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Coating research aimed at improving difficult machining applications.

Under Development

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With more parts being made of abrasive materials that are difficult to machine—especially in the aerospace and automotive industries—and the trend toward dry machining, cutting tools have their work cut out for them. To match these demands, new coatings are continually entering the marketplace that extend the life and wear resistance of cutting tools. This article looks at a few recent developments: "smooth" diamonds, a laser-based diamond-deposition process and laser-enhanced coatings for dry machining.

Smooth Diamonds

CemeCon GmbH recently introduced DiaLine, which the German company describes as a comprehensive line of CVD-diamond coatings. The line incorporates two different morphologies: conventional coarse diamond and smooth diamond. The coatings are available in five standard thicknesses—4µm, 8µm, 12µm, 15µm and 20µm—and three pretreatment options that help ensure optimal adhesion. Each diamond-coated carbide tool can be tailored to meet wear, performance and cost/value criteria established by the customer, says CemeCon.

The coating makeup of both morphologies is crystalline diamond. Crystal size differentiates one coating from the other. The smooth diamonds have a crystal size of 10 to 20 nanometers, while the coarse ones measure 1µm to 5µm.

The wear resistance of the coarse structure and a thick coating (12µm to 20µm) make this an ideal product for operations involving abrasive materials, such as milling graphite, says CemeCon.

However, coarse diamond coatings don't adhere well to the sharp cutting edges necessary for milling and drilling aluminum and other nonferrous alloys that require finer surface finishes. CemeCon claims that its smooth diamond meets these critical sharp-edge requirements.

Guhring Inc.

Efforts to limit the use of metalworking fluids have spurred research into coatings designed for dry machining.

Gary Lake, president of CemeCon Inc., the company's Horseheads, N.Y.-based subsidiary, said: "The key is to find the balance between coating thickness and morphology selection for the specific application, coupled with the ideal tool geometry. DiaLine should not be viewed as a coating added to a standard tool, as has been the case in the past for most PVD-coating processes. Instead, it is a complete product that involves the optimization of the substrate, geometry, coating preparation and coating itself."

CemeCon reports that its CVD process is suited for coating complex geometries on a variety of tools and sizes. These include multiple-edge inserts, tools smaller than 1mm in diameter and tools measuring 26mm (approximately 1") in diameter by 200mm (8") in length, with up to 80mm (3.2") of coated cutting length. The coating thickness is controllable to ±1.5µm over the entire length of the tool.

With current mixtures and test results, CemeCon recommends DiaLine coatings for dry milling aluminum alloys having the following percentages of silicon: 12, 17 or 20.

To help improve overall performance, CemeCon stresses the importance of having a substrate that will encourage and support the growth and adhesion of the diamond layer. The carbide substrate of choice is WC-Co with a maximum cobalt binder of 6 percent, no mixed carbides and a nominal carbide particle size of 0.5μm to 3μm, stated Lake. He added that since most carbide manufacturers are seeking ways to improve the toughness and performance of their products through the addition of chrome carbide, nickel binders, fine grains and other methods, process variations make it difficult to achieve a high level of adhesion.

CemeCon's process reportedly is very robust. Process yields are in the range of 98 percent adhesion when the optimal carbide substrate is selected.

Control of the substrate is the primary reason that CVD-diamond coatings are delivered exclusively through tool manufacturers, said Lake. Diamond Tool Coating, an independent firm that should be fully operational in May 2001, will distribute DiaLine technology to the North American market.

Laser-Deposition Process

Diamond technologies have not quite fulfilled their initial promise, according to William Banholzer, manager of engineering for GE Superabrasives, Worthington, Ohio. He said many "diamond-like" films lack the strength and adhesion characteristics necessary to harden tools effectively, and the coatings tend to flake away from the substrate.

Turchan Technologies Group, Dearborn, Mich., claims to have a technology that solves this problem: A laser-based deposition process being developed by researcher Pravin Mistry. Although TiN, AlN and SiC have been successfully deposited with this technique, the primary focus is on deposition of diamond.

Currently entering the experimental stage, the method shows promise for replicating the characteristics of a coating rather than that of a film. The diamonds are grown at room temperature to thicknesses that do not interfere with the overall tool geometry. Therefore, unique and intricate forms are not difficult to coat.

