

The relation between the inductive capacity of an oxide surface structure of hard alloys and their wear resistance

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Abstract. The purpose of this research is to determine the value of specific inductive capacity of oxide structures formed on the contact surfaces of carbide cutting tools. This paper also deals with the study of the effect of specific inductive capacity of polyoxide structures on the wear resistance of cutting tools exposed to intensive adhesive wear. It was established that the decrease of specific inductive capacity of the oxide film mass formed on the contact surfaces of a wedge leads to the increase of the wear resistance of cutting tools.

1. Introduction

The wear resistance magnitude of cutting tools and the variation of its parameters depend considerably on the properties of the oxide film structures formed on contact surfaces. Thin oxide films, formed on the contact surfaces of a wedge, affect such operating characteristics of cutting tools as their wear resistance, durability and reliability. They reduce the intensity of adhesive processes in contact areas by shielding of intermolecular interaction with a work material. It was found that the intensity of the intermolecular interaction between tooling and work materials depends mainly on the specific inductive capacity of oxide structures formed in contact areas. The wear resistance of cutting tools used in processing of materials which cause intensive adhesive wear tends to increase under the conditions when the specific inductive capacity magnitude of oxide structures decreases. Steel which belongs to austenitic, austenitic- martensite, austenitic- ferritic classes and chrome-nickel alloys are work materials causing accelerated adhesive wear of a wedge. These materials are processed with carbide cutting tools which usage class is K [1]. Simultaneously with the wear resistance increase and the decrease of specific inductive capacity magnitude of the oxide surface structure formed on contact surfaces of cutting tools there is a reduction of the variation coefficient for a particular performance characteristic.

2. Experimental technique

The study of wear resistance of carbide cutter plates belonging to the class K was performed on a screw-cutting. 12X18H10T steel which causes intensive adhesion wear was used as a work material. Carbide plates of the engineering grade BK8 belonging to the above mentioned class were used as a cutting tool. When testing it was necessary to fix the cutting speed at 70 m/min, the cutting depth to 1,5 mm and the cutting rate at 0,21 mm/r. The wear resistance of a cutting tool was measured in



minutes till the specified criterion at which the cutting tool lost its cutting properties. The back surface wear of a wedge equaling to 0,6 mm was assumed as the criterion of cutting properties loss.

After testing the carbide cutters were firstly cleaned in a special solution, then dried and finally oxidized in an electric furnace with atmospheric air free access to the heating area. The oxidation temperature of carbide cutters in a furnace was approximately equal to the temperature in contact areas of tooling and work materials, and was equal to 850°C. After that the cutting plates were taken from the furnace, the polyoxide structure formed in the process of oxidation was removed, crushed into powder and compounds with the same weight of 10-20 gr were prepared from this powder. These compounds were placed in a cell equipped with the electrode made of copper. The cell, serving as a condenser with a polyoxide mass, was placed in a special compressor between insulating plates. A dynamometer was used to record the pressure acting on the polyoxide mass. This pressure was equal to $0,02 \pm 0,005 \text{ kg/mm}^2$. The cell was connected to a measuring a.c. circuit to record the capacitance of a polyoxide mass. A special device E7-8 designed to meter the capacity, inductance and ohmic resistance at a.c. frequency of 1000 Hz was used to measure this capacitance.

The magnitude of specific inductive capacity of polyoxide samples was determined by the known equation [2] using the magnitude of capacitance obtained by its measuring:

$$\varepsilon = \frac{C \cdot H}{\varepsilon_0 \cdot S}, \quad (1)$$

where C is the capacitance of a polyoxide structure of investigated samples. The capacitance was measured in picofarads using the E7-8 device.

H is the layer thinness in millimeters of a polyoxide structure between copper electrodes.

ε_0 is the electric constant.

S is the electrodes area, mm^2 .

The thickness of a compressed mass in a cell was determined after metering its electric capacitance when removed from the device. A tool length indicator was used to measure the thickness of the compressed polyoxide mass. The accuracy of this measurement was 0,005 mm.

We constructed the dependence diagram of the wear resistance magnitude expressed in nonfailure operating time of a cutting tool till the specified dulling criterion on the magnitude of specific inductive capacity of a polyoxide with the “wear resistance-specific inductive capacity” structure. This dependence diagram was constructed based on the data obtained from the wear resistance determination of cutting tools belonging to K class by processing chromium-nickel steel of austenitic category causing intensive adhesive wear and on the data from electric capacitance obtained by measuring with subsequent calculation of the specific inductive capacity magnitude.

