FRACTURE FEATURES OF METAL BINDING WHEN DIAMOND-SPARK GRINDING

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Abstract: *The hypothesis of the influence of binding energy of metal on the processes of destruction and mass transfer at high-speed machining is considered. Some nonconventional processes of cleaning of intergranularity spaces from waste products at diamond-spark grinding are explained, the approach to assessment of metal resistance in these processes is proposed and eo ipso modern conception of processes in chip formation zone under condition of electric discharge effect is supplemented.*

Keywords: high-speed diamond-spark grinding, binding energy of metal, explosive sublimation

1. INTRODUCTION

The most known implementation of abrasive machining accompanied by introduction of additional energy of electric discharges in cutting area is the process of diamond-spark grinding developed at the Kharkov Polytechnic Institute [1].

The processes of high-speed machining which enabled with variety of favourable practical features of new method of combined processing, first of all smaller level of force intensity became one of the leading tendencies in development of techniques and technologies of diamond-spark grinding. A typical example can be development of technique and technologies of internal diamond-spark grinding of hard-to-work materials. In particular, the Saratov machine-tool plant masters the manufacture of special internal grinding semiautomatic machine of model 3M227ВЭРФ2 for realization of the technologies of double high-speed grinding (with high speed of peripheral preparation per grinding wheel).

Investigation of processes dispersion of chip in the area of diamond-spark grinding has shown that such processes in the electric discharge channel are accompanied by its partial evaporation with the lowered resistance (high current density), especially at long thin sections of a cut (chips), characteristic to double high-speed grinding. So it is corroborated experimentally, including natural modeling, that chips at bridging interelectrode space in grinding zone, i.e. coming in sliding contact with conductive bond of wheel, can explode ("exploding wire"), and when the peripheral feed of work-piece per grinding wheel becomes higher and a chip becomes thinner and the interelectrode potential becomes higher, a probability of such events becomes higher.

Known assessment of erosive resistance of metals by L.S. Palatnik criterion [2] taking into account the aftereffect of electric discharge on a surface of stationary object of rather bulky mass when energy of electric discharge is redistributed between evaporation of metal from a surface of massive object and its heating, is not to the full suitable for real dynamic conditions in cutting area, including electric "exploding wire" (chip). However this criterion of a comparative assessment of "pliability" of metals to erosive destruction under the influence of energy of electric discharge is almost with no alternative recommended and used for corresponding assessment under condition of diamond-spark grinding [3].

2. PHYSICAL IDEAS AND PRESENT-DAY EXPERIENCE

From the classical physical positions it is possible to explode metal by means of two forces: electric or mechanical, influencing only on free electrons.

Experiences of G.Wertheim (1844-1848) to which in the researches of the mechanism of explosion of metals address M. Marakhtanov (Moscow State Technical University n.a. N.E. Bauman, Russia) and A.Marakhtanov (Berkeley University of California, the USA) [4] are indicative in this plan, and according to which already concerning a small electric current (some tens of amperes) essentially changes characteristics of metals, namely reduces their rupture strength, and the module of elasticity of metals considerably decreases. It, in particular, argues in favour of electric current in cutting area from the positions of facilitation of mass microcutting of surface to-be-machined by abrasive grains of wheel at diamond-spark grinding.

