FORCES AND ENERGY EFFICIENCY OF DIAMOND AND DIAMOND SPARK GRINDING OF TUNGSTEN-COBALT HARD ALLOY

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Abstract: The presented work continues the cycle of research and comparative analysis of the energy consumption of mechanical cutting in the processes of conventional diamond grinding and diamond-spark abrasive machining with the introduction of the energy of electric discharges into the cutting zone. A decrease in the thermo-mechanical tension of mass micro-cutting in the zone of diamond spark grinding, which is ensured by the development of its working relief, supported by the action of electric discharges on the bond of the wheel, expands the technological capabilities of diamond-abrasive processing and allows to consider approaches to organizing this process using the methodology of minimal lubrication. The paper presents and summarizes the experimental results with a calculated yield on the grinding factor and the specific work of chip formation during diamond spark machining of the difficult-to-machine tungsten-cobalt alloy VK6.

Keywords: difficult-to-machine material, processing performance, grinding ratio, specific work, energy balance.

Introduction to research

It would not be an exaggeration to believe that the development of the method of diamond spark grinding, which began at the Kharkov Polytechnic Institute on the eve of the last quarter of the last century [1], was motivated by hard alloys known for their difficult machinability due to wear-resistant carbide genesis. The first completed dissertation research of a new processing method [2] and the first state order for technological development based on it [3] are devoted to hard alloys. The entire subsequent history of the development of the method and its mastering by industry is also largely associated with the processing of hard alloys, in which it is most effective [4, 5]. This study focuses on the grinding of a tungsten carbide-based hard alloy known to be particularly difficult to machine.

Previously performed author's presentations at conferences in Ukraine [6], Russia [7], Hungary [8], Serbia [9], Romania [10] convincingly show the increased energy efficiency of chip formation during diamond spark grinding in comparison with conventional diamond abrasive processing. However, the increased demand for the development of modern technological platforms in the context of reducing water consumption [11], respectively, minimal lubrication [12], arouses scientific and practical interest in identifying appropriate and promising basic technologies, understanding the physical foundations and possibilities of transition to non-traditional environments for diamond abrasive processing and diamond spark grinding as its flagship in the shaping of conductive difficult-to-machine materials.

In the science of cutting materials, the study of the forces required to remove the chips is usually associated with the identification and analysis of the force projections in the direction of the main movement in the working contact of the tool and the workpiece, which determines chip formation (P_z), and in the direction of immersion of the tool in the machining allowance , which determines the unproductive energy of interference from the position of chip formation and overcoming friction in the considered dynamic working contact (P_y) [13, 4]. Obviously, in comparable performance capabilities, the most attractive for the reorganization of diamond abrasive processing technologies in accordance with the concept of minimum lubrication will be those with a higher value of the dimensionless grinding coefficient K_G:

$$K_G = P_z / P_y.. \tag{1}$$

From this point of view, let us return here to the previously obtained initial experimental data and results [6-10, 14], carry out their additional expanded presentation and analysis, with the introduction of cutting forces and their productive reflection in the specific work of chip formation A_s (J/mm^3) spent on the removal of Q_m (mm^3/s) material per unit of time. With a usually low value of the workpiece speed V_d (m/min) in relation to the speed of the grinding wheel V_c (m/s), regardless of the grinding scheme (counter, passing), the calculation of A_s is carried out according to the formula [15]:

$$A_s = P_z \cdot V_c / Q_m. \tag{2}$$

Main results and discussion

In conventional diamond processing, the grinding ratio is significantly influenced by the degree of dullness of the cutting grains and the intensity of contact interaction of the bond with the metal (more than 50% of the friction can account for this).

In diamond spark grinding, when only cutting grains (without the participation of a bond) interact with the metal, the grinding factor is a clearer reflection of the working processes in the grinding zone. It can be argued that the grinding coefficient of a tool operating in the diamond spark mode is in the range between the coefficient of friction of diamond with metal f_a and the coefficient of abrasive cutting with a sharp diamond grain K_C. These are the boundaries of the possible change in the grinding coefficient:

$$f_a < K_G < K_C. \tag{3}$$

Hence it follows that the closer the K_G value to the K_C value and the greater its difference from the friction coefficient f_a, the higher the efficiency of the tool work.