3. Results and discussion

Upon the research results it was found that there is a close correlation between the wear resistance of carbide cutting tools belonging to the class K and the magnitude of specific inductive capacity of oxide surface structures formed when heated. Figure 1 represents the dependence of wear resistance variation of cutting plates made from hard alloy BK8 belonging to hard alloys of the class K on the magnitude of specific inductive capacity of oxide mass formed on the surface when heated at high temperature in an electric furnace. Chromium-nickel austenitic steel of the class 12X18H10T is used as a work material. As it can be seen from the diagram with the decrease of specific conductivity magnitude of the oxide surface mass there is a stable tendency to the increase of cutting tools wear resistance.

Adhesive wear is the major destruction of carbide cutting tools belonging to class K occurring when they are used to process austenitic chromium-nickel austenitic steel [2]. The decrease of the specific inductive capacity magnitude of a structure located in an intercontact space leads to more

reliable shielding of intermolecular interaction between tooling and work materials. The durability of micro dot connections in the contact zone does not reach the cutoff value. The contact areas do not develop into the seat of destruction by the disconnection of a cutting wedge and work material.

Close relation between the wear resistance of hard-alloy cutting instruments and the specific inductive capacity of polyoxide structures obtained by oxidation of cutting tools in a muffle electric furnace points out the fact of formation and operation of ultra-thin polyoxide structures on the contact surfaces of a cutting wedge and confirms its great influence on all characteristics of the cutting operation. From the received data it is obvious that polyoxide structures formed in the contact areas are identical to physical and chemical properties of structures formed by oxidizing heating of hard-alloy samples in an electric muffle furnace.

It can be stated that if the conditions of thin oxide film formation in the contact areas approximate the conditions of polyoxide compound formation by heating hard-alloy plates in an electric furnace, the closeness of correlations between the wear resistance and specific inductive capacity will also increase. To create favorable conditions for polyoxide structure formation in an electric furnace identical to those arising by cutting, it is necessary to have profound knowledge of all the processes taking place in interfacial spaces.

Hydrogen, oxygen and other controlled and uncontrolled impurities being a part of the formed polyoxide structure affect considerably the magnitude of specific inductive capacity. The properties of polyoxide structures in the contact surface areas of cutting and work materials are formed both due to the oxidation and simultaneous reduction of formed oxides.

The oxidation process of contact surfaces of a cutting tool in the areas of their interaction with the work material takes place due to the oxygen entering the intercontact space from the surrounding gaseous atmosphere and the oxygen coming from the hard-alloy structure.

Both the oxides reduction process and the formation of lower oxides and other oxide structures formed in the oxide mass are carried out by hydrogen accumulated by a hard alloy with its further entering the intercontact spaces from composite volumetric structure caused by its diffusion. Oxygen penetrates into the inner structure of the hard alloy components at their preparation stage. These stages include tungsten, carbide and cobalt powder preparation from deoxidization (oxide reduction) and powder grinding. While the oxide restorative process is proceeding there is some residual oxygen concentration in the optimal form, the formed tungsten carbide as well as in the metallic cobalt. The content of oxygen in components of a future hard alloy structure can significantly increase as the result of further powder activation when grinding. The saturation of the component structure by atmospheric oxygen in all cases is caused by adsorptive processes [3].

The initial hydrogen accumulation in a hard alloy structure takes place at the preparation stage of its components when sintered in a hydrogenous medium. The introduction of hydrogen in the forming thin-film oxide structure of interfacial space causes significant changes of its properties including chemical, physical and mechanical.

Hydrogen affects both the formation of the surface and near-surface polyoxide structure of a hard alloy and processes developing in the interaction zones between the cutting medium and work material. Hydrogen absorbed by hard alloys components due to its high penetration power is also accumulated on the surface of samples and in their volume. The hydrogen molecules are firstly absorbed by more chemically active parts of the surface and near-surface areas where hard alloy is molded. Surface relief areas belong to carbide granules, cobalt layers and interphase boundaries. Diffusion makes hydrogen penetrate into the near-surface layers of a sintering compound. The area of interacting and closed pores and the surfaces at which boundaries a sharp change of structure properties can be observed (including density, porosity, acting inner stresses) belong to the components of surface and near-face structures of sintering molding where a considerable hydrogen molecules adsorption takes place. The highest concentration of pores and cracks is in the structure of cobalt granules and the interphase space. The cobalt layer has mainly high concentration of short branched cracks. The porous system in a carbide structure is formed at high-temperature processing of tungsten powder while its carbonaceous component is being saturated. The crack system of carbide

and cobalt particles is formed at the stage of their grinding in a ball mill. The process of hydrogen saturation when sintering is accompanied by the formation of new systems of pores and cracks and their annihilation [4].

