100 YEARS OF CUTTING TOOL PROGRESS

Continuous demands for maximum production speed, longer tool life and process security drive cutting tool development, and have for the past century. As workpiece materials and machining operations become more complex, so have the tools and coatings created to boost metalcutting productivity for today's manufacturers.

Advancements in cutting tools started as early as the mid-1920s when tool developers applied cemented tungsten carbide to cutting tools. This entailed sintered metal-matrix composites of hard carbide granules bound together with a metallic binder material via the powder metallurgy process. Doing so provided a hard, tough alternative to steel cutting tools.

Additions of titanium carbide to the tool material mix in the 1930s further boosted tool life in the machining of steel workpieces. Subsequent developments included the manipulation of the binder components and carbide grain sizes to adapt tool operating characteristics for different applications and materials.

The coatings revolution

The advent of hard cutting tool coatings including TiN, TiC and TiCN in the late 1960s brought about dramatic improvement in tool performance. The greater lubricity, along with resistance to thermal deformation and abrasive and chemical wear of these coatings enabled reliable use of higher cutting speeds while increasing tool life by 10 times or more. Research and development in coating processes and materials such as Al2O3 further multiplied the productivity benefits of coatings.

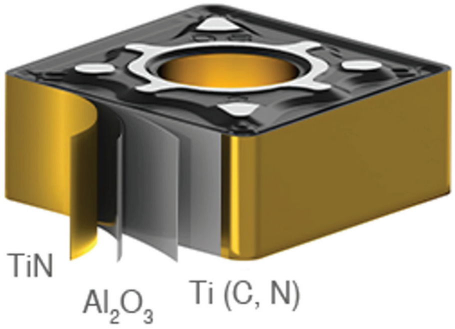
Toolmakers first applied coatings via the chemical vapor deposition (CVD) process, in which tools are heated to approximately 1000˚C and exposed to streams of gasses that deposit on the tool surfaces. For example, a combination of TiCl4, hydrogen and nitrogen gases produces the basic titanium nitride (TiN) coating. Typical CVD coating thicknesses are 5 μm – 20 μm, depending on the tool's intended application.

CVD generally provides a homogenous coating with good adhesion to the carbide tool substrate. However, CVD's high process temperatures can cause substrate components such as W, C, and Co to diffuse into the coatings and create a brittle layer called eta phase at the substrate-coating interface.

Depending on its thickness, eta phase will negatively affect coating adhesion. Accordingly, control of the interaction between the coating and the cutting tool substrate is a critical consideration in coating process development. In addition, the difference between the thermal expansion coefficients of the tool substrate and the coating at high temperatures can cause residual tensile stresses in the coatings that can lead to cracking.

The advent of multi-layer coatings

In the mid-70s, toolmakers began to apply coatings in multiple layers using a variety of materials including TiN, TiC, TiCN and Al2O3. These multi-layer coating structures were created to take advantage of the differing performance characteristics of each coating material applied.



For instance, TiN is effective at lower speeds, TiC and TiCN provide abrasive wear resistance at medium cutting speeds, while Al2O3, with high microhardness at elevated temperatures and chemical inertness, is suited for high speed machining of ferrous materials. When Al2O3 coatings were deposited directly on carbide tools, poor adhesion was a problem, but this was overcome with the introduction of an intermediate layer of TiC.

Besides adding different machining capabilities, interrupting the coating process for the formation of a new layer results in slower grain growth and smaller grain size that improves coating toughness and adhesion. A multi-layer coating may go through 30 to 40 individual steps to create four different layers on a tool.

A significant step forward in coating technology occurred in the 90s when toolmakers found ways to CVD coat inserts via a medium-temperature (~800˚C) process. The lower temperatures enable use of different varieties of coating materials and also reduce diffusion of carbide from the substrate into the coating. Narrowing the differences in thermal expansion between the coating and substrate also minimizes residual tensile stresses.

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Introduced in the late 1970s, physical vapor deposition (PVD) coating technology occurs at relatively low (~500˚C) temperatures and involves vaporizing coating material via arc discharge or cathodic sputtering and depositing it on the tool in a line-of-sight stream. Typical PVD coating thickness is 2 μm – 5 μm, making it well suited for coating sharp cutting tool edges.

In addition to the benefits of lower-temperature application, the PVD process can apply a wide variety of coating materials and produces compressive residual stress in the coating. However, because PVD coating is a line-of-sight process, applying the coating evenly can be challenging.

This is why implementing PVD requires careful fixturing of the tools relative to the stream of coating

Tooling being prepared for coating process

material to ensure full coverage. Fixturing may involve methods such as placing the tools on a rotating carousel, or magnetic holding is another way to position tools for unobstructed coating.

To adjust tool performance, tooling manufacturers manipulate coating thickness. When varying coating thickness, it is necessary to rebalance the relationships between the substrate and different coating materials. Coating grain structure also influences tool effectiveness; in the early 2000s tool manufacturers began to work with the orientation of the grain structure, finding that coatings with a hexagonal structure have improved properties in some applications.

In addition to the manipulation of coating thicknesses, post-coating surface treatments can also influence coating effectiveness. For instance, the surface roughness of CVD coatings is usually higher than that of PVD coatings, thus requiring post-treatment processes such as blasting or brushing to not only reduce surface roughness but also to relieve residual tensile stress in the coating. The method and intensity of post-coating treatments depend on the geometry and shape of the tool. If the cutting edges are delicate, the treatment must be carefully controlled so as to not produce edge damage.

Regardless of single or multiple layers, a key issue in coating technology development is process security. Reliable performance is crucial in maintaining production flow and controlling manufacturing costs. Coating methods are chosen in consideration of the failure modes expected in specific applications. For example, thick Al_2O_3 coatings can moderate crater wear precipitated by heat-generated diffusion between the coating and workpiece in high-speed machining. Harder, highly wear-resistant coatings, on the other hand, can reduce excessive abrasive wear of the cutting tool edge.

Workpiece materials and the operations being performed dictate tool compositions. Turning grades, for example, are designed to cover a wide range of materials, from low carbon steel to harder materials, and operations from finishing to roughing, heavy interrupted cuts to smooth cuts. This requires choosing among carbide substrates ranging from very hard to very tough, complemented by coatings fine-tuned to resist the heat, pressures and interruptions present in the operation at hand.

Toolmakers have to be wary of making substrate/coating systems too complicated. End users would prefer that a single product cover an extensive range of applications. But achieving that from a technical point of view requires compromises in tool performance throughout the application range.

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Modern tool development also takes into account the individual characteristics of the tool substrate, the coating, the workpiece material and the interactions among them. With that said, larger cutting tool manufacturers tend to have an advantage because they can create and control the entire toolmaking process from powder manufacturing to formulation of tool substrates and coating materials.

These more capable toolmakers consequently produce tools engineered for specific end uses, whereas smaller manufacturers may lack development flexibility because they have to utilize tool blanks from outside manufacturers and have coating performed by a contract tool coating company. Developmental testing of the tools may also be limited at smaller toolmaking businesses.

Article courtesy of CERATIZIT Group