DECEMBER 2003 / VOLUME 55 / NUMBER 12

Composition Matters

New equipment allows deposition of hard and tough nanocomposite tool coatings.

▶ BY MARK OLBRANTZ, SWISS TEK COATINGS INC.

Most cutting tool manufacturers and users are sold on the benefits of titanium- and aluminum-based, thin-film hard coatings applied by the physical vapor deposition process. They account for anywhere from 25 to 55 percent of all coated tools.

It all started with titanium nitride, the "gold standard" coating that first got the metalworking industry to sit up and take notice. TiN-coated tools enable users to exponentially increase productivity for almost any application and material by running longer at more aggressive speeds and feeds. TiN's high hardness, low friction coefficient, low thermal conductivity and chemically inert surface combine to deliver remarkable cutting performance and improved workpiece quality.

The envelope was pushed even further with titanium aluminum nitride coatings. Armed with TiAlN-coated tools and their high heat resistance, users could further extend tool life and enhance cutting performance at even higher speeds when dry or near-dry machining.

More recently, coatings manufacturers have boosted aluminum content even higher—beyond 50 percent—with aluminum titanium nitride, which is ideal for dry, high-speed machining of hard metals, cast iron, titanium and other difficult-to-machine metals.

Layer Upon Layer

Another exciting development has been the application of titanium- and aluminum-based coatings in multiple layers. Multilayer coatings can effectively combine the benefits of two or more coatings into a single "super coating." For example, TiN and TiAlN, when combined in alternating layers, give a tool hardness, heat resistance and improved toughness.

Perhaps most importantly, coatings manufacturers have found that as more layers are added, crack absorption improves and, therefore, toughness increases. The belief is that the more thin layers a tool has, the better the performance. But that's true only to a point. These layers must be applied with great precision and care to achieve the same nanometer thickness from tool to tool. Anything different than the ideal leads to a coating with lower-than-desired hardness characteristics.

As a result, the coating equipment required to apply nanolayers with such precision becomes vitally important. PVD is generally considered the best process for depositing nanolayer hard coatings. Unlike chemical vapor deposition, PVD does not require a chemical reaction between the coating and the tool substrate.

Instead, the PVD coating is applied in a high-vacuum chamber. With cathodic arc coating—a PVD method—once the chamber is heated to about 500° C to "activate" the substrate surface, a striker wire initiates an electric arc that vaporizes the target material, such as titanium, which is mounted on a cathode. This positively charged vapor is deposited with high kinetic energy on the negatively charged substrate. A small amount of reactive high-purity gas, such as nitrogen, is added to the chamber. The result is a thin, hard layer.

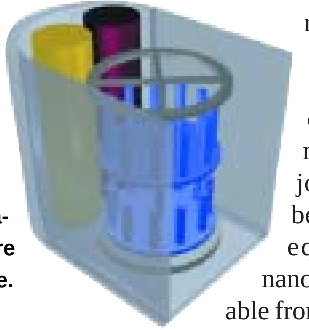
Different targets, either pure metals or alloys, are used to deposit different coatings. While the PVD process has been perfected for depositing all common coating structures, the deposition of coatings in nanolayers

All images: Platit

The π^{80} PVD coating unit.

is considerably more difficult. Applying the optimal nanometer thicknesses via PVD requires exact timed synchronization of the cathodes with the rotation of the substrates. Realistically, this is only possible when coating large batches of the same size and shape of tool. A consistent nanolayer thickness on a batch of large and small cutting tools, molds and dies or other wear parts in one chamber cannot be achieved.

The nanolayer thickness requirements vary too much for even an incremental change in the shape or size of the tools. That's why it's impractical to apply nanolayer coatings in an industrial setting. *Nanocomposite* coatings, on the other hand, can be.



The lateral cylindrical cathodes/targets require minimum chamber space.

The Benefits of Nano

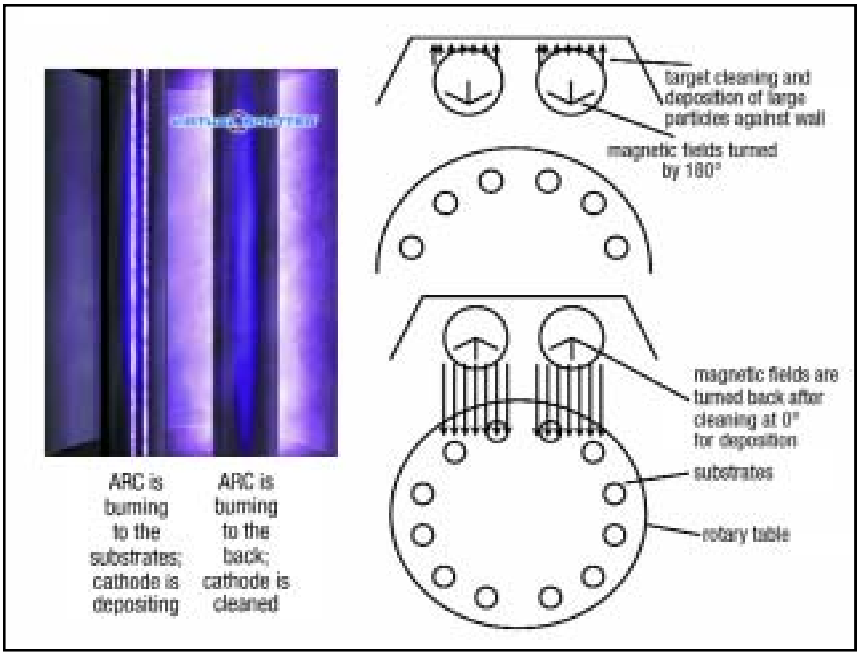
With nanocomposite coatings, nanocrystalline grains, such as AlTiN, are embedded in an amorphous, nonrepeating matrix such as silicon nitride. This creates an enormously compact and resistant structure, not unlike that of a honeycomb.

