Application of protective coatings in combined electric diamond grinding

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Abstract. The article discusses the practical use of combined electro-discharge diamond grinding characterized by metal bond grinding wheel operation in a self-sharpening mode with minimal wheel consumption. The upgrading of grinding equipment technological capabilities at processing high-strength materials is possible due to the galvanic deposition of anti-friction and anti-corrosion films on the surfaces of the diamond wheel and the workpiece. These conditions facilitate the cutting process thereby increasing performance and the quality of the processed surfaces of machine parts. The application of this method provides the diamond wheels operation in self-sharpening mode and guarantees the continuity of its geometric shape which in turn ensures that no defective layer is formed on the treated surface and the cutting tools have longer efficient life.

1 Introduction

The urgent issues in the field of machine technology are improving the quality and preserving the physical and mechanical properties of the processed surface conditioned [1–4] by the corrosion protection as well as improving performance by reducing the dissipation of energy in friction during the surface treatment of machine parts by abrasive wheel [5–8].

These tasks can be accomplished by implementing the device for combined electric diamond grinding (CEDG) of machine parts with continuous wheel dressing [9–12]. The device consists of the dressing electrode installed outside the processing zone. Both the electrode and the diamond grinding wheel (DGW) are connected to AC source. The used AC source is a transformer with three secondary windings, the beginnings of which are connected at a common point. With the help of controlled thyristor rectifiers the windings leads are connected, respectively, to the workpiece and the additional electrode with the positive pole, which is immersed in the electrolytic bath, and to the dressing electrode with the negative pole.

Such combination of elements results in enhancing the technological capabilities of the modernized equipment [13, 14] by enabling the galvanic deposition of anti-friction and anti-corrosion films on the DGW and the workpiece surfaces.

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2 The device for protective coatings application

We propose technically effective solution to the problem, namely, the device for CEDG with simultaneous wheel dressing with the AC transformer. One midpoint output is connected to the wheel via a current collector. The other three outputs are connected via controlled thyristor rectifiers: the first one forms the electric circuit of wheel dressing using a special device for continuous wheel dressing; the second forms the electric circuit of anodic workpiece dissolution; the third forms the electric circuit of cathodic deposition of anti-friction films on the wheel.

All controlled thyristor rectifiers have the control units (CU) with independent adjustment from 0 to a certain maximum. The contours of the electrical circuits are joined in accordance with the major technological movements of the grinding machine and work independently from each other. Electrolyte is supplied in the gaps between the anode and cathode of the electrical circuits (Figure 1).

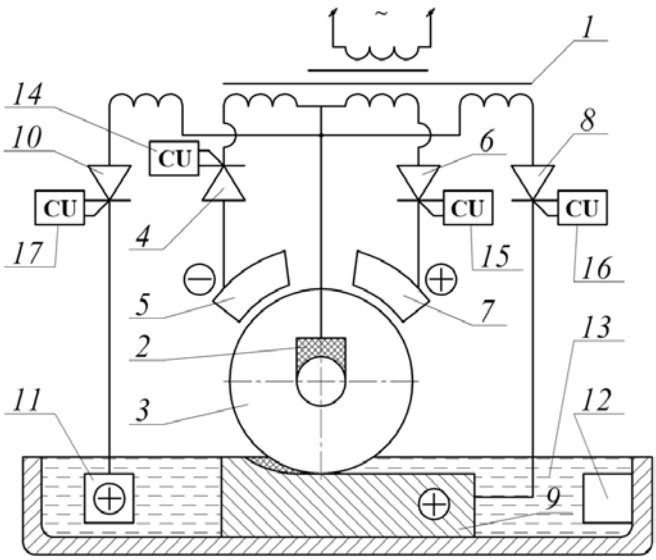


Fig. 1. Diagram of the CEDG device with deposition of oxide films on the DGW surface and the treated surface

