POWDER MATERIALS, PARTS, AND COATINGS

WEAR-RESISTANT COATINGS MADE OF TOOL MATERIALS (Survey)

G. G. Gnesin and S. N. Fomenko

Introduction. The performance of a cutting tool can be improved by altering the surface properties of the tool material so as maximize the resistance of the contact areas of the tool to abrasive, abrasive-fatigue, corrosive-oxidative, and diffusional wear at elevated and room temperatures. The tool material must also have sufficient reserve strength when subjected to compression, bending, impact, or alternating stresses.

Most tool materials have only some of these properties, which greatly narrows their range of application. For example, ceramic cutting tools have high hardness and wear resistance and, in some cases, high thermal conductivity. However, they also have a low impact toughness and are brittle. Also, it is usually thought that oxide-free cutting ceramics should be used mainly for turning and cutting cast irons and superalloys, since a cutter that contains Si$_3$N$_4$ and is used for high-speed turning actively reacts with the steel of the product being turned and is subjected to intensive diffusional wear [1]. Tools made of high-speed steels have relatively low thermal stability, moderate hardness, low flexural strength, and low impact toughness. They are therefore best used at low and moderate cutting speeds [2]. The use of tungsten-free and low-tungsten hard alloys is limited to operations with alternating and impact loads, due to their inadequate ductility. It is also necessary to rapidly remove heat from the cutting zone, since these alloys are characterized by low thermal conductivity [3].

One way of ensuring good service properties in cutting tools and expanding their area of use is the application of layers with optimum physico-chemical characteristics to their working surfaces. The wear resistance of a ceramic cutting tool with a coating is improved as a result of the following: the closure of defects in the surface of the cutting blades after the machining of semifinished products; the realization of high hardness, strength, and fracture toughness in the coating material due to the creation of a nondefective structure with a controllable grain size, texture, and composition; the creation of two-, three-, and multi-layer coatings with improved mechanical and friction-engineering characteristics [4]. Most of these coatings are composed of compounds of transition metals of groups IV-VI of the periodic table.

Methods of Applying Coatings to a Cutting Tool. As regards the specific features of the processes involved in the formation of coatings, existing methods of coating application can be divided into three groups.

The first group includes the methods in which the coating is formed primarily as a result of diffusion processes between the saturating elements and the phase components of the tool material. These are thermochemical methods (TCM) of forming coatings based on solid-, liquid-, or gas-phase saturation of the tool surfaces. The diffusing elements can be poured over the surface of the tool directly, without the formation of intermediate phases, or with their formation at the interface between the tool material and coating. The saturation process results in the formation of diffusion layers whose crystallochemical structure and properties differ sharply from the corresponding parameters of the tool material. The rate of formation of the coating, the kinetics of its growth, and its structure and properties are determined to a significant extent by the temperature of the process, saturation time, and the diffusion parameters of the saturating components in the tool material and depend appreciably on the chemical composition, structure, and properties of the material itself. Thermochemical methods produce coatings with a thickness in the range 10-40 μm. They are used to apply coatings on tools made of plain carbon, alloy, and high-speed steels. Here, the cutting parts of the tools can have any desired shape. The coatings can also be applied to hard-alloy tool tips, mainly of planar form (method of thermodiffusional saturation of the surface of a hard alloy from the solid phase [2]).
The second group consists of methods that involve chemical deposition of coatings from the vapor–gas phase (CVD). These methods are widely used to apply coatings based on carbides, nitrides, and carbonitrides of titanium, as well as aluminum oxide. The coatings are formed by a complex mechanism involving reactions between vapor–gas mixtures consisting of compounds of the metaliferous component and the carrier of the second component. This carrier acts as a gas transporter and a reducing agent. A large contribution to the formation of the coating is made by the structure of the surface of the tool material and heterodiffusion reactions between the condensate and the tool material. Located between the coating and the hard alloy is a transitional region consisting of the \( \eta \)-phase (Co\(_3\)W\(_3\)C) — a stable but brittle carbon-depleted compound formed in the application of a titanium carbide coating to a hard-alloy matrix. Chemical vapor deposition methods are usually realized at 1000-1100°C, which precludes their use for applying coatings to tools made of high-speed steels that are heat-treated [2]. However, the use of the plasma of a glow discharge to lower the working temperature in coating deposition makes it possible to obtain coatings of TiN, TiCN, and TiC at 350-550°C [5].