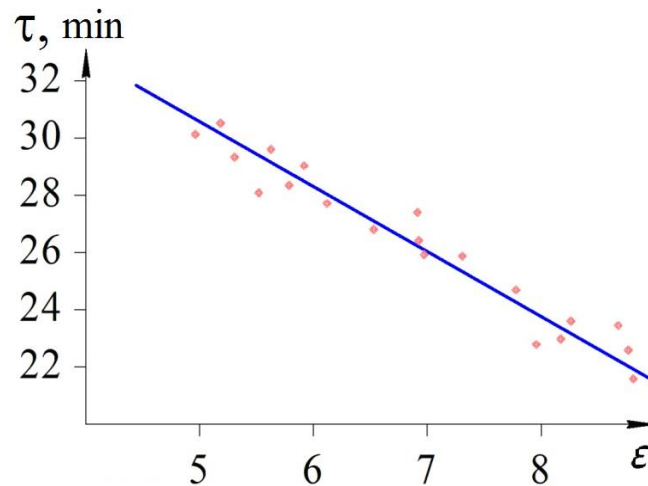


Figure 1. Wear resistance change of cutting plates produced from the hard alloy BK8 by cutting the steel 12X18H10T depending on the specific inductive capacity magnitude of a polyoxide structure formed on the contact surfaces of a cutting tool.

The real impact of the intercontact poly-oxide structure properties on the cutting operation, and hence, actual wear resistance parameters of cutting tools are determined by the hydrogen concentration penetrating into the polyoxide mass and the level of reaction activity between oxides and hydrogen which may result in the formation of dissipative compounds with different frictional characteristics. The impurities included in the hard-alloy structures which are exposed to oxidation also affect considerably the formation of properties in the intercontact polyoxide structures.

The shielding property of a thin-film mass against the intermolecular interaction of contact surfaces of tooling and work materials is caused by improving the dielectric characteristics of intercontact poly-oxide structures associated with the decrease of their specific inductive capacity. The wear resistance of hard-alloy cutting instruments of the class K tends to increase when used for material cutting causing intensive adhesive wear.

The lowest specific inductive capacities have polyoxide structures in the contact areas, if they consist of oxides with higher oxidation level of tungsten and cobalt. The compounds of the contact areas with a stoichiometric composition are formed under the most favorable and optimal conditions [5].

The probability of forming structures in intercontact spaces with the above specified properties will increase if the content of hydrogen and hydrogenous compounds in a polyoxide mass decreases.

The maximum wear resistance of hard-alloy cutting tools of class K used to process materials causing intensive adhesive wear will be achieved if the content of a polyoxide mass concentrated in an intercontact space is as specified above. This can be explained by high dielectric characteristics of a polyoxide structure which shields the intermolecular interaction of contact surfaces and functions as a solid lubricant. In this case dielectric losses and the magnitude of polyoxide specific inductive capacity will reach the lowest magnitude.

Specific inductive capacity of a polyoxide film formed in the intercontact areas is determined by its degree of polarization. The decrease of polyoxide mass polarization rate leads to the decrease of its inductive capacity and the improvement of its dielectric characteristics. On the contrary, the increase of the polarization rate of a polyoxide mass leads to the increase of its inductive capacity and deterioration of its dielectric characteristics. The latter results in the degradation of a polyoxide

structure which enhances the chances of intermolecular interaction of cutting and working surfaces. The polarization increase can lead to the increase of dielectric losses, electric conductance and the decrease of thermal capacity which in turn results in the reduction of wear resistance of carbide cutting tools used for processing materials causing intensive adhesive wear [6].

The hydrogen leaving hard-alloy structures penetrates into the contact areas and forms solid solutions and different complex compounds with oxides of film surface structures. Hence, the polarization increases and the degradation of dielectric characteristics of the intercontact dissipative poly-oxide mass is observed. This causes the degradation of shielding properties of a polyoxide mass against the intermolecular interaction of contact surfaces. There is also degradation of polyoxide structure properties as a solid lubricant caused by the reduction and redistribution of atomic bond strength between planes in a crystallographic oxide structure. The polarization process induced by electric and mechanical fields is an example of structural instability formation near the polyoxide composition. Instability takes place if the post oxidation and the renewal processes might develop similarly. The development of the post oxidation processes results in increase of the oxide stoichiometry, while the renewal processes lead to the decrease of oxidation level of a polyoxide structure. In this case we can observe the origination of some areas on the surface or in the whole polyoxide volume with a very high probability for intermolecular interaction of tooling and working materials.