The device consists of an AC power transformer 1, the output midpoint of which via the current collector 2 is connected to the wheel 3. The other four outputs of the circuits are: the first output via thyristor 4 with the special device for continuous wheel dressing 5 forms the electric circuit of wheel dressing; the second output via thyristor 6 with a special cathode 7 forms an electric circuit of cathodic films deposition of on the wheel; the third output via thyristor 8 forms an electric circuit of workpiece 9 anodic dissolution; the fourth output via thyristor 10 with a special anode 11 which is immersed in non-conductive electrolyte bath 13, whose temperature is controlled by a special device 12, forms the cathode circuit of film deposition on the workpiece. The thyristors are controlled by CU 14, 15, 16 and 17; they are independently adjustable from 0 to the specified maximum. All electric circuits are closed through the current collector to the wheel and work in opposite directions, being blocked with the major technological movements of the grinding machine and working independently from each other. Electrolyte is supplied in the gaps between the anode and cathode of the electrical circuits.

2.1 Principle of the device operation

When grinding machine is enabled, DGW 3 starts rotation and can work independently. When the transformer 1 is on, the electric current of the secondary winding is fed from the transformer common point to the current collector 2, and from the windings leads to the thyristors 4, 6, 8 and 10 in the circuits of wheel dressing, anodic dissolution of the workpiece and the cathodic films deposition on the wheel and the workpiece. The circuit of wheel dressing is activated via thyristor 4 to a special device 5 and is closed to the surface of the wheel 3 via the electrolyte which is fed into the gap between the wheel and the special dressing device. Thus, the wheel dressing device is the negative pole (cathode) and the wheel is the positive pole (anode) in the wheel dressing circuit. The optimum current density of wheel dressing set by CU 14.

The anodic dissolution circuit of the workpiece treated surface (thyristor 8 and the workpiece 9) works in a similar way, but the current is of reverse polarity, i.e. the workpiece 9 is the anode, and the surface of the wheel 3 is the cathode. The optimum value of the etching current density during the work is set by CU 16. The circuit of the cathodic films deposition is designed to strengthen the abrasive grains, to prevent clogging and to apply solid lubricants to the surface of the diamond wheel. The deposited material electrode 7 in this circuit is connected to the anode via thyristor 6, and the diamond wheel is connected to the cathode.

The circuit of cathodic film deposition on the workpiece includes thyristor 10, special anode 11, electrolytic bath with the electrolyte. The optimum current density value of film deposition on the workpiece during the work is set by CU 17 and the electrolyte temperature set by the temperature CU 12.

The electric circuits can work separately in different combinations, i.e. when thyristor 4 is closed, only the circuits of anodic workpiece dissolution and the cathodic film deposition of solid lubricants are working. This mode of operation is economically feasible for processing of, e.g., hard alloys, cermet and nanoreinforced materials with hard metal bond DGW (such as type MO4, MO16, MV, MO13E), because under these conditions the wheels can operate in the self-sharpening mode.

When thyristor 8 is closed, only the circuits of continuous wheel dressing and cathodic deposition of films and solid lubricants are working. This mode is efficient for metal bond wheels in the processing of viscous materials (steels, nonferrous metals, etc.) as well as non-conductive materials (glass, ceramics, etc.). Separate and independent operation of these circuits is also advisable for pre-dressing of new DGW.

When thyristors 6 and 10 are closed, only the circuits of anodic workpiece dissolution and continuous wheel dressing are working. This mode is efficient for the work of different metal bond wheels operating in the self-sharpening mode at small electric modes.

Thus, the application of the proposed device allows to significantly expand the technological capabilities of the equipment. It facilitates independent operation of the continuous wheel dressing circuits, as well as the circuit of anodic dissolution of the treated workpiece surface and cathodic deposition of solid lubricants on the wheel surface and the films on the workpiece surface. It simultaneously increases the performance and quality of the processed workpiece and reduces the consumption of the wheel abrasive layer.