Furthermore, the laser makes it possible to mask a tool and only coat the desired areas. And because the laser beam penetrates the substrate and can reorganize material at the molecular level, deeper diamond deposition is possible without adding to the overall size of the tool.

Through complex testing and application analysis, the company is working on developing a means of adjusting the coating formula, thickness and structure of the layers to accommodate specific applications.

The deposition technique does not require a vacuum, hydrogen, or chemical or physical pretreatment of the surfaces. The process utilizes a combination of various pulsed lasers operating at atmospheric pressures and is performed with CO_2 and N_2 as the shrouding gases.

Crystalline-diamond films and diamond-like coatings, or, more accurately, tetrahedral noncrystalline carbon, have been formed on various substrates. On WC cutting tools, the rate of crystalline diamond deposition is as high as 1μm/sec. A normal coating is 45μm to 50μm thick. In fabricating a diamond coating on a substrate, the entire presurface treatment and material synthesis process, including the coating regime, is performed in one step.

Essentially, each laser beam is directed through the opening of a nozzle toward the surface of the substrate, preferably WC, along with the gas. The

Patented technology 'locks' coating layers together

Cutting tool manufacturers and coating producers expend a lot of energy developing new and exotic coating compositions that improve metalcutting operations. One company, Stellram, has found a different way to enhance the process of cutting metal. The La Vergne, Tenn., toolmaker combines proven coatings in an innovative way.

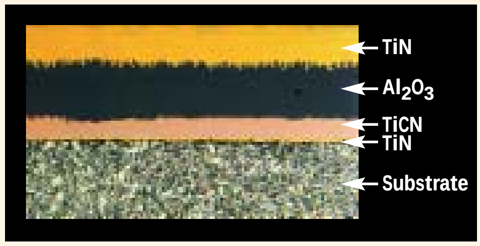


Figure 1: Stellram's Nitro-Lok coating process causes the individual coating layers to interlock, providing a stronger bond than conventional coatings.

Stellram's manager of coatings research, Dr. Deepak Bhat, said the company's family of Nitro-Lok (NL) multilayer coatings are applied with a patented process. The mixture of gases used during the CVD process produces a rough crystalline topography on the coating surface. This creates an interface area that is reportedly several hundred percent greater than interface areas of standard multilayer coatings. As a result, NL layers act like interlocking "fingers" that adhere more tightly to one another than smooth layers do.

Stellram applies the combination of coatings shown in Figure 1. Because there is greater layer-to-layer adhesion, thicker coatings can be deposited. This makes an NL-coated tool more resistant to wear and cratering, reports Stellram.

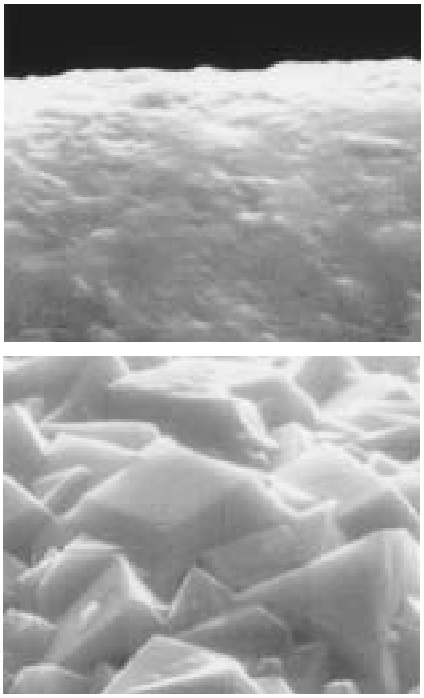
NL-coated tools can machine a spectrum of materials, including cast irons, nickel alloys and stainless steels. They are not intended or recommended for titanium alloys, plastics or abrasive materials.

Stellram recently introduced the NL family of CVD coatings for its turning inserts. Bhat said that although the coatings are intended for turning applications, customers have also successfully used them for milling cutters as well.

—P. Fretty

Workpiece Material	Part Type	Cutting Speed (sfm)	Feed Rate (ipr)	DOC (inch)	Results With Other Multilayer Coatings (Baseline)	Nitro-Lock Results Over Baseline
Ductile Iron	Piston	600	0.008	0.040	100	128%
Ductile Iron	Piston	650	0.006	0.040	100	130%
Ductile Iron	Piston	750	0.008	0.040	100	184%

An automotive-parts supplier used NL-20 inserts to turn ductile iron pistons. Compared to other multilayer coatings, the NL-20 inserts lasted significantly longer.