Temperature, contact stress, the availability of reducing and oxidizing medium affect the polarization processes of a polyoxide mass in the contact areas [7]. The electron shells of polyoxide compositions of a polyoxide mass are mixed in the external force field. With the increase of displacement there is also the increase of polarization level. This kind of polarization can be classified as an electron polarization. The higher the polarization, the lower the resistance of the shielding property of a film polyoxide mass to the intermolecular interaction of contact surfaces is. There is a decrease of electron polarization level with the temperature rise till the temperature reaches its optimum or is higher than the cutting temperature. The volume increase of a polyoxide mass and the reduction of particle numbers per unit volume is caused by the density reduction of a substance.

If the poly-oxide mass exposed to cutting operation experiences spontaneous polarization caused by several external actions like elastic or plastic deformation, friction and sudden temperature rise, there is an instant reduction of shielding properties of dielectric medium and increase of intermolecular interaction force in certain local points of contact surfaces. Hence, there is intensification of a micro-welding process between contact surfaces with the further destructive disconnection of welding joints which results in gradual micro- or macro - surface destruction of a cutting tool. Gradual and continuous accumulation of defects and reduction of hard alloy service life are caused by cyclic increase of intermolecular interaction between contact surfaces.

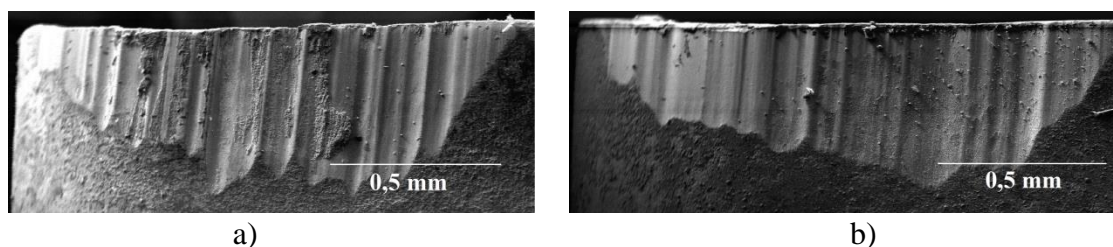


Figure 2. Worn out surfaces of cutting blade (cutter plate) made of BK8 a) with a specific inductive capacity of a polyoxide structure $\epsilon=10$, b) with a specific inductive capacity of a polyoxide structure $\epsilon=6$.

Hydrogen, which is a constituent part of polyoxide structure, creates some concentration of various electron defects in an oxide lattice at high temperatures developing by the use of cutting tools. Therefore, the electron shells are additionally exposed to the displacement under the action of external force fields. This kind of polarization can be described as electron - relaxational. This polarization is

likely to develop in polyoxides with serious structural defects caused by the This type of polarization developed in a polyoxide mass indicates the additional increase of its dielectric properties and eliminates the intermolecular interaction in the contact areas.

Besides the electron nature of the chemical bond between metallic elements and oxygen, the polyoxide mass of the intercontact space has ionic bonds. Hydrogen penetrating into the tungsten and cobalt structure facilitates the formation of an ionic bond. Therefore, we can observe another type of electric instability of an oxide mass which can be defined as the polarization of ions. It develops by a relative displacement of ions in a lattice. The displacement of electron shells of these compounds will differ due to the unequal composition of the oxide mass and different magnitude of the forbidden zone. As a result, the polyoxide film structure has a heterogeneous electric structure that distinguishes by the quantity of reduced and enhanced charges in a volume. This fact contributes to the increased probability of intermolecular interaction between contact surfaces.

The total hydrogen concentration in an intercontact oxide mass will decrease if high temperature is established in contact areas of tooling and working materials. It is possible since the concentration of desorbing hydrogenous compounds leaving contact zones exceeds the hydrogen concentration which enters the intercontact spaces of the bulk hard alloy structure. This fact leads to the decrease of compound concentration with an ionic bond of a polyoxide mass and hence, its polarization reduction. This can result in improving the dielectric properties of a polyoxide mass and reducing the specific inductive capacity. In this case the screening capacity of the intercontact structure to shield the intermolecular interaction between tooling and working materials will increase.

