Physical-chemical processes of diamond grinding

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Abstract. The article focuses on the relevance of the research into the problem of diamond abrasive metal-bonded tool performance loss with a view to enhancing the effectiveness of high-strength materials finishing processing. The article presents the results of theoretical and empirical studies of loading layer formation on the surface of diamond wheels during processing high-strength materials. The theoretical part deals with the physical and chemical processes at the contact area of the diamond wheel and work surface with the viewpoint of the electrochemical potentials equilibrium state. We defined dependencies for calculating the loading layer dimensions. The practical part of work centers on various electron-microscopic, spectral and X-ray diffraction studies of the metal-bonded wheel samples during diamond grinding. The analysis of the research results revealed the composition and structure of the loading layer. The validity of the theoretical data is confirmed by sufficient convergence of the calculated values with the results of empirical research. In order to reduce the intensity of loading and improve the cutting properties of metal-bonded diamond abrasive tools, it is recommended to use combined methods for more efficient processing of high-strength materials.

1. Introduction
The increased use of competitive high-strength and hard-to-machine materials products in various industries causes the necessity to improve the technologies of forming the qualitative and operational characteristics. Grinding is among the common methods of finishing machine parts processing. At the same time, the performance of abrasive instruments is reduced during processing resulting in the complete loss of their cutting properties due to loading. Loading of the grinding wheels cutting surface during final processing is one of the main reasons for the increased intensiveness due to the need of repeated tool dressing to ensure the quality of the processed products. This problem is particularly relevant for the metal-bonded diamond wheels, especially while processing high-strength composite materials. Therefore, it is of great importance to solve the problem of improving the cutting properties of metal-bonded diamond wheels for the processing of a wide range of high-strength materials. This paper informs of theoretical and empirical research of the physical-mechanical processes occurring in the contact area between the diamond wheel surface and that of high-strength materials.

2. The theory and methodology of the research
There are several known hypotheses of the loading layer formation on diamond wheels loading to the

loss of cutting capacity during grinding. It is suggested that the mechanism of loading should be viewed as electrochemical potentials equilibrium state at the contact area between the diamond wheel and the work surface. Assuming that the loading layer has a crystalline structure caused by the formation of new types of binding at the level of the processed material and wheel metal bond crystal lattices, it is possible to conclude that the formation mechanisms of the intermediate layer on the surface of the wheel are reduced to identifying the structure of these bindings. Based on this assumption it was necessary to take into account the components of the wheel metal bond and hard-alloy material and performed the calculation of maximum loading layer H [µm] using the expression [10, 14]:

$$H = \frac{(W_2 - W_1) \cdot \varepsilon_0 \cdot S}{e^2 (n_2 - n_1)}, \tag{1}$$

where S is the area of the wheel contact with a workpiece, [m^2]; e is the elementary charge, [C]; ε_0 is the electric constant, [F/m]; n_1, n_2 are the concentrations of free electrons in the elementary volume of the metal bond and processed material, respectively; [m^{-3}]; W_1, W_2 are the energy level of conduction electrons of the diamond wheel metal bond and processed material, respectively [eV].

According to the estimated data [14]: $W_1 = 14.04$ [eV]; $W_2 = 29.12$ [eV]; $n_1 = 7.54 \cdot 10^{28}$ [m^{-3}]; $n_2 = 22.42 \cdot 10^{28}$ [m^{-3}]; $S = 8.9 \cdot 10^{-4}$ [m^2]; $e = 1.6 \cdot 10^{-19}$ [C]; $\varepsilon_0 = 8.85 \cdot 10^{-12}$ [F/m]. The calculation of H values taking into account the given data allowed one to determine with the help of expression (1) the maximum amount of loading layer for the specified conditions that amounted to $H = 31$ [µm].

The 3E711 machine tool was used for conducting a series of experiments designed to study the process of loading layer formation on the diamond wheel surface during diamond grinding [11-13].

The changes of the surface condition of the 1A1 150×10×3×32 AS6 M2-01 100/80 diamond wheel after processing VC (WC-Co) group hard alloy were assessed on the samples cut from the diamond layer. The prepared samples were studied by an ARL X'TRA X-ray diffractometer, a Carl Zeiss EVO50 raster electronic microscope with a built-in l EDS X-Act chemical analyzer [11].