The energy efficiency of mechanical cutting during the transition from diamond to diamond spark grinding was previously considered [6-10, 14] for processing tungsten-cobalt alloys of grades VK6, VK8 and VK15 (with a mass content of cobalt, respectively, 6, 8 and 15%; the rest is tungsten carbide). In accordance with the formulation of the problem of this study, additional data are presented here for the VK6 alloy, which is the most difficult to machine in the series under consideration due to the greatest presence of tungsten carbide in the composition.

From Tables 1 and 2, it can be seen that with the intensification (increase in productivity) of the machining process, the advantages of diamond spark grinding over the usual when processing the VK6 hard alloy are much more noticeable. So, with a twofold increase in operating performance due to an increase in the cutting depth, K_G in the diamond-spark mode increases to 20% or more, and in the normal mode it decreases by 6-12% (Table 2).

Experiments and analysis of their results (Tables 1 and 2) show that in diamond-spark machining of hard alloys, the mechanical component in most cases is much less (due to lower cutting and friction forces) than the specific work in conventional diamond machining.

Of course, in the general energy balance of the organization of the working process during diamond spark grinding, it is necessary to take into account not only the mechanical work spent on cutting, but also the electric discharge energy. Taking into account the energy of electrical impulses E_i and their frequency f_i, the unit costs for chip formation are determined from reducing (2) to an expanded form:

$$A_s = (P_z \cdot V_c + E_i \cdot f_i) / Q_m. \tag{4}$$

Comparison of the total specific energy costs shows that they are approximately comparable for conventional diamond and diamond spark grinding. The main reserve for increasing the efficiency of combined processes with the introduction of additional energy of electrical discharges into the cutting zone is the joint optimization of electrical and mechanical processing modes [16].

Table 1. Physical indicators of conventional (DG) and electrical discharge (DSG) external cylindrical grinding of VK6 hard alloy with a given productivity under conditions of using a tool of various grain sizes (*Z*), varying longitudinal (*S*) and transverse (*t*) feeds

S, m/min	*t*, mm/ double pass	*Z*, μm	P_y, N DSG/DG	P_z, N DSG/DG	K_G DSG/DG	A_s, J/mm^3 DSG/DG
0,5	0,02	125/100	78/118	28/40	0,36/0,34	42/60
		250/200	67/136	25/49	0,37/0,36	37,5/73,5
1,0	0,01	125/100	82/141	29/48	0,35/0,34	43,5/72
		250/200	69/142	23/47	0,33/0,33	34,5/70,5
1,0	0,02	125/100	152/225	54/72	0,36/0,32	81/108
		250/200	121/262	48/77	0,40/0,29	72/116

Table 2. Relative change in physical parameters of conventional (DG) and electro-erosive (DSG) external cylindrical diamond grinding of VK6 hard alloy with a twofold increase in the specified productivity

Z, μm	$t_2=t_1$ $S_2=2S_1$ DSG/DG	$t_2=2t_1$ $S_2=S_1$ DSG/DG	$t_2=t_1$ $S_2=2S_1$ DSG/DG	$t_2=2t_1$ $S_2=S_1$ DSG/DG
125/100	1,00/1,06	1,03/0,94	1,93/1,8	1,86/1,5
250/200	1,08/0,81	1,21/0,88	1,92/1,58	2,09/1,65

Conclusions

As it follows from the data presented, an increase in the values of the grinding ratio during diamond spark machining (especially under conditions of increased requirements for productivity) can be regarded as a characteristic of relatively more favorable operating conditions for the tool. At the same time, we can talk about a certain reserve for increasing the efficiency of the wheel work: it is possible to bring the grinding coefficient of the tool closer to the coefficient of abrasive cutting of sharp grains – through the use of more durable wear-resistant grains and creating conditions for reducing wear and increasing their sharpness. This statement is based on considerations about the upper limit of the grinding coefficient, based on the data on the micro-cutting forces of the hard alloy under working with ordinary diamond grains, when the coefficient K_C is 0.6 ... 0.7.

A decrease in the mechanical stress of mass micro-cutting in the zone of diamond spark grinding, which is ensured by the development of its working relief, supported by the action of electric discharges on the bond of the wheel, allows to consider approaches to organizing this process using the minimum lubrication methodology.

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