Polyoxide molecules form large complex compounds with polar radicals by their interaction with hydrogen. Ordering process of polar radicals in a force field represents a dipolar-relaxation polarization. Whereby there is a certain alignment of polar macro-molecules. The probability of molecular alignment is simplified with the temperature rise which leads to the increased intensification of the given dipolar-relaxation polarization and sharp rise in specific inductive capacity. However, alongside with the cutting temperature rise there is a destruction of complex oxide-hydrate compounds in an intercontact space. The latter causes the reduction of the growing polarization and hence, the decrease of specific inductive capacity of a polyoxide film structure.

The polyoxide mass, formed on the contact surfaces of a cutting tool, has a layered structure consisting of tungsten and cobalt oxides and can be exposed to the interlayer polarization. However, this type of possible polarization is not associated with the degradation of dielectric behavior of a polyoxide. This is due to the postoxidation and the volume growth of a polyoxide mass in contact areas caused by the temperature rise by heating and cutting. In this case, there is the stabilization of specific inductive capacity and even its decrease.

The polarization processes of a polyoxide mass in the contact areas can proceed due to its elastic and plastic deformation as well as due to the friction. The highest magnitude of polarization, so called electric structural instability of a polyoxide, can be achieved at one certain temperature or various temperatures.

Under the impact of elastic and plastic deformation, friction and high temperatures the formed and destructive polyoxide film structure can change its composition and aggregate state, and consequently it can change the level of intermolecular interaction between contact surfaces and work materials.

Volumetric layers of a hard alloy contain high concentration of free and dissolved oxygen [8]. Oxygen diffusion from inner layers of a volumetric carbide structure into the contact areas is able to stabilize the oxidation process of the interfacial polyoxide mass and improve its dielectric properties. Specific inductive capacity will decrease. Thus, shielding properties of the intercontact polyoxide structure from intermolecular interaction between contact areas will improve.

Other controlled and uncontrolled impurities found in hard alloys and exposed to diffusion at high temperatures during the use of cutting tools can increase or decrease the level of specific inductive capacity of an intercontact polyoxide mass.

As it has been established that oxides of phosphorous, sulphur, germanium, niobium, calcium, nickel, iron and other chemical elements as impurities enter into the composition of surface polyoxides. These impurities can considerably affect the magnitude of specific inductive capacity.

Figure 2 presents the images of cutting tools wear. From this figure it's obvious that the hard-alloyed cutting plates, whose poly-oxide structures have low specific conductivity and are less exposed to adhesive effect from the material being processed, are more resistive to wear.

At sufficiently high temperatures at which the cutting tools operate, the part of the poly-oxide mass located in interfacial surfaces is exposed to sublimation and converts from a solid to gaseous state. The gaseous state has lower dielectric characteristics compared to those of a solid poly-oxide mass. Gaseous poly-oxide distinguishes by high dielectric losses and high magnitude of inductive capacity. The gaseous oxide substance formed in the intercontact space leads to the increase of intermolecular interaction between the cutting tool and work material and hence, to the increase of adhesive wear and the reduction of wear resistance.

The transition of the polyoxide of an intercontact space to gaseous state when it is used for steel and alloy cutting is possible at high temperatures. The process is periodically repeated after poly-oxide mass formation and its sublimation.

The gaseous poly-oxide mass can take part in a convection heat exchange. Hydrogen contributes to the development of this process. The complex hydride compounds and hydroxyle groups will also participate in the solid lubrication and contact areas cooling. It should be noted that the effect of these processes on the reduction of wear rate at high temperatures is negligibly small.

The efficiency of sublimated poly-oxide gaseous environment is not high enough when it performs as a shield against intermolecular interaction.

The whole process of the poly-oxide mass formation, its sublimation, partial condensation and the execution of its lubricating and shielding functions against intermolecular interaction of contact surfaces are continuous. However, each next oxidation of carbide contact surfaces depending on the carbide structure state and external factors can be restored at some certain temperature range. With the decrease of this range the cutting stability of hard-alloys will increase.

Thermal pretreatment and some types of radiation exposure of hard alloys affect differently the oxidation processes and inductive capacity of the poly-oxide mass formed when exposed to heating. There is a wide range of magnitude variations and its values do not always correspond to the changes of wear resistance magnitude of carbide cutting tools. These pretreatment types affect not only the nature of the oxidation processes but also other composition properties. Simultaneously with the change of the oxidation processes behavior, the bonds on the interphase boundary of carbide granules and the cobalt layer as well as the chemical bond in carbide granules are exposed to destruction.

Thus, it can be concluded, that the decrease of inductive capacity of poly-oxide structures leads to the increase of wear resistance of cutting tools exposed to intensive adhesive wear.

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