In our earlier investigations [1, 2], which were concerned with the manufacture and physicochemical properties of VKM (tungsten carbide–cobalt–copper) composites, it was established that copper additions increase the electroerosion resistance of VK type hard alloys. In subsequent studies, the wear resistance of tool electrodes was further increased by additionally alloying VKM composites with nickel and boron nitride, which in turn stabilized the alloys by markedly strengthening the copper and cobalt additions.

Before considering the properties of composites based on TK hard alloys with nickel and copper additions, which were investigated in the work described below, it must be stated that TK hard alloys easily surpass VK alloys in electroerosion resistance, ordinary and red hardness, and many other qualities. However, the electroerosion resistance of titanium carbide (TiC) at large pulse energies is appreciably less than that of tungsten carbide (WC).

This is attributable mainly to brittle rupture, to which titanium carbide is much more prone than tungsten carbide—the only carbide possessing some ductility. On passing from the carbides of the Group IV metals to the carbides of the Groups V and, next, VI metals, ductility increases. The reason for this is that it is in this order that the valence electrons of the metals become less and less capable of stabilizing the $sp^3$ configurations of the carbon atoms in the carbides, which are responsible for high hardness and brittleness [3, 4]. At the same time, the melting temperature of carbides, which is determined by the presence of weakly bonded electrons, is a maximum for the carbides of the Group V metals, since nearly all the unlocalized electrons of the metals become localized on the Me–C bonds during the formation of these compounds. In contrast to this, in the case of the carbides of the Group IV metals some of the electrons remain in an unlocalized state, while in the carbides of the Group VI metals delocalization of the valence electrons of the carbon atoms takes place.

Apart from experiencing brittle rupture during pulse type electrical discharges, tool electrodes suffer also electroerosion wear induced by the action of high local temperatures. Under these conditions, tungsten carbide becomes strongly decarburized [5] because the Me–C bond is a low-energy one, and the electrode surface becomes enriched in metallic tungsten, whose electroerosion resistance is much higher than that of tungsten carbide (WC) or titanium carbide (TiC) [5].

According to [6, 7], titanium carbide decomposes at high temperatures by the reaction $\text{TiC} \rightarrow \text{Ti} + \text{C}_3$, also, the rate of evaporation of titanium exceeds that of carbon. Because of this, owing to the rapid evaporation of the titanium at high local temperatures, carbon will become concentrated, in the form of graphite, on the surface of a TiC electrode. Hydrodynamic shocks (generated during the electroerosion...
process at high pulse energies) would then be expected to knock out this carbon into the gap between the electrodes. However, the effect of this phenomenon on the wear of titanium carbide (TiC) electrodes is less pronounced than that of brittle rupture. This has been established in an investigation [5] into electroerosion due to small energies in pulses and in random ionic bombardment in a glow discharge, where the erosion wear of titanium carbide is less than that of tungsten carbide, since here lattice strength rather than brittleness plays the dominant role.

During the formation of a complex TiC-WC carbide which is a solid solution of tungsten carbide in titanium carbide (the maximum solubility of WC in TiC is 70 mole %), the carbon atoms of the tungsten carbide become stabilized by the valence electrons of the titanium. As a result, the proportion of covalent linkage in the TiC-WC solid solution increases, and the system as a whole becomes energetically more stable, bringing about an improvement in physicomechanical properties. In the specific case of TK alloys, this manifests itself in increases in microhardness, red hardness, and electroerosion resistance, a rise in melting temperature, and improvements in various other properties compared with VK type alloys.

Examination of the electroerosion wear resistance of tungsten carbide (WC), titanium carbide (TiC), a complex TiC-WC carbide, and TK alloys (Fig. 1) shows that the carbides themselves are subject to severe wear. By contrast, the wear of TK hard alloys is only 8-10%, and that of the carbides TiC and TiC + WC 35%, of the wear of the carbide WC. Thus, the decrease in the electroerosion wear of hard alloys is mainly due to their cementing element — cobalt.

However, cobalt has — as shown by experimental data [2] — low wear resistance. In this connection, it is necessary to consider the question of the formation of skeletal (cellular) structure in electrode-tool alloys. In Fig. 2 is depicted the wear resistance of tool electrodes made of composites based on VK and TK hard alloys, plotted as a function of the amount of copper added to them. The results obtained demonstrate that, with rise in copper content, the electroerosion wear of both composites increases, at first (up to 40% Cu) only very slightly and then quite strongly. The wear behavior of these composites is linked with their structure, consisting of a refractory skeleton whose "cells" are filled with a low-melting-point constituent [8]. As the amount of copper is increased, the cells grow in size. This weakens the carbide skeleton, until the point is reached when it ruptures (copper contents of 40% or more), resulting in increased wear.

In spite of their improved wear resistance, TK hard alloys cannot be used extensively for tool electrodes, since their high hardness makes them difficult to machine, while in the manufacture of tool electrodes