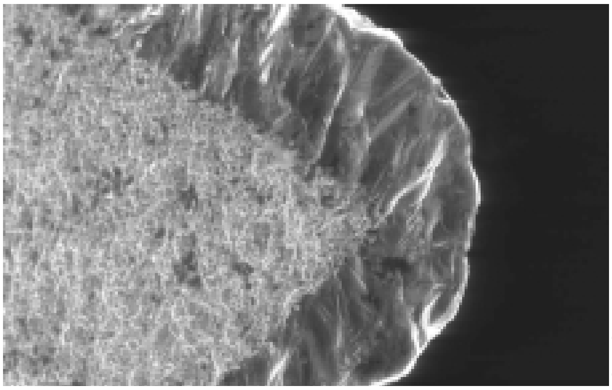
A diamond coating completely covers and protects the complex shapes of inserts and round tools, such as this endmill.



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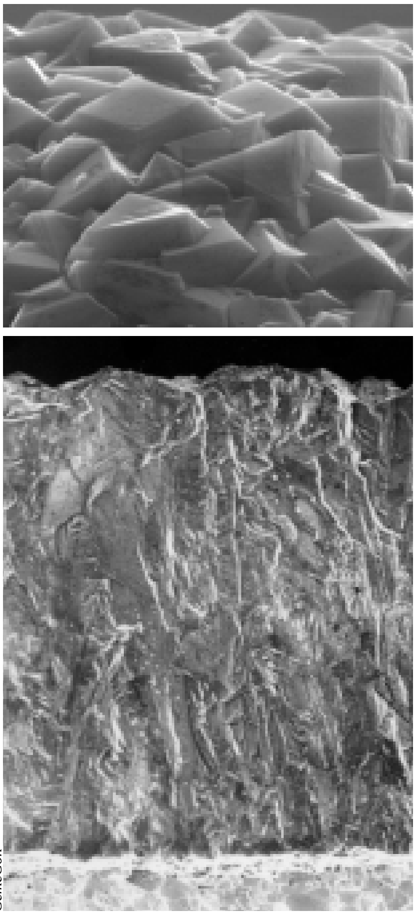
A thicker diamond coating, such as this 20μm-thick one, acts like a hone to prevent the cutting edges from chipping.

sion-resistance—applications for which uncoated carbide tools are not suitable.

The trend toward applying diamond-coated, application-specific tools is similar to the way in which tools were upgraded for high-performance operations with PVD coatings during the ’90s. However, designing a high-performance, diamond-coated tool involves more upfront work between the coating service provider and the tool engineer who specifies the coating. There are also new coating-design decisions to make when specifying a diamond coating.

The Decision Process

Usually, PVD-coating suppliers enhance tool performance by modifying the PVD coating. This can be accomplished by developing new coating materials or changing the composition of existing coating materials. The tool engineer’s role in improving PVD-coated tools, therefore, is mainly limited to



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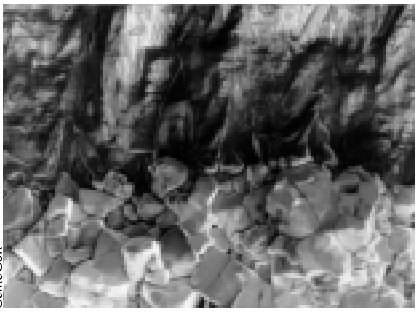
Surface (top) and cross-section views of a polycrystalline-diamond coating with crystals measuring from 1µm to 5µm.



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The interface between the diamond coating and the tool’s carbide substrate.

providing feedback about the coating’s performance in various applications and fine tuning tool geometry to optimize the carbide cutter.

In the world of crystalline-diamond coatings, however, the coating supplier directly solicits advice from the tool engineer at the beginning of the process. The engineer provides crucial input into the decisions concerning coating design for a given application, based on the material being machined and the specific cutting operation. Working as a team, the coating supplier and the tool engineer determine the coating’s thickness, crystal size and pretreatment procedures to prepare the tool substrate for coating.

The substrate must be properly pretreated to ensure that the coating completely adheres to the tool surface during use. A mechanical and chemical bond causes the crystalline-diamond coating to adhere to the tool. This bond is made possible by removing the cobalt binder from the tool surface, leaving microscopic pores that become anchoring sites for crystalline-diamond growth.

The amount of surface pretreatment required for sufficient adhesion depends on the abrasiveness of the workpiece material, the coating thickness and the size of the diamond crystals. Performance testing of the coated tool is the best way to verify the level of adhesion.

Thick vs. Thin

The thickness of most PVD coatings ranges from 1µm to 5µm. Diamond coatings have thicknesses from 3µm to 30µm, depending on the cutting operation and the abrasiveness of the workpiece material.

Diamond coatings thicker than 10µm are used to machine the most abrasive materials, especially those containing a high percentage of hard-particle additives. Aluminum with more than 9 percent silicon, plastics reinforced with more than 30 percent fiberglass and composites with more than 30 percent carbon fiber are typical examples.