M. and A. Marakhtanovs have achieved the explosion of the thin metal films of tungsten and aluminum of the thickness up to 45 *nm*, i.e. in some atomic layers, and in so thin layer metal was well cooled by air and heated not up to 180 ^{o}C. It should be noted that to a certain extent these tests can be considered as an analog of real processes in thin chips, bridging an interelectrode gap at diamond-spark grinding with cooling. With increase in current density to very large values, of the order of 1 GA/m^2, the electron stream due to quantum processes in a crystal lattice turns to a wave packet, i.e. current strength in various places of conductor becomes various, and metal heats up irregularly by electrons grouped in a wave, with a difference in temperature on a wave crest and in node of wave by several times after that for some microseconds the explosion of hard metal follows, passing a liquid state (similarly to explosive evaporation of metal with formation of an erosive trace (a crater) in a point of the channel of electric discharge of enough high capacity). At current strength of the order of 100 *A* (corresponds to the characteristic of the commercial wide-range pulse-generators used for power-supply of electrical discharge processes in the area of diamond-spark grinding) the current density of the order of 1 GA/m^2, corresponding to described by M. and A. Marakhtanovs explosion of particles equilibrium in metal crystals of aluminum and tungsten, is observed at its advancing through a conductor of section of the order of 0,1 mm^2, and this value takes in the sizes of sections of a cut (chip), characteristic to conventional grinding processes (finishing), especially with thin cross-sections of cut. Hence we are challenged to optimize fully chip formation (control of mechanical modes of processing and characteristics of grinding wheels) and electrical discharge processes (control of electric modes of processing), focused on non-conventional processes of cleaning of intergranular spaces from processing products at diamond-spark grinding. Speed v of body movement before impact, atomic weight A of metal of which it consists, kinetic energy $W \approx 10^{-8}Av^2/2$ (in electronvolts) of its every atom, corresponding to speed of movement, energy ε of c oonnection of particles in metal and their relation $\alpha \approx W/\varepsilon$ are the signs which determine whether the metal will explode or not.

It follows from this that in order to the metal object explodes on impact with hard barrier, it is necessary to increase its speed and to choose for it metal with maximum atomic weight and minimum energy of connection. M.Ja.Fuks et. al. [3] state a fact that "energy of connection in a lattice decreases in the same sequence as for erosion resistance of metals (*W, Mo, Ni, Fe, Co, Cu, Ag, Al, Zn, Pb, Cd, Sn, Bi*)". Here it should be noted that for the listed metals energy of connection in a lattice as it follows from table 1, decreases nevertheless in a bit different sequence (*W, Mo, Co, Ni, Fe, Al, Cu, Sn, Ag, Bi, Pb, Zn, Cd*).

Table 1: *Atomic characteristics of some metals: mass (A) and energy of connection (ε). Ratio of energies: kinetic and connection ($\alpha_{(v=1)} = w_{k(v=1)}/\varepsilon$) at unit speed of motion (v=1m/s). Speeds of monometallic bodies, keeping some prescribed ratio of energy*

Metal	Parameter					
	$A^x 10^{27}$, kg	$\varepsilon^x 10^{21}$, J	$\alpha_{(v=1)}{}^x 10^6$	*v, m/s*		
				α = 0,1	α = 0,5	α = 1,0
Pb	344,1	324	0,531	434	970	1372
Bi	347,0	329	0,528	435	973	1377
Cd	186,6	185	0,504	445	996	1409
Zn	108,6	216	0,252	630	1409	1993
Sn	197,1	502	0,196	714	1596	2257
Ag	179,1	473	0,189	727	1625	2298
W	305,4	1527	0,1	1000	2236	3162
Cu	105,5	531	0,099	1003	2243	3171
Fe	92,7	565	0,082	1104	2469	3491
Mo	159,3	1094	0,073	1172	2621	3707
Ni	97,5	703	0,069	1201	2686	3798
Co	97,9	706	0,069	1201	2686	3799
Al	44,8	538	0,042	1550	3465	4901

Atomic properties of metals in table 1 are presented according to [5]. When there are no data on value of specific sublimation heat ΔH_{subl} (parameter ε in table 1), but there is an information on values of specific heat of fusion ΔH_{fus} and evaporation ΔH_{evap} then to determine ΔH_{subl} one can use the dependence $\Delta H_{subl} = \Delta H_{fus} + \Delta H_{evap}$ as enthalpy of sublimation is spent at sublimation, and enthalpy is invariable function [6].