There are several problems with CVD methods: the danger of explosion and the toxicity of hydrogen as the carrier-gas; the large residue of unreacted components; the complexity of the process equipment; internal stresses in the coating layer. Also, CVD methods cannot be used to coat tools having sharp cutting edges [6].

The third group consists of methods involving physical vapor deposition (PVD) and includes the following: condensation of coatings from a plasma with ion bombardment (IBC); reactive electron-beam deposition of coatings from a vapor-plasma phase in a vacuum (REP); activated reactive sputtering (ARE). The coatings are formed as a result of chemical and plasmochemical reactions involving a flow of particles in volumes of space directly adjacent to the tool-material surfaces being saturated. Physical-vapor deposition processes usually include the vacuum evaporation of a refractory metal, its partial or complete ionization, the delivery of a reactive gas, the occurrence of chemical and plasmochemical reactions, and condensation of the coating on the working surfaces of the cutting tool. The IBC and REP methods are the most widely used of the above-mentioned procedures.

The most distinctive feature of coatings applied by vacuum-plasma methods is the absence of a transitional region between the coating and the tool material. This fact is very important, since it makes it possible to impart a complex of additional properties to the working surfaces of the tool with almost no deterioration in its bulk properties — strength and fracture toughness. The possibility of broadly varying temperature within the deposition zones makes it possible to use vacuum-plasma techniques as universal methods for applying coatings to tools made of hard alloys, steel, and ceramics. There are also the plasma and detonation methods of spray-coating, the use of these techniques being limited to the production of cutting tools.

Despite certain inherent disadvantages of PVD methods (such as the impossibility of depositing coatings in deep recesses and the difficulty of heating the substrate in a vacuum), on the whole they are promising for applying wear-resistant coatings to cutting tools. This promise stems first of all from the possibility of closely regulating the parameters of the process (temperature, alloying dose, etc.) and fully automating it. Secondly, the low temperature of the process makes it possible to coat any tool material and achieve a high level of adhesion with the substrate. Thirdly, the coatings are formed at relatively high rates. Finally, PVD methods are safe for the environment and cost-efficient.

Wear-Resistant Coatings and Their Characteristics. Four categories can be recognized as regards the requirements established for coatings applied to cutting tools [2] when consideration is given to the specifics of the tool, the need for the properties of the materials of the coating and tool to be compatible, and the technical features of the different methods.

First of all, there are the requirements that pertain to the service conditions of the tool, i.e., its functional designation. The coatings should have the following: high hardness, exceeding the hardness of the tool material (and retaining this hardness at the cutting temperature); resistance to adhesion to the material being machined throughout the range of cutting temperatures; stability against high-temperature corrosion; stability of the mechanical properties up to the temperature corresponding to the heat resistance of the tool material; inertness to dissolution in the machined material at high temperatures; resistance to fracture with significant fluctuations in temperature and stress.

Secondly, there are the requirements that pertain to compatibility of the materials of the coating and tool; the affinity of the crystallochemical structure of the coating and tool materials, which determines their adhesive strength; the existence of an optimum relationship between the tool and coating materials with respect to elastic modulus, Poisson’s ratio, coefficient of linear expansion, thermal conductivity, and diffusivity; low susceptibility to the formation of brittle secondary compounds.

Thirdly, there are the requirements that concern the technological features of the coating method: the formation of the coating at temperatures that preclude recrystallization and phase transformations in the tool material; the possibility of reproducing the properties of a coating of the chosen composition for a specified relationship between the process parameters.