3 Methodology of the protective film deposition

The use of the electrolyte confirms the theoretical and experimental part as well as the conclusions. Oxidation-reduction reactions under these conditions can be represented in such a way that there is a possible range of low-activity metal ions (such as Cu_2+; Al_3+; Zn_2+) on the surface of the wheel which are supplied to electrolyte flow of the dissolving anode, i.e. DGW during its dressing. As a result, anodic dissolution products can be transferred onto the processed surface, as, for example, in the reaction:

$$2AlO + 3Cu_2^+ + 6NO_3^- = 3CuO + 2Al_3^+ + 6NO_3^-,$$

$$Cu(NO_3)^2 \rightarrow Cu_2^+ + 2NO_3^-,$$

$$Cu_2^+ + 2e = CuO.$$

$Cu(NO_3)^2$ is sometimes specially added to the electrolyte for the cathodic deposition of copper.

If the salts of electropositive metals, such as $CuSO_4$, $Cu(NO_3)^2$, $NiNO_3$, $AgNO_3$, $Hg(NO_3)^2$, are added to the electrolyte, the whole processed surface is covered with a thin layer of this metal.

Corrosion phenomena (anodic dissolution, the formation of galvanic couples) at each moment are restricted by the thin surface layer of metal from being active on the treated surface, and therefore, the structure of the deeper layers is not disturbed.

Let us consider the case of negative electrode. In this case, the positive ions, primarily the ones with the most electropositive electrode electrochemical potential $\varepsilon 0$, are reduced from the solution on the negative electrode. It results in:

1. Hydrogen is produced in acidic medium, according to the reaction:

$$2H^+ + 2e = H_2$$

In neutral medium the reaction is described by:

$$2H_2O + 4e = H_2 + 2OH–$$

Hydrogen can be partially liberated in the atomic state dissolving in the wheel bond:

$$H^+ + e \rightarrow HO,$$

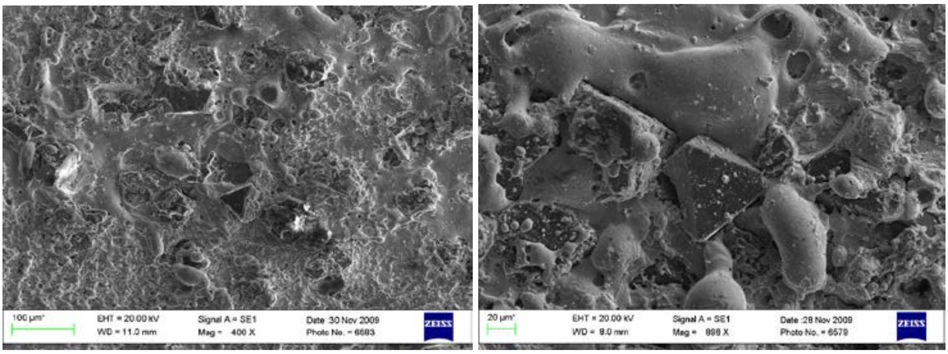
and may be partially oxidized by the electrolyte:

$$NO_3^- + 2H \rightarrow NO_2^- + H_2O.$$

2. Metal ions are reduced on the surface of the wheel from the electrolyte:

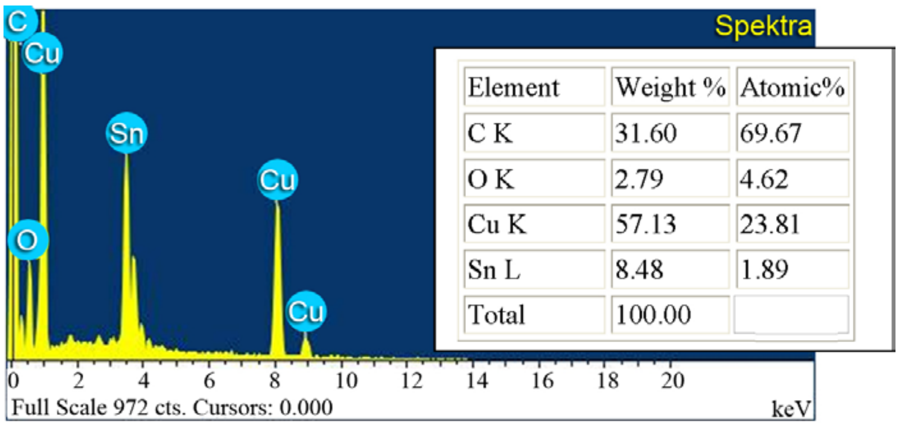
$Cu_2^+ + 2e \rightarrow CuO$	$\varepsilon 0 = +0,34$ V
$Ni_2^+ + 2e \rightarrow Ni$	-0,250 V
$Sn_2^+ + 2e \rightarrow Sn$	-0,236 V
$Co_2^+ + 2e \rightarrow Co$	+0,277 V
$Fe_2^+ + 2e \rightarrow Fe$	-0,44 V