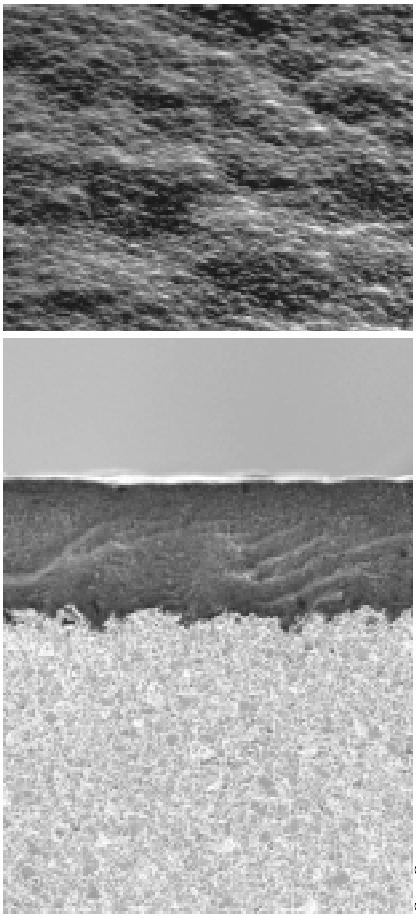
Thicker diamond coatings extend tool life more than thin coatings because they protect the carbide substrate better. While a thicker coating tends to create round cutting edges, this also provides a natural hone, which can prevent the cutting edges from chipping when the tool contacts hard particles.

Tools with a thin diamond coating (3µm to 10µm) have less edge rounding. A thin coating helps minimize TIR on round tools, because the tolerance of the coating thickness can be held to ±1µm. A thin diamond coating protects round tools as small as 0.010" in diameter, as well as finishing tools and tools for cutting less-abrasive nonferrous materials and composites that would prevent a PVD-coated tool from performing adequately.

Crystal Sizes

Diamond coatings traditionally have been comprised of highly faceted crystals measuring from 1µm to 5µm. This polycrystalline structure has proven very successful for cutting hard abrasives, such as graphite and green ceramics, which are crushed into a powder when machined. The peaks and valleys of the highly faceted surface can act as a microroughing tool, enhancing cutting efficiency. However, this surface also tends to load up when cutting gummy material, which impedes chip flow and imparts an unacceptable finish.

A diamond-coating crystal structure called “nanocrystalline,” which is produced via a specialized CVD process, helps solve these problems. Because the crystals measure only 0.01µm to 0.2µm (10 to 200 nanometers), a nanocrystalline-diamond coating has a finer grain structure and a smoother surface than a coating composed of larger, highly faceted crystals. Its smoother surface presents less opportunity for material to load up and weld



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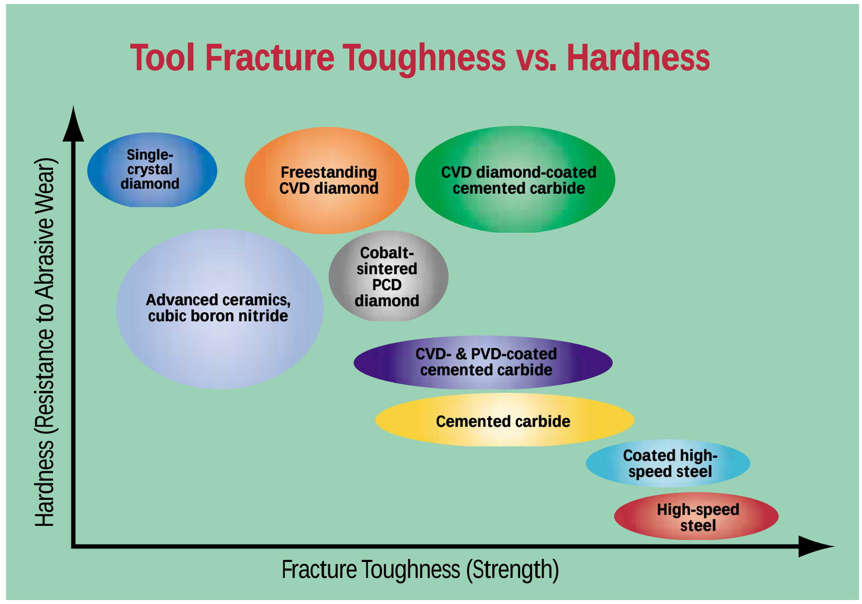
Surface (top) and cross-section views of a smooth, nanocrystalline-diamond coating with crystals from 0.01μm to 0.2 μm.



Cline Innovations

The hardness values of tooling materials are indexed in relation to their toughness.

MATERIALS AND APPLICATIONS FOR DIAMOND-COATED TOOLS

Materials	Applications
Graphite and hard carbon	EDM and other electrodes
Aluminum-silicon alloys	Automotive engine parts
Carbon-fiber composites	Brake discs
Fiberglass-reinforced plastics	Circuit boards, fiberglass parts
Green and bisque ceramics	Insulators
Solid and reinforced plastics	Medical parts
Metal-matrix composites	Brake-system components
Brass and magnesium	Valves and screw-machine products

Diamond Tool Coating

to the tool surface, which improves chip flow and finish.

Productivity Potential

Development of high-performance, diamond-coated tools in the future will depend on close cooperation between coating suppliers and tool engineers, and their ability to fully exploit the tool-design possibilities inherent when combining diamond coating and carbide. In developing new diamond-coated tools, tool engineers should be more actively involved in coating-design decisions. They must be aware of the relationships among coating thickness, crystal size and surface pretreatment procedures, and how they relate to the cutting application.

An example of this cooperation resulted in the development of a diamond-coated drill for machining high-silicon aluminum and metal-matrix composites. The application called for drilling 69 holes in 23 prototype brake discs made of aluminum reinforced with 20 percent silicon. The holes measured 12.5mm in diameter and 5mm deep. The diamond-coated drill finished the job without discernable wear, whereas an uncoated drill failed after nine holes.

High-performance, diamond-coated tools are competing to achieve the best performance-to-cost ratio for machining advanced materials. In addition, tool engineers and end users are learning more about how the properties of diamond coating can be combined with carbide tools to optimize machining efficiency.

Those who are first to find applications for diamond-coated tools will have a competitive advantage, based on the productivity gains these tools offer. And, these users will be in a better position to take advantage of the next technological breakthrough in diamond coatings.

About the Author

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