Nanocomposite coatings have proven to deliver high hardness of 40 to 50 gigapascals (1 GPa equals 100 HV) and high heat resistance of up to 1,100° C, making them well suited for dry, high-speed machining.

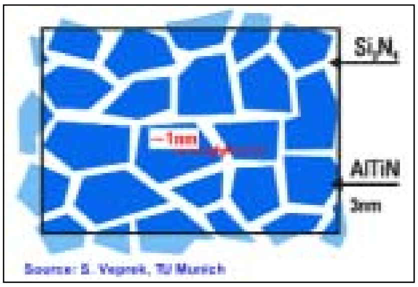
An advantage of nanocomposite structures is that they provide toughness and hardness comparable to nanolayers without the complexity and precision required to apply nanolayer coatings. With a coating machine designed for the job, enormous benefits can be realized. A new piece of equipment for depositing nanocomposite coatings is available from Swiss coatings equipment manufacturer Platit.

Called π^{80}, the equipment derives its name from the fact that its two cathodes are cylindrical. The cathodes in other PVD units are flat and either circular or rectangular. The two cathodes in the π^{80}, one for titanium, for example, and the other for aluminum silicon, which deposits the silicon for the Si_3N_4, are placed close together.

This design delivers a host of benefits for the deposition of nanocomposite coatings compared to other PVD systems. Most obviously, the surface area of a cylindrical target is π times greater than that of a rectangular planar target of the same height and width, but a wider chamber isn't required. (Figure 1).



The π^{80}'s Virtual Shutter design makes it possible to clean the targets before the coating process begins.



Source: S. Veprek, TU Munich

A typical nanocomposite coating consists of nanocrystalline AlTiN embedded in the amorphous Si_3N_4 matrix. The result is an enormously compact structure that produces an extremely hard and heat-resistant coating.

More importantly, the size and number of droplets that result from the erosion of the targets once the arc is introduced are considerably smaller than with planar targets. This produces extremely smooth nanocomposite layers.

Platit calls this design LARC (LAteral Rotating arc Cathodes). With LARC, the cathodes are positioned laterally and rotate, which makes the company's Virtual Shutter possible.

The Virtual Shutter quickly and automatically rotates the arc away from the tools, thereby cleaning the targets and eliminating large droplets during the initial arc ignition. The Virtual Shutter is the magnetic field in each cathode, which is turned 180° away from the substrate and toward the wall; the arc is ignited from the back. Large droplets are deposited against the wall, while the substrates are cleaned simultaneously by the arc. Then the magnetic field is turned back toward the substrate and a fast arc-spot movement, combined with the targets' fast rotation, begins the deposition process.

Unlike planar targets with their slow arc movement, the π^{80}'s fast arc-spot movement permits a high-intensity magnetic field without cutting through the targets. The resulting nanocomposite structure leaves no space between the nanocrystalline structure because nanocrystals are embedded in the amorphous, or random, Si_3N_4 matrix. This structure is enormously compact

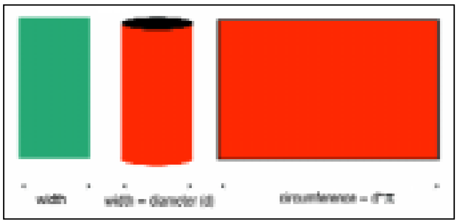


Figure 1: The surface area of a cylindrical cathode is π times greater than a planar target.

and heat-resistant, giving it a toughness and hardness that rivals nanolayers.

Harvesting Results

The design makes the π^{80} more economical to purchase than comparable PVD systems. At a list price of $500,000, the π^{80} costs about half as much as a conventional PVD unit.

Users can reap the following benefits:

■ The fast rotation of the π^{80}'s cathodes means that "pure" targets, which may have lower melting points and are much less expensive than alloyed targets, can be used. For example, an alloyed target with 50 percent aluminum and 50 percent titanium costs about $3,000, compared to about $1,000 for a pure titanium one. As a result of using pure targets, the coating composition can be easily changed without having to buy a host of different alloyed targets.

■ Because the targets are cylindrical, they have more material and last about three times as long as a planar target of the same thickness. Cylindrical targets typically deliver up to 200 batches before they need to be replaced.

■ Because the cylindrical cathodes are placed close together, the chamber is compact. This enables the user to more economically deposit nanocomposite coatings in small batches. In addition, batch cycle times are 3.5 to 4 hours vs. 8 hours for coating a batch in a larger, conventional machine.

■ The π^{80} is versatile, enabling the deposition of all types of coatings—not just nanocomposite ones.

With this coating equipment, manufacturers and end users of cutting tools can realize the benefits of nanostructure coatings in a practical, economical way.

About the Author

Mark Olbrantz is vice president and general manager of Swiss Tek Coatings Inc., New Berlin, Wis. For additional information about the coating center, call (262) 784-6100 or visit www.swisstekcoatings.com. Information about U.S.A. Platit Inc., Addison, Ill., is available by calling (630) 458-8575 or visiting www.platit.com.