The ions of an electropositive metal can be deposited on the cathode, which in this case is the DGW. However, the metal is transferred in the form of ions to the solution both from the cathode and the anode, just as the clogging products are. The image of the diamond wheel surface with the passivating film and its spectrum are shown in Figures 2, 3.



a) ×400 b) ×900

Fig. 2. The surface of the AC6 80/63 M2-01 100% wheel with the passivating film



Element	Weight %	Atomic%
C K	31.60	69.67
O K	2.79	4.62
Cu K	57.13	23.81
Sn L	8.48	1.89
Total	100.00	

Fig. 3. The passivating film spectrum

4 Results and discussion

Film theory of materials bonding in the solid phase is based on the assumption that the formation of compounds is possible provided the juvenile surfaces are at a distance of interatomic interaction. The compound is thus formed as the result of the seizure representing the diffusion-less process of the diamond grains crystalline grids [15–18] and wheel bond unification. In the system under consideration there is an exchange of atoms between these regions resulting in their boundaries shift. The speed of this shift and, accordingly, the grain growth rate are obviously determined by the speed of the directed atoms migration across the boundary between grains, which, in turn, depends on the atoms jumping frequency in both directions.

The softer is the film, the more it spreads in the deformation process and the process of the contacting surfaces area increase. Solid film crack without increasing their surface and enable the ions and electrons of the metal to migrate to the contact surface [19–24]. It is therefore important to know the characteristics of the formed layer on the DGW surface. The film is protective if it has sufficient adhesion and high corrosion resistance. In addition, it should have a high formation rate and a sufficient elasticity. As the film layer thickens, the action of orientation forces on the surface is weakened, and the film aims to acquire a stable structure in the given conditions. Owing to the fact that the heterogeneity in chemical composition is formed in the atomic layers, the passivating film components fall in the direction of the workpiece.

If the film has a high viscosity or low formation rate and sufficient rigidity, it is destroyed by external action and may serve as a solid lubricant. This can be beneficial since the film, being a new formation, is delivered to the contact point of the tool and workpiece materials. However, for our research it is important that the film should have conductivity as well so that the currents of dressing and etching could work efficiently.

The destruction of the oxide film results in corrosion. It often occurs on a completely smooth surface and is of pointed local character. The rest of the protective film is resistant to external actions. This process is explained by the presence of coming to the surface defects, such as vacancies, dislocations, unstable atoms, including ions-activators, which cause the appearance of salts and oxides.

In addition, metal films, in contrast to the oxide ones, are electroconductive, so they do not prevent the electrochemical processes from taking place on the treated material.

5 Conclusion

Aluminum is the most stable phase at diffractograms of spectral and x-ray diffraction analyses. Therefore, the oxidation of *Al* is the most important from a practical point of view. Easy *Al* oxidation leads to the formation of dense refractory film of aluminum oxide Al_2O_3 on the DGW surface. The density of this film is 3.6 g/cm^3, the melting point is over 2000°C, which makes it resistant to both chemical interactions and deformation during grinding.

The adhesion energy calculation of the contact interaction confirmed the absence of physico-chemical associations of tool and workpiece materials during CEDG.

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