Energetic activation of the processes of abrasive diamond metal processing

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Abstract. The possibility of energetic activation of the processes of abrasive diamond metal processing is considered. Emphasis is placed on thermal activation of coolants and lubricants and on electrical activation of the grinding zone. It is shown that under certain conditions, the external energy supply can significantly improve the performance of abrasive-diamond processing. The role of the electrode potential during electrical activation is disclosed. Physical aspects of energetic activation are discussed. The prospects of other schemes of electric activation are demonstrated.

1. Introduction
Abrasive diamond processing of metals is one of the leading technologies in machine building and instrument making. It is this processing method that often provides the final required dimensional accuracy and surface quality of the product. Therefore, much attention is paid to the improvement of abrasive diamond processing in the scientific and engineering sphere. Traditional methods of improving the efficiency of abrasive diamond processing processes, such as improving the tool, optimizing the processing modes, and improving the quality of liquid coolants, are so deeply developed that they give a slight increase in efficiency. Innovative and promising is the energetic activation of the abrasive diamond processing processes, consisting in the directional influence of external energy flows on a detail being processed, on an abrasive diamond tool, on a coolant or, in a complex, on a treatment area.

Of the many known methods of energetic activation for the study of prospects in the abrasive diamond processing processes, two were selected: thermal and electric.

2. Results and Discussion
The mechanism of energetic activation of species and processes is complex and poorly studied [1]. It is assumed that as a result of the action of the energy supplied by external currents, the potential and kinetic energy of the atoms and molecules of the object being activated increases, and the activation energy of the processes in which the object participates accordingly decreases. The activation energy is an energy barrier that must be overcome in order for the desired interaction between objects to occur.

For most physicochemical processes associated with abrasive diamond processing, the activation energy values under normal conditions are quite large, so the necessary reactions do not take place at all or are very sluggish.

The relationship between the velocity of processes and their activation energy is described by the Arrhenius law [2], from which it follows that even a slight decrease in the activation energy is accompanied by a strong acceleration of the interaction:
\[ k = e^{\frac{-E}{RT}}, \]  

where: 
k is the interaction velocity;  
A is a constant;  
E is the activation energy, kcal/mol;  
R is the universal gas constant;  
T is the temperature.

For processes between valent-saturated molecules, which are characteristic for traditional abrasive diamond processing, \( E \approx 1-10 \text{ kcal/mkm} \).

When additional external energy is activated by activated objects, the potential and kinetic energy of atoms and molecules of the object may increase so much that they will decay with the formation of new reactive particles (ions, electrons, free radicals). As a result, not only ordinary reactions are significantly accelerated, but also new unpredictable types of interaction can occur.

Thermal activation, the most accessible for an applied implementation, lies in temperature rise of any of the interacting objects by supplying thermal energy. From the aforementioned Arrhenius equation it follows that a change in temperature in an arithmetic progression causes a change in the reaction rate constant in a geometric progression. So, if it is impossible to synthesize water from hydrogen and oxygen at 20 °C (it would take 54 billion years), then at 500 °C, this would take only 50 minutes, and at 700 °C, the reaction proceeds immediately [2].

The most accessible scheme was studied - thermal activation of coolant liquids used in the processes of abrasive diamond processing.

When heated, widely used water-based coolant lubricants (emulsions, chemical solutions of salts and polymers) significantly improve its many physical and technical properties that positively affect the performance of the process. So, when coolants heat up, their viscosity decreases significantly, the wetting ability with respect to metals and ceramics improves, the surface tension decreases, and the washing potential increases. In some situations, thermal activation of coolant liquids can lead to negative results due to a decrease in the cooling effect, destruction of hydrocarbon components, a decrease in anti-wear properties of coolant liquids based on doped oils. In each case, experimental testing is required.

The study of the effect of the temperature of a standard 5% water-oil emulsion was carried out on a flat grinding operation of hardened 40X steel circles 24A95CM1K5 at a cutting speed of 35 m/s, a reciprocating speed of 8 m/min, and a vertical feed of 0.02 mm/double move.

Experiments have shown (figure 1) that the temperature of the emulsion significantly affects the specific productivity \( g \), the dimensional wear \( \Delta R_y \) and durability of the circle \( T \). The effect of temperature on the indicator \( R_a \) (arithmetic average deviation of the profile) of the treated surface is insignificant. The dependence of specific productivity and dimensional wear on temperature is extreme. The optimum is observed at 45 °C. Circle strength decreases linearly when the emulsion temperature increases. The value of the optimal temperature depends on the composition of the coolant liquid and processing conditions and is in the range of 40–60 °C.
Figure 1. The effect of heating temperature and emulsions on the performance of the process of flat grinding of steels. 1 — circle strength; 2 — specific productivity; 3 — specific dimensional wear of the wheel; 4 — indicator.

In the well-known works on thermal activation of coolant liquids, static isothermal heating of the entire mass of liquid was used. Apparently, large reserves are laid in the dynamic high-gradient heating mode, as well as in the effects of a non-uniform thermal field. Model experiments in this sphere have shown a number of interesting effects. Thus, it has been established that when a liquid droplet spreads over a solid surface in the non-isothermal mode, thermocapillary and thermoosmotic effects, which can act in opposite directions, play a significant role. Therefore, when the liquid flows in the direction of decreasing temperature, the speed of spreading increases, while when it flows in the opposite direction, the movement slows down. As the temperature gradient increases along the sample, the flow rate of the liquid increases from the heated end of the sample to the cold one. With this flow, the process’ kinetics is described not by a cubic parabola, as in case of isothermal spreading, but by a quadratic one [3]. Thus, by creating the required temperature gradient on a detail being processed or a tool, it is possible to intensify the flow of the coolant into the treatment zone [4].

