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➤BY FREDERICK J. TEETER,
SURFACE ENGINEERING COATING ASSOCIATION


Valenite

Valenite developed its turning grades with bicolor black and gray coatings for the auto industry. The gray flank aids in seeing the used edges under the poor lighting generally found in automotive plants, and the dark rake face has an ultrasmooth finish to decrease adhesive-type failures.

Thin Wins

Thin-film coatings evolve to improve cutting performance and accommodate new tool and workpiece materials.

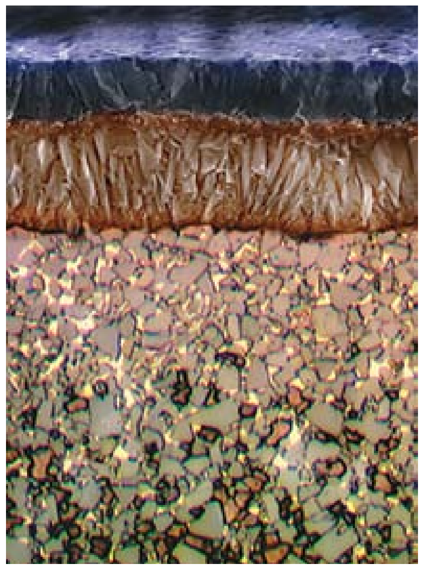
Nearly all metalcutting applications benefit from coatings. Innovations in substrate selection, coating formulations and pre- and post-coating preparation have greatly improved the performance of cutting tools and expanded the limits of metalworking.

The impact of thin-film, wear-resistant coatings on the cutting tool industry—and the benefits for end users—cannot be overstated. For almost 40 years, thin-film chemical-vapor-deposition, wear-resistant coatings, and for over 25 years, thin-film physical-vapor-deposition, wear-resistant coatings have played vital roles in improving the performance of a variety of cutting tools.

In this article, I examine how tool coating technology has changed over the past 4 decades; current developments in CVD, diamond-film CVD and PVD technology; the impact of nanotechnology on tool coating; substrate pre- and post-coating preparation; and post-coating treatments.

"Modern coatings enhance performance in almost all materials and applications," said Stefan Gyllengahm, senior turning specialist for Sandvik Coromant Co., Fair Lawn, N.J. "Coatings not only provide increased wear resistance; they also protect the insert from the heat generated at higher cutting speeds."

According to Mark Greenfield, director of global materials technology for Kennametal Inc., Latrobe, Pa., a challenge for tool suppliers is to increase tool productivity and reliability while meeting the challenges of new workpiece materials, such as harder, more wear-resistant materials that are also more abrasive. For example, the high-silicon aluminum used to make some auto parts and the high-grade stainless steels used to produce medical parts present unique challenges. In these kinds of applications, a functional cutting edge must be a finely tuned combination of substrate, geometry and surface treatment.



Sandvik Coromant

Cross-section of Sandvik Coromant's GC4225 insert grade that has a CVD layer of Al_2O_3 for chemical wear resistance on top of an MTCVD layer for mechanical wear resistance. According to the company, the insert's gradient substrate is optimized for hardness and toughness.

Pioneering CVD Treatments

CVD coatings revolutionized cutting tools when introduced in the late 1960s. By the early 1980s, CVD had evolved into multilayer coating compositions of TiC, TiCN and Al_2O_3, according to Dennis Quinto, technical director at Oerlikon Balzers Coating USA Inc.'s coating center in Amherst, N.Y.

"Al_2O_3 has been the most important coating for high-speed, high-temperature cutting operations and is still unsurpassed," he said. "Lower-temperature PVD technology came along in the '80s with some distinct advantages, and can replace CVD coatings of the same composition—except Al_2O_3." The PVD process takes place at lower temperatures (350° F to 900° F), compared with 1,800° F to 2,000° F in the traditional CVD process. This means that PVD can be applied on a wider range of substrate materials than CVD, which can damage heat-sensitive tool materials. (Newer CVD processes, such as MTCVD, take place at lower temperatures.)