3. The research results and their discussion

The analysis of the optical research of the diamond wheel samples results established that the performance of the abrasive tool decreases in the first few minutes of high-strength materials processing; after 30 minutes of operation diamond grains on the wheel surface are almost completely covered by a loading layer (figure 1), which requires its replacement or additional repeated dressing.
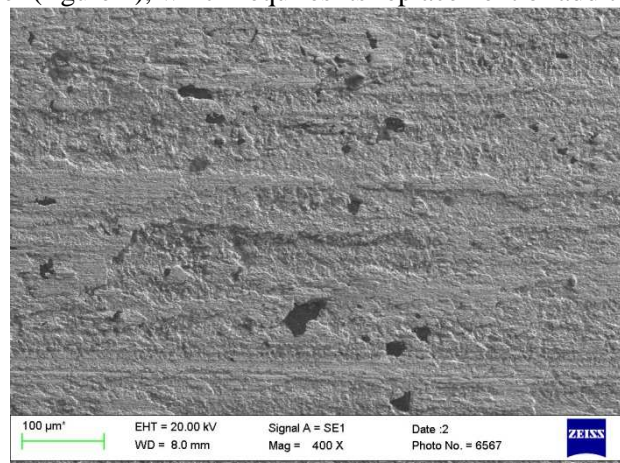

Figure. 1. The loading layer on the diamond wheel sample surface

The spectral analysis of the samples revealed that the wheel surface loading layer structure is largely defined by the composition of the processed material.

Analyzing the spectrum (figure 2) from a point near a diamond grain, it was possible to conclude that the loading layer consists of about 40% of tungsten W and 3% of cobalt Co of the mass composition that is found in the processed hard-alloy material.
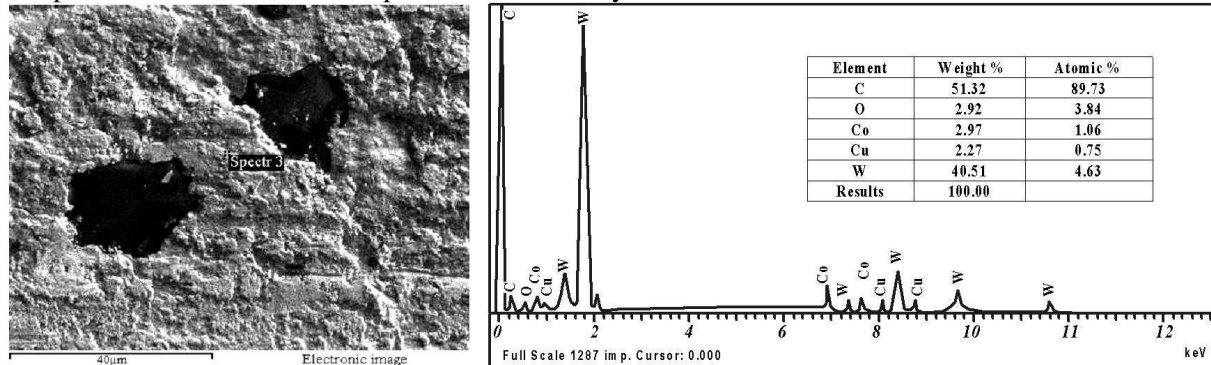

Element	Weight %	Atomic %
C	51.32	89.73
O	2.92	3.84
Co	2.97	1.06
Cu	2.27	0.75
W	40.51	4.63
Results	100.00	

Figure. 2. Chemical analysis of diamond wheel surface spectrum after 30 minutes of processing

