coatings

Editorial

Carbon and Carbon-Based Composite Thin Films/Coatings: Synthesis, Properties and Applications

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The production of composite thin films/coatings with desired properties is currently an important scientific and technical area [1–3]. Here, there are broad prospects for composite electrochemical coatings (CEC), which are obtained from electrolyte suspensions containing a different dispersed phase. CEC deposition not only saves non-ferrous metals, but also makes it possible to significantly improve the performance characteristics of metal surfaces (hardness, wear resistance, corrosion resistance, etc.), as well as impart new qualities to them (for example, anti-friction properties). Therefore, CECs are used in various industries (chemical, engineering, oil and gas, etc.). The properties of composite coatings are largely determined by the dispersed phase. In this regard, various carbon materials (carbides, nanodiamonds, carbon nanotubes, graphene, etc.) are of great interest to researchers. Carbon and carbon-based composite thin films/coatings are currently being actively researched.

It was shown in [4–7] that the addition of silicon carbide particles into the nickel–metal matrix leads to a noticeable increase in the physical, mechanical (microhardness and wear resistance) and corrosion properties of the resulting coatings. In particular, the wear rate of nickel–SiC composite coatings decreases by more than two-fold, and the microhardness increases by 50%–70% compared to pure nickel [7]. The main wear mechanism is tribooxidation accompanied by abrasion. This is due to grain refinement and the formation of dense finely crystalline nickel–SiC CEC deposits. In this case, the best effect is achieved by using non-stationary (pulsed and reversible) electrolysis [5–7]. The use of non-stationary currents contributes to a significant increase in the content of the dispersed phase in the metal matrix and its uniform distribution over the thickness of the electrochemical deposit. Moreover, the advantage of these modes is the ability to control a greater number of parameters of the electrochemical deposition of coatings.

The use of ultrafine diamonds (nanodiamonds) also has a positive effect on the performance properties of carbon-based composite thin films/coatings [8,9]. Nanodiamond particles have an oval or spherical shape without sharp edges and a large specific surface area (up to 450 m^2). They are a diamond core in the shell of amorphous carbon structures with oxygen-containing functional groups. The addition of only 5×10^{-2} g/dm^3 nanodiamonds into nickel-plating sulfate electrolyte makes it possible to obtain composite coatings with increased microhardness and wear resistance [9]. The addition of nanodiamonds into a nickel matrix leads to the formation of a coarse-grained surface and an increase in its roughness. However, in this case, a decrease in the coefficient of sliding friction of the CEC deposits is observed. Due to their unique structure and high-performance properties, composite thin films/coatings modified with nanodiamonds can be used to increase the service life of various cutting tools [8].

Another type of carbon material used to produce composite thin films/coatings are carbon nanotubes [10–13] and fullerenes [14–16]. Carbon nanotubes (CNTs) are graphite planes (graphenes) rolled into cylinders with a diameter of one to several tens of nanometers. CNTs can be either single or multilayer. At the same time, CNTs have unique physical and mechanical characteristics, in particular, high tensile strength and high modulus of elasticity. The wear rate of the nickel-CNT CEC deposited from the Watts electrolyte decreases by 1.40 times compared to nickel coatings without a dispersed phase. The addition of particles of multiwalled CNTs into a nickel matrix decreases the friction coefficient more than twice [12]. This result is due to the graphitization and self-lubrication effect of CNTs. A significant decrease in the coefficient of sliding friction also takes place when CNTs are added into the composition of electrochemical zinc deposits. In this case, the corrosion resistance of zinc-CNTs composite coatings increases [10,11]. The best effect, as in the case of other carbon materials, is achieved by using non-stationary electrolysis modes. It should be noted that the addition of fullerene C_{60} dispersion into a sulfate–chloride nickel-plating electrolyte also leads to the formation of composite coatings with improved tribological and corrosion properties [16].

Perhaps one of the most studied carbon materials at present is graphene and its derivatives (in particular, graphene oxide). The interest in graphene is due to its remarkable performance properties: high thermal and electrical conductivity, mechanical strength, etc. Graphene and graphene oxide, which are synthesized via the chemical or electrochemical oxidation of graphite, are used to obtain composite thin films/coatings based on metals and alloys [17–21].

When graphene oxide is added into the sulfate–chloride nickel-plating electrolyte, the microhardness and wear resistance increase, and the friction coefficient of the deposited composite coatings decreases. This is due to the fact that graphene has not only mechanical strength, but also a lubricating effect [17–19]. The corrosion resistance of nickel–graphene CEC and nickel–graphene oxide also increases in comparison with pure deposits of electrochemical nickel, which is explained by the uniform distribution of the dispersed phase in the composite coating. In turn, this contributes to the uniform distribution of corrosion currents over the surface [22]. With an increase in the content of graphene oxide in the nickel-plating electrolyte, a gradual increase in the corrosion resistance of CEC takes place, due to the induced growth of the coating along relatively low-energy planes and the impermeability of graphene particles for aggressive media [21].

Thus, carbon materials significantly improve the performance properties of composite thin films/coatings, and further research based on them is an important and promising task.

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