It follows from table 1 that ability to explosion of the metals considered in it decreases in the following sequence: *Pb, Bi, Cd, Zn, Sn, Ag, W, Cu, Fe, Mo, Ni, Co, Al.*

3. PECULIARITIES OF HIGH SPEED MACHINING

In the processes of abrasive machining where potential readiness of metals to explode is worth to use in local microvolumes of intergranular spaces, increase in speed of product to-be-machined in the technologies of double high-speed grinding is one of the factors favourable for effective use of this readiness at introduction of additional energy of electric discharges. Another factor, also mechanical one, is increase in speed of processing surface (grinding wheel). Discharge processes in grinding area, in addition to electric effects, are accompanied with shock action too which speed is rather great. On various, but almost the same in the order of sizes, assessment given as an example by A.L.Livshits and Ju.S.Volkov [7], these speeds reach several hundred meters per second, up to 500-1000 *m/s*.

The specified values, in particular, are reached the observable speeds of scattering of particles from erosive pit on surface of the object subjected to pulse discharge influence. In processes of diamond-spark grinding, wheel bond is such basic object. On the other hand, it is possible to consider action of front of shock wave capturing microvolumes of bond in point of the channel of discharge with their subsequent explosive evaporation as direct effect of electric discharge action on bond of a fast-moving working surface of wheel.

4. DISCUSSION AND CONCLUSION

The approach under consideration explains well-established conception on comparative erosion resistance of metal bonds of various grades properly. So, for example, it is known that among two metal bonds, the most used at manufacturing of diamond grinding wheel, namely brand M1-01 (copper- aluminium-zinc) and M2-01 (copper-tin) [8], the latter is more erosion-resistant. From the considered positions it is possible to explain it by the fact that except copper its structure includes tin, and on readiness for explosive processes as it follows from table 1, this metal is worse a little than zinc (by 22 %), but considerably exceeds aluminum (by 4,7 times), which added to copper in other bond.

It follows from the presented in [4] analysis of conditions and results of impact contact for some metal bodies (Fe^{56}, W^{184}, U^{238}) that in conventional impacts (without additional wave pressure of electrophysical fields of additional energy effects) the selection of excess energy exceeding kinetic energy and evaporation of metals are observed since the order of values $\alpha \approx 0{,}1$. So if for rather light metal the selection of excess energy is already noticed from considered [4] (Fe^{56}) at $\alpha = 0{,}08$ in observable practice, then for nearest heavier (W^{184}) it is not in these tests marked at all even at $\alpha = 0{,}09$. By analogy in the same range $\alpha = 0{,}6 \div 0{,}7$ a meteorite (Fe^{56}) with preimpact rate $\upsilon \approx 3000$ *m/s* evaporates completely, and the armour-piercing shell (U^{238}) with preimpact velocity $\upsilon \approx 1700$ *m/s* evaporates only partly (20 %). Rates of contact mechanical processes at modern conventional cutting-grinding by tools made of superhard materials in practice of the development of industrial techniques do not usually exceed 150-200*m/s* [9, 10], and rare – 300 *m/s* [11]. Thus machining process with rates over 250 *m/s* is already related to high-speed one [11]. It is obvious from tab. 1 that modern limits of grinding rates in conventional processes for all metals are rather far from necessary for at least fractional immediate sublimation of removable allowance.

Scientific novelty in the elucidation of destruction processes of metals in working area of diamond-spark grinding and other types of the combined processing using high-speed processes of the influence on metal and electric currents in the processing area (for example, processes of electroerosive machining), is not only in the interpretation and development with regard to them the newest ideas about possibility of metal explosion by force of mechanical or electric effects especially as such explosion can be unachievable or inexpedient for technical and economic reasons at the available level of practical adoption of separate technical and technological innovations. At the state-of-the-art techniques and technologies, the combined decision of such problems when effects of mechanical and electric influences supplement and strengthen each other with achievement of qualitatively new integrated result, in particular with selective predestruction and the metal destruction, allowing to create working processes of the raised efficiency, stability and controllability is much more important.

The technique of diamond-spark grinding [1, 12-14] noted by the Cabinet of Ministers of Ukraine within the framework of the nation-wide action devoted to the 20 anniversary of the country independence "Barvysta Ukraina" as "the Best domestic commodity 2011" is an effective instance of the combined approach to such solutions.

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