X-ray diffraction research of the diamond wheel surface showed the formation of the loading layer that completely hides the grains and prevents them from renovating during processing. The analysis of the X-ray diffraction pattern allowed marking the phase transformations on the wheel surface that result in forming of a new complex of cobalt and tungsten carbide Co3W3C in addition to tungsten carbide WC (figure 3).
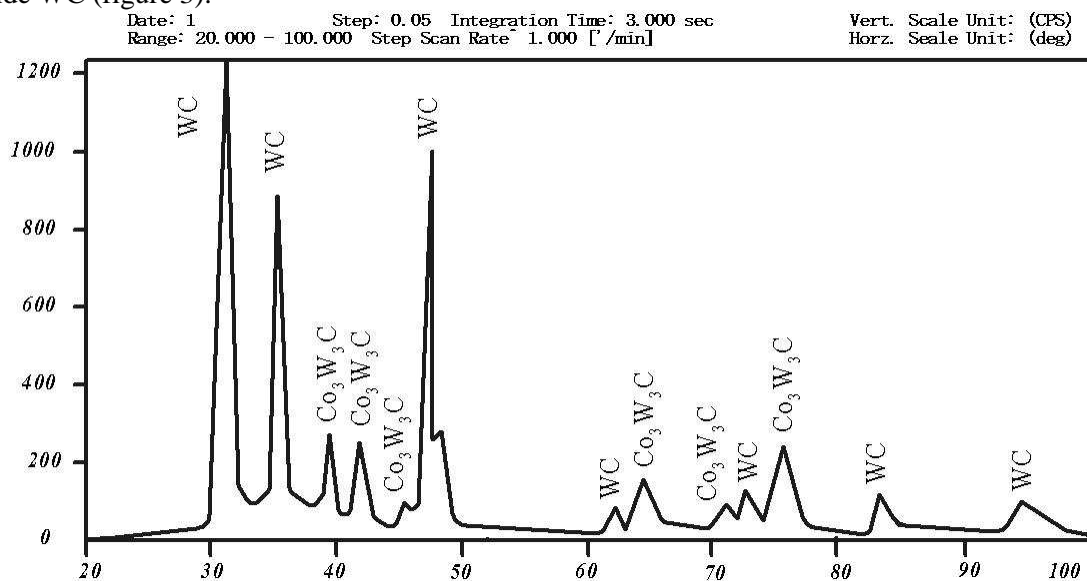

Figure. 3. X-ray diffraction pattern analysis of the diamond wheel surface sample
after 30 minutes of processing

Versatile empirical research of diamond wheel samples, such as the results of the optical and electronic microscopy, spectroscopy and X-ray diffraction research of different surface areas confirm that the loading layer has a crystalline structure that is connected with the new types of binding formation at the level of the crystal lattices during the interaction of the wheel and the processed material.

It has been established experimentally that the loading layer is formed during diamond grinding of hard-alloy materials by metal-bonded wheels, its maximum value being about 30...40 μm (figure 4).

The comparison of the obtained experimental data of the loading layer formation on the diamond wheel surface with the calculated value demonstrates that the relative error does not exceed 10%, which indicates the validity of the proposed theory.
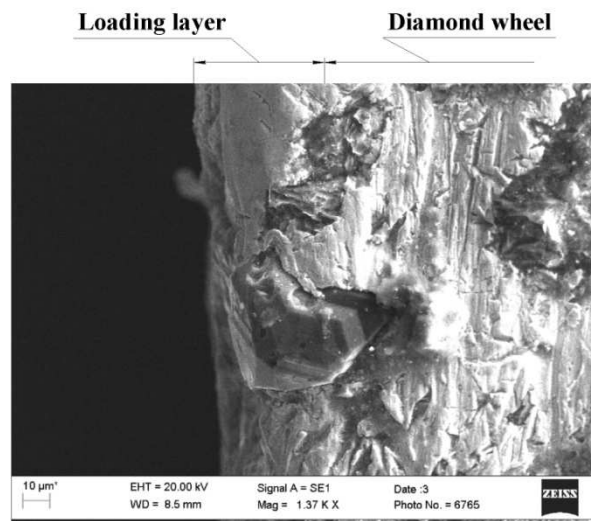
Figure. 4. The maximum size of the loading layer on the surface of the diamond wheel sample

4. Conclusion

The conducted theoretical research of the diamond grinding wheel and processed high-strength material interaction revealed the loading layer formation mechanism and composition as well as determined its maximum value. The experimental research confirmed the presence of the loading layer, the formation intensity of which depends on the processing time; its maximum value was measured experimentally and is comparable with the calculation data. For practical purposes it should be recommended to apply combined methods for high-strength materials diamond processing which would facilitate the wheel high performance due to continuous electrochemical dressing.

5. Acknowledgments

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