Rick Horsfall, business director of cutting tools for IonBond LLC, Madison Heights, Mich., added that since PVD coatings were introduced in the early 1980s, coating technology has either been ahead of the technology used by machine tool builders or slightly behind. For example, as machine builders developed faster, more rigid machines, tool companies had to respond with coated tools that could withstand higher speeds and temperatures.

"Current coating technology enables the newest machine tools on the market to machine faster and, in many instances, machine under dry cutting conditions," he said. Since new coatings have up to three to four times higher hardness than the tool substrate materials, they provide exceptional wear resistance. With a lower coefficient of friction that offers natural lubricity and reduced heat, and a non-reactive barrier, these coatings lead to more opportunities for dry or near-dry machining.

Niagara Cutter was an early user of coating technology, depositing PVD coatings on HSS cutting tools in 1982. According to Sherwood Bollier, president, "PVD coatings were important to increase performance on HSS tools, but they are essential to increase performance on tungsten-carbide tools," which are more costly and operate at higher rates than HSS.

What's New in CVD?

Quinto said CVD, while not making major headlines, has seen important technological improvements, including:

■ Thicker multilayer coatings on carbide inserts, e.g., up to 20-micron-thick, medium-temperature CVD TiCN and Al_2O_3 multilayer designs for high-speed machining of abrasive workpieces. These coatings are nearly twice as thick as traditional multilayer CVD coatings, and provide greater wear resistance and longer tool life.

■ More sophisticated control of CVD Al_2O_3 nucleation to obtain the desired alpha or kappa crystalline phases of the coating. It is argued that alpha-phase Al_2O_3 is the most stable and also the most high-temperature resistant and wear-resistant phase among several phases that can be CVD deposited.

Brian Hoefler, manager of product development for Valenite LLC, Madison Heights, Mich., said process control has improved CVD coating quality. "Today, PC-based furnace control technology is adding a lot of benefits to tool coating processes," he said. "Cutting tool manufacturers rely on precise coating temperatures and gas-flow distribution to generate exceptional coating thickness and adhesion consistency, not to mention brilliant colors. Thickness variation from lot to lot is, on average, about 50 percent less than a decade ago."

Also, Greenfield said Kennametal has introduced grades featuring substrates with greater deformation resistance and toughness that can be combined with new CVD coatings with a highly wear-resistant oxide layer to produce higher productivity through longer tool life, lowering downtime.

There are a number of approaches to improving the performance of CVD coated products, according to Don Graham, manager of turning products for Seco-Carboloy, Warren, Mich. "Fine adjustments to the chemistry in coating furnaces, more careful structural control of the individual coating layers, top and bottom grinding of the coated inserts and even polishing the insert edges after coating all provide [higher-quality, longer-lasting coatings.]"

Even a topic as seemingly mundane as coating color can have a big impact on improving cutting tool performance. One market trend is to have colored inserts that add other values, according to Valenite's Hoefler. "Customer feedback on functional edges led us to introduce bicolor black and gray grades specifically for the auto industry," he said. "The gray flank aids in seeing the used edges under the [poor] lighting and work conditions generally found in automotive plants. The dark rake face has an ultrasmooth finish to decrease adhesive-type failures."

Fruits of Research

Following years of both university and corporate research, diamond film coatings produced by CVD technology became a reality in a flurry of new product announcements by several major tool manufacturers during the 1994 IMTS. Since that time, great strides have been made in the quality and economics of this coating technology.

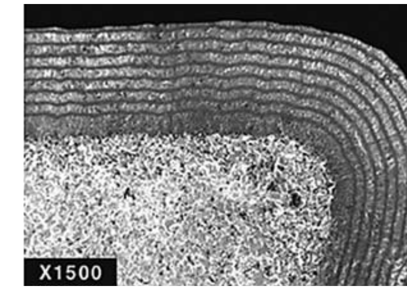
There have also been several important diamond-film-coating developments in recent years. Roger Bollier, president of Diamond Tool Coating, North Tonawanda, N.Y., said, "While our coating is still 100 percent crystalline diamond with all of the properties of natural diamond, the product has been improved from a single-layer polycrystalline coating that we started with in 2001 to a multilayer nanocrystalline diamond coating that we produce today."

