

SYNTHESIS OF CARBIDE PHASES IN SURFACE METAL LAYERS UNDER ELECTROSPARK ALLOYING WITH GRAPHITE AND TRANSITION METALS IN GROUPS IV–VI

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The paper examines the electrospark synthesis of carbide phases in the surface layers of some steels (structural and tool) and titanium using graphite and transition metal electrodes: Ti, Cr, Mo, and W. Various options for processing with compact electrodes and powders of these materials were used. The electrospark alloying (ESA) of metal surfaces relies on the phenomenon of polar transfer of the anode tool material to the cathode when pulse discharges flow in a gaseous medium. The specific ESA features include high adhesion of the deposited material to the substrate, lack of heating to the part during processing, and use of pure metals and alloys as processing materials. The electrospark alloying process is very simple, and the required equipment is small, reliable, and transportable.

Keywords: *electrospark alloying, carbide phase, transition metal, graphite, metal powders, discharge energy, coating deposition, phase composition, wear resistance.*

INTRODUCTION

To modify (harden) the service surfaces of machines and tools by electrospark alloying (ESA), standard electrodes produced from carbides of transition metals in groups IV–VI of the Periodic Table are primarily used. These electrodes are manufactured at specialized factories of countries with in-situ resources of raw materials and a developed powder metallurgy industry. The regions without such industries are experiencing critical shortage of the electrodes.

The experts who use ESA to modify metal surfaces are facing a challenge of finding an alternative to the standard electrodes such as VK6, VK8, T15K6, TT7K12, etc.

Graphite electrodes were used in previous efforts [1–6] to harden the service surfaces of machine parts and cutting tools. In ESA of metallic surfaces with graphite, the latter interacts with low-voltage discharge plasma; as a result, carbon diffuses to the substrate, and carbides, oxides, and nitrides form if the process proceeds in air. A significant drawback of the resultant hardened layers is that they are thin (10–15 μm) and thus have limited life.

If we consider that carbon interacts with transition metals in groups IV–VI to form a series of carbides, then the latter should be very likely to emerge in the surface layers under successive ESA with electrodes made of these materials in the low-voltage discharge plasma that develops high temperatures (orders of 10^4 °C) and pressures (hundreds of thousands of pascals).

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The objective of this research effort is to produce carbide phases on steels and titanium by successive alloying with transition-metal electrodes (Ti, Cr, Mo, W) and graphite.

EXPERIMENTAL PROCEDURE

We used compact electrodes made of graphite (MPG-6 and EG-2 grades), titanium, chromium, molybdenum, and tungsten 5 mm × 5 mm × 40 mm in size or rods 5 mm in diameter and 35 and 40 mm in length, as well as powders of these materials.

When powders were used, we employed different options to supply them to the spark-discharge zone. In one option, the powder was fed to the alloying zone through a hollow electrode made of the substrate material (steel or titanium). In the second option, the material was fed from the side of the alloying electrode from a hopper mounted on the anchor of the vibrating tool electrode (applicator). This option allowed the powder to be supplied to the electrode gap in portions so that the spark discharges could ‘process’ all the material. To this end, the sample was placed into a cell of dielectric material. A small portion of the stoichiometric powder mixture was filled into the cell. Electric pulses passed through the powder mixture when it periodically approached the sample (substrate). To determine the optimal electrode gap for the powder material to get into it readily, the vibration frequency of the alloying electrode was varied between 100 and 300 Hz.

Commercial (EFI-10M, EFI-23M) and experimental units were used to generate electric pulses. The ESA process took place over a wide range of discharge energies: 0.3–1.0 J.

To produce thicker layers of titanium, molybdenum, and tungsten on the substrates, rotating electrode wires of these materials with a diameter of 1.5–2.0 mm were used. A rotating applicator is a ‘spinner’ whose electrode wires rotate in the plane perpendicular to the surface being alloyed. Therefore, when the electrodes move tangentially to the surface being alloyed, an electric discharge occurs at the breakdown distance and the eroded anode material (alloying electrode) is transferred to the substrate (cathode).

The samples after ESA were examined by X-ray diffraction in $\lambda\text{Cu-}K_{\alpha}$ radiation. Metallographic analysis of the coated samples was carried out with a NEOFOT-30 microscope at 200 and 500 magnifications.

The microhardness of the coatings was determined on cross-sections with a PMT-3 meter. Tribological characteristics of the coatings were tested using a reciprocating machine in running-in mode for 10 h (under a load from 19.6 to 88.2 N) and in duty cycle for 20 h (under a load of 88.2 N) with a liquid paraffin lubricant.

DISCUSSION OF EXPERIMENTAL RESULTS

We studied the effects of discharge energy, pulse frequency, and processing time and found that the most favorable conditions for producing high-quality layers with the greatest number of carbide phases by ESA with compact electrodes were promoted at a discharge energy of 1.0 to 3.0 J, a pulse frequency of 100–200 Hz, and an operating current of 1.5–3.0 A.

Electrospark alloying at higher discharge energies enhances oxidation processes and leads to numerous burns, microcracks, and pores.

Figure 1a is a cross-sectional microphotograph of an R6M5 tool steel sample produced by ESA with the tungsten + graphite material at a discharge energy of 1.5 J, an operating current of 2.0 A, a pulse frequency of 100 Hz, and a processing time of 1.5 min/cm² and Fig. 1b is a cross-sectional microphotograph of the sample produced at a discharge energy of 2.0 J and an operating current of 2.5 A at the same pulse frequency but with a processing time of 1 min/cm². As is seen, the coating has worse quality at higher discharge energy: there are discontinuities and defects such as pores and microcracks (Fig. 1b).

In the case of powder-contact ESA, when titanium, molybdenum, or tungsten powder is additionally introduced into the discharge zone, the formation of hardened layers is somewhat different. The discharge that occurs between the anode (alloying electrode) and the substrate through the powder lying on its surface is somewhat shielded and single-pulse energy is simultaneously distributed over a greater number of powder particles. Hence, higher discharge energy is required to process the powder particles.