Electric activation of the processes of abrasive-diamond processing can be implemented according to various schemes. The analysis showed that the preferred scheme is the transmission of electric current through the circuit "coolant — the detail being processed." The physical model of such activation in aquatic environments is as follows. When a metal surface comes into contact with an aqueous medium, a double electric layer and an electrode potential arise spontaneously at the interface. As a result, all the physicochemical processes occurring on the wetted metal surface are influenced by the field of the electrical double layer and depend on the magnitude of the electrode potential. Such processes include wetting, adsorption, the formation of phase films, etc.

Studies have shown that such properties of the metal being processed as microhardness, surface energy, dispersibility, friction coefficient, deformability, etc., depend on the magnitude of the electrode potential [5]. The electrode potential reacts sensitively to structural and phase transformations in the surface layer of the metal being processed and is associated with the magnitude of the residual stresses [6].

The substantial dependence of the strength of the metal, as well as the nature and kinetics of the physicochemical processes occurring on the surface of the detail, on the magnitude of the electrode potential makes it possible to activate the processing by displacing the electrode potential in one direction or another. The electrode potential can be shifted by polarizing the detail being processed, i.e. imposing external potential on it. Depending on the sign of the imposed potential, the polarization can be cathodic and anodic.

The effects of electrical polarization on the diamond honing process showed that during cathodic polarization, a decrease in the electrode potential below the potential of a zero iron charge is accompanied by a significant decrease in the surface roughness of the machined surface and an increase in the efficiency of the process. Polarization was carried out from an external power source assembled according to the galvanostat scheme. As a current source, ordinary batteries were used. The current flowed through the
"detail being honed – coolant liquid" circuit. Electrolytes and emulsions were used as coolant. In a wide range of changes in the electrode potential, the processing productivity varies along an extreme curve. The results obtained are explained by the manifestation of the electrocapillary effect [3]. Hydrogen absorption of the metal surface, which is inevitable during cathodic polarization, is insignificant.

The use of polarization of carbide plates made of T15K6 alloy with AChK circles 125×10×3 ACP 50/40 K1 100% being grinded in the electrolyte medium made it possible to reduce diamond consumption by 20–60%. In this case, the polarizing current was 10 mA, the voltage in the circuit “detail – coolant” was 15 V, the current density was 2 mA/cm².

Of considerable practical interest is the possibility of activating the processes of abrasive diamond processing in hydrocarbon media [7]. In experiments, the process of round grinding with corundum abrasives was activated by a constant electric field. Mineral oil was applied to the surface to be processed by contact using a porous gasket. A metal electrode was placed under the gasket, to which, like the detail, an electric charge was applied. In fact, the part and the electrode performed the function of the capacitor plates. The detail was isolated from the walls.

Activation was accompanied by an improvement of many indicators of the processing process. In particular, cutting forces have decreased, the abrasive wheel resistance has almost doubled, the surface geometry has improved. The voltage of the permanent electric field varied in the range of 20–100 V/cm. A positive result of activation can be explained by an increase in the strength of lubricating adsorption films on the metal, as well as by better oil wetting of hard-to-reach areas of the surface micro-profile.

The electrostatic field can activate the processes taking place at the “macro level”, i.e., to increase the heat transfer from the detail to the coolant, to influence the hydrodynamics of the coolant. In order to improve pumping and cooling action of the coolant during grinding, in the USA it was proposed to supply sufficiently large dissimilar charges to the jet of liquid and the detail being processed. This method was modified by the introduction of a second electrostatic field, which allowed for infinite adjustment of the power and direction of the coolant flow (figure 2).

![Figure 2. Scheme of regulation of hydrodynamic processes during grinding by imposing electrostatic fields.](image)

A negative charge from an external source is supplied not only to the detail 1 being grounded by grinding 2, but also to the plate 5 installed under the processing area and having the opportunity to occupy an arbitrary position in space. The coolant jet, which is fed to the cutting zone through the nozzle 3, imparts a positive charge, with results in a potential difference between the jet and the detail 1 being grounded through the machine components. Above the zone of ejection of the coolant from the nozzle the plate 4 is installed, it is charged with the same charge as the jet of coolant and has the ability to occupy arbitrary positions in space. An additional electrostatic field (between the plates 4 and 5) is turned relative
to the zone of contact between the circle and the detail so that the resultant between it and the main field corresponds to the required hydrodynamic parameters.

It can be assumed that important applied results will be obtained when activating the processing process with variable and asymmetric electric fields, as well as when leading to the processing zone of other types of energy (ultrasonic, magnetic, radiation, etc.)

3. Conclusion
Energetic activation of the processes of abrasive diamond processing is both an innovative direction in the scientific foundations of engineering technology, and a means of improving efficiency in real production. The obtained positive results on the consideration of thermal and electrical activation is an incentive to study other schemes of activation effect on the processes of abrasive diamond processing.

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