The multilayers of nanocrystalline diamond increase the fracture toughness of the coating and the fine grain structure of the submicron crystals leaves a smoother surface on the cutting edge for imparting finer part finishes, said Bollier. "The multilayer structure is more resistant to cracking because each horizontal layer of diamond coating acts as a barrier that stops cracks from propagating further through the coating. This makes the coating stronger and helps it hold up better on cutting edges that experience mechanical shock from difficult-to-machine part materials or interrupted cuts."

PVD Developments

After its introduction 25 years ago, PVD supplanted some CVD coatings. Since it was a lower-temperature process that could be used on heat-sensitive tool materials such as HSS, PVD also extended the range of tools that could be coated. Today, PVD and CVD are largely complementary processes, with each having key tool coating applications. Combination CVD/PVD coatings are often utilized, with CVD comprising the first coating layer(s) and PVD comprising the smoother, finer top layer(s).

Recently, PVD coating development



Diamond Tool Coating

Cross-section of a nanocrystalline diamond coating.

has focused on new compositions, nanocomposite coatings and Al_2O_3. According to Quinto, AlTiN coatings applied via PVD have been called "the next best thing" to Al_2O_3, and until recently could only have been deposited on a commercial scale via CVD. This electrical insulating oxide coating had been a challenge for PVD, since depositing the correct coating structure had proven quite difficult.

According to IonBond's Horsfall, PVD coatings that incorporate materials such as silicon and use new, nanotechnology-based materials perform better, enabling the newest machine tools to machine faster and, in many instances, machine under dry or near-dry cutting conditions.

While PVD coatings have been introduced to compete with many traditional CVD coatings, until recently Al_2O_3 had been the exception due to the difficulties mentioned previously. However, at the 2005 EMO trade show in Hannover, Germany, Walter AG presented a PVD Al_2O_3 coating on carbide inserts aimed at harder, more abrasive workpieces.

Nanotechnology News

There is much legitimate discussion—as well as hype—concerning nanotechnology products based on materials up to 100 nanometers in size. Many CVD and PVD film coatings are already "nano," because they range from 1 to 10 microns in thickness. However, new, higher-resolution equipment is allowing for better measurement and control of smaller nanosized crystals.

The key factor in nanotechnology is what the product does, rather than its size. Instead of looking at nanotechnology as a size range, it is more important to explore the point at which emergent properties can offer significant performance benefits, such as eliminating the defects that become failure mechanisms in tool coatings. These failure mechanisms can lead to cracks and tool stress.

For example, Kennametal is producing inserts with a "nanograined" TiAlN PVD coating that it says provides increased speed capability and improved wear resistance with superior coating adhesion.

"Nanolayers in nanocomposite coatings have features so small, they can only be imaged with high-resolution, electron microscopes," said Quinto. "Nanolayers are formed parallel to the substrate surface by rotating the tools in and out of the line-of-sight deposition regions of coating targets mounted in

The following companies contributed to this report:

Diamond Tool Coating
(716) 693-5050
www.diamondtc.com

Ionbond LLC
(248) 398-9100
www.ionbond.com

Kennametal Inc.
(800) 446-7738
www.kennametal.com

Niagara Cutter
(716) 689-8400
www.niagaracutter.com

Oerlikon Balzers Coating USA Inc.
(800) 792-9223
www.oerlikon.com

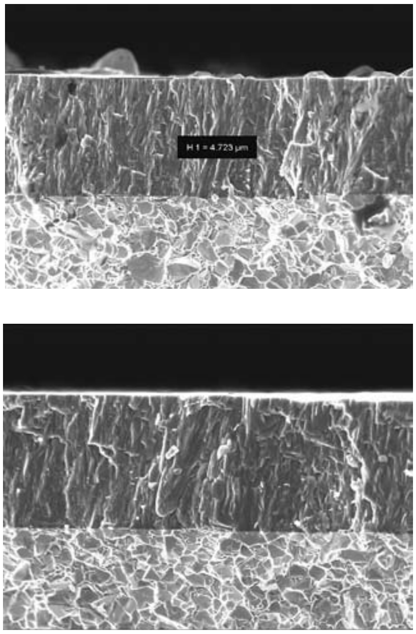
Sandvik Coromant Co.
(800) 726-3845
www.coromant.sandvik.com/us