CemeCon

The crystals in CemeCon's smooth diamond coatings are 10 to 20 nanometers in diameter (top), while coarse crystals are 1µm to 5µm. The finer crystals allow smooth diamond coatings to adhere to sharper cutting edges than is normally possible.

gas decomposition that occurs on the surface yields diamond or diamond-like carbon, depending on the process conditions.

The substrate temperature during the laser-enhanced process is about 50° C. Mistry said the intense heat at the spot where the lasers converge breaks up some of the gas into electrically charged plasma. The lasers also vaporize a very thin layer of the object being coated.

According to researchers at Penn State University, the chemical reactions occur between the surface of the object and the ionized atoms of the gas, forming an ultrastrong bond. By continuing to deposit atoms from the hot gas onto the coated object, the thickness of the coating can be rapidly increased to ½".

The entire process is computer-controlled, including the loading and unloading of workpieces. A computer controls process elements such as laser pulsing, power modulation, gas flow, system diagnostics, real-time in-process diagnostics, and pre- and post-inspection.

The coating method shows promise because it demonstrates that adhesion is possible on substrates where adhesion is normally very poor. However, more work is required to optimize the process and obtain the best film properties. A major drawback could be the high capital cost of setting up such a system, which requires expensive laser equipment.

Mistry's group initially made its discovery in 1994, while using this interacting laser technique to apply a coating of hard titanium-diboride to the surface of an aluminum object. Accidentally, CO_2 was substituted for N_2 and a dense coating rapidly formed, but it was not the intended TiB_2 coating. It turned out to be diamond.

Mistry recently opened QQC Inc., a company spun off from Turchan that focuses entirely on the continued promotion and development of the unique laser-deposition process. QQC, though located within Turchan's Dearborn facility, operates independently, developing, licensing and producing advanced materials and surfaced-enhanced products.

Coatings for Dry Machining

Since 1996, researchers at Oklahoma State University have been conducting a study aimed at developing highly lubricious coatings for dry machining, especially for automotive and aerospace applications. The growing number of regulations governing the use of metalworking fluids is driving their research, which is being underwritten by a combined grant from the Environmental Protection Agency and the National Science Foundation.

The NSF portion of the research concentrates on hard, tough, multilayer coatings, including B_4C/W, SiC/W, B_4C/SiC (Class I). The EPA portion focuses on low-friction (tribological) coatings, including MoS_2/Mo, WS_2/W, and TaS_2/Ta (Class II).

The research team (F.M. Kustas, L.L. Fehrenbacher and R. Komanduri) has thoroughly tested two methods of deposition. However, the first method, called the "closed-field unbalanced-magnetron-sputtering process," had problems with unsatisfactory material adherence. Therefore, the team has primarily focused on the pulsed laser-deposition technique using the university's excimer laser. Their intention is to deposit alternating layers of lubricating and metal coatings—such as MoS_2/W, WS_2/W and TaS_2/Ta—onto cutting tools to a thickness of 1µm to 5µm. Hundreds of alternating nanolayers are deposited.

With a low substrate temperature, team members experienced low deposition rates and unsatisfactory adhesion. To solve these problems, they adopted two procedures. First, they installed a high-temperature (up to 950° C) heater to heat the substrate in an attempt to promote adhesion. Second, they used part of the laser beam to activate the surface and the remaining fraction to deposit the nanolayers. By providing a magnetic field around the chamber, deposition rates and adhesion levels improved significantly. The magnetic field seems to focus the deposition material more toward the tool substrate.

Nanocoatings have allowed the team to maintain crisp cutting edges that are atypical for traditional crystalline-coated tools. Although the heat method is a routinely slower process than the one Turchan-QQC is developing, the use of an excimer laser and magnetic field places the Oklahoma State team's deposition rate between the PVD/CVD and QQC methods.

The Oklahoma State team has industry partners in both the aerospace and automotive industries, but the comprehensive machining capabilities at the university has allowed almost immediate testing of experimental coatings in a highly controlled environment.

As the regulations governing the use of metalworking fluids continue to tighten, it's likely that growing attention will be paid to developing coatings able to work in dry and semi-dry machining applications.