Seco-Carboloy
(586) 497-5000
www.secotools.com

Valenite LLC
(800) 544-3336
www.valenite.com

the chamber walls at higher rpm, so that instead of multilayers of about 200nm thickness, the individual layers are reduced to 10nm to 20nm thicknesses."

The PVD process has always been viewed by material scientists at the atomic level, using atom-by-atom deposition to transform plasma-vapor ions into solid coatings. PVD coatings have inherent nanostructures that determine properties such as nanohardness, residual stress, microfracture toughness and coating adhesion—all of which are being theorized, researched and explained as near-atomic-scale phenomena. Users of cutting tools can review these theories to better understand the sometime miraculous performance of such thin coatings during machining.



Niagara Cutter

Droplets found on the coating's surface (top) are removed during a postfinishing process.

Substrate Coating Prep

While coating chemistry and technology are the focus of much R&D, another key factor in improving tool performance is the preparation of the substrate, prior to and after coating.

"Tool manufacturers are currently focusing on the entire tool design, including substrate, geometry and coatings," said Niagara Cutter's Bollier. However, he added that coating technology encompasses many different options, including cleaning technologies (coating adhesion); surface preparation (edge preparation/honing); coating properties (chemical composition, coating layers and coating thickness); and post-coating polishing. "Opportunities for higher tool performance and enhanced part surfaces come directly from these new, subtle techniques."

Valenite's Hoefler added that "probably the largest area of improvement during the last decade in coating technology is not even part of the application process. It is the post-coating treatments applied to inserts that have, in some cases, increased performance by as much as 200 percent."

Hoefler explained that some manufacturers have developed proprietary treatments targeting localized coating performance properties. For example, surface smoothness can reduce adhesive failures caused by a soft material adhering to the tool (generally described as built-up edge) and increase coating strength. Increasing a coating's compressive strength (akin to the shot-peening effect) prolongs tool life by counteracting tensile loads found when cutting metal.

Another treatment, edge refinement, can improve coating uniformity and mechanical properties at tool edges. Done prior to coating, edge treatment produces a higher-quality, smoother edge with the desired geometries. For example, edge treatment can produce an easier-to-coat radiused corner instead of a dead-sharp corner. Most insert failures start at the edge, so tailoring edge properties to reduce failures can increase productivity.

Sandvik Coromant has patented a method for post-treating inserts called "A New Insert Generation." This process involves slightly polishing the edge but, more importantly, it reduces residual stresses in the coating. The extra coating strength and the reduced tendency for smearing and BUE provides improved performance, according to the company.

Seco-Carboloy is taking a different approach to coating enhancement, according to Graham. "One of the reasons companies in our industry polish insert edges on some grades—and this is a step we also use—is to remove modest defects in the coating. We can, of course, improve smoothness and reduce residual stress and chip drag by polishing. But what would happen if the defects were not there in the first place?"

To answer this question, Seco-Carboloy has focused on improving the structural integrity of individual coating layers in multiple-layer coatings. Unlike single-layer coatings, strong multiple-layer coatings can disrupt thermal and mechanical stress factors the tool encounters while cutting.

New workpiece materials, tool substrates and tool designs continue to evolve to meet the demands of end users. Changing part materials specified for end user products, part tolerances and the new machine tools purchased for ultrafast machining all will affect the direction of cutting tool coating development. △

About the Author

Fred Teeter is president of Teeter Marketing Services LLC, Niagara Falls, N.Y., and managing director of the Surface Engineering Coating Association (SECA), Amherst, N.Y. Contact him at (716) 791-8100, by e-mail at Fred@TeeterMarketing.com or go to www.teetermarketing.com.