Express Control of Abrasive Tool Operational Characteristics

V. M. Shumyacher, S. A. Kryukov and O. G. Kulik

Abstract The analysis of evaluation method of abrasive wear resistance and the correlation welding of their operational and physical and mechanical characteristics has been carried out. Studies of the relative wear resistance of abrasive tools samples in conjunction with the technological and operational characteristics have been performed. A method for determining the relative wear resistance of abrasive tools samples using the "Schlif" instrument of the Volzhsky Research Institute of Abrasives and Grinding Scientific-Technical Center is given. A linear relationship has been established between the wear of a sample of an abrasive tool on the "Schlif" instrument and its operating characteristics during grinding. A method is proposed for monitoring the wear resistance of a grinding tool on model samples that is sensitive to technological and operational factors, which makes it possible to use it for an express analysis of the quality of a tool at the stage of its development.

Keywords Wear resistance · Operational characteristics · Abrasive tool · Structure

1 Introduction

Evaluation of the quality and operational characteristics of an abrasive tool in the process of its design is carried out either under the working conditions of a specific consumer or at research centers of manufacturing companies. This contributes to the growth of unproductive costs in the factories producing abrasive tools and insufficient objectivity of control due to the impossibility of analyzing a large sample of test circles.

In the absence of objective methods and means for the operational control of the production technology of grinding wheels, it is difficult to guarantee the stability of

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its quality, the most important characteristic of which is the wear resistance of the tool that determines the durability and grinding coefficient.

When choosing a foreign-made abrasive tool, domestic consumers face a serious problem, the essence of which lies in the fact that the world's leading manufacturers usually specializes in a specific operation performed on given equipment.

As a result, the costs of abrasive tools are increased dramatically, while productivity and quality of processing are reduced. When fulfilling an order for the grinding wheels production, enterprises of the abrasive industry have a minimum of information on its operating conditions and are usually guided by recommendations for the manufacture of universal products.

Attempts to adjust their production based on the results of bench tests that are made by manufacturers of grinding wheels are largely unsuccessful, because the discrepancy in the abrasive indices in the laboratory and production conditions is quite significant.

The grinding wheel is a complex multi-parameter system that interacts with the processed workpiece and provides a specified amount of metal surface roughness and the required physical and mechanical properties: micro-hardness, wear resistance, and vibration resistance. In accordance with the existing concepts, the basis of the abrasive tool is the abrasive material and efficiency of processing depends on its interaction with the workpiece surface.

Information about the principles of selection of the structural and mechanical characteristics of the grinding wheel—hardness, structure number, and type of binder—has an indefinite general nature.

Depending on the requirements for the tool performance indexes, various structural and mechanical characteristics of the grinding wheel should be implemented. For profile grinding of parts for fuel, hydraulic, pneumatic equipment, grinding wheels with high hardness and density, with good edge resistance are necessary. Sharpening of the blade tool is performed by wheels with low hardness and density.

Creep feed grinding with high speeds is performed using a highly porous and durable tool with low hardness. Finishing processes are performed with tools with high elasticity, strength, and wear resistance.

In accordance with the existing concepts, the formation of the abrasive tool structure is made by the molding and heat treatment operations. When forming a grinding wheel blank, along with the shaping from the abrasive mixture, its components are distributed: binders and abrasive grains, i.e., fixing the structure.

Coagulation reversible contacts are formed between the particles of the dispersed phase, which under the influence of the firing temperature are transformed into condensation (irreversible). As a result, the instrument acquires the final structural and mechanical parameters: density, strength, and porosity.

Based on the analysis of the abrasive processing, it can be noted that the technological approach currently being implemented at the choice of rational characteristics of the grinding wheel is based on bench testing in a wide range of grinding conditions using samples produced on the basis of recommendations that do not take into account changes in machine tool building and abrasive industry.

In actual practice, during a specific grinding operation under set modes using the exhaustive method for tools with different characteristics, a grinding wheel is selected that provides the required productivity and qualities. It is obvious that this method is very expensive, and most importantly does not allow to respond to the requests of manufacturers of abrasive tools, who want to have information about the required characteristics of the grinding wheel, which must be made.

That means that the information obtained during the monitoring of the actual process should allow you to assign the required tool characteristics to ensure the performance and quality of grinding.

2 Relevance

The reduction of costs during the design of grinding wheels at manufacturers of abrasive tools, as well as at enterprises-consumers with an objective control of its effectiveness requires the creation of a method of express quality control of the tool.

3 Formulation of the Problem

Within the framework of existing ideas, the wear of the grinding wheel is realized in the form of torn abrasive grains from the ligament, local and bulk destruction, and mechanical wear by abrasion (surface damage of the grain) [1–8]. The wear resistance of the grinding wheel depends on many factors: pressure on the actual contact area, friction coefficient, the environment, and physical, mechanical, and chemical properties of the tool and the workpiece.

The abrasive materials' wear resistance is determined by the micro-cutting method with a single grain under conditions close to its actual work in the grinding wheel: cutting speed and cutting depth, processed material. In order to implement this method, the abrasive grain is embedded in the holder, which is attached in the periphery of a metal disk that simulates a grinding wheel of a given diameter and is mounted on the faceplate of a circular grinding machine. Index lines are applied on a cylindrical sample at a given depth of cut with an abrasive grain. The process of micro-cutting is carried out until the complete cessation of micro-cutting. The path traveled by the abrasive wheel to complete wear is a criterion of its wear resistance.

In the works [9, 10], it was shown that abrasive grains' wear resistance during micro-cutting is consistent with the operational characteristics of grinding wheels.

The described method for assessing abrasive grain wear resistance correlates with the finishing grinding process, because the conditions of interaction between "abrasive–metal" pair are identical.

In conditions of grinding with a large cross-feed tool, specified method is ineffective. A known method for assessing the operational properties of an abrasive grain for given conditions is based on the limiting thickness of a metal cut, at which its destruction occurs [11].

For all the results obtained, the abovementioned methods do not allow to reliably determine the relative wear resistance of an abrasive, which characterizes its resistance to mechanical abrasion without the influence of high temperatures, pressures, and physicochemical processes in the abrasive–metal contact. In the work [10], the possibility of determining the grinding materials wear resistance by abrading the counterface on the lapping tool with a suspension of abrasive powder of a certain grain was shown.

The most important characteristic of the grinding tool, which determines its quality, is durability. According to current standards, the quality indicators of grinding materials are impact resistance of grinding grain, abrasive (cutting) ability, strength of single grains, as well as their micro-hardness, micro-fragility, and micro-strength. In the work [12], it was shown that of all the known mechanical properties of grinding materials—micro-brittleness, micro-hardness, and micro-strength—the latter is most closely associated with the wear of the grinding wheel. As the analysis of the results of works [13–22] in the group of corundum and carbides shows, there is a relationship between the micro-mechanical properties of abrasives and their operational properties. The higher the micro-strength of the abrasive grain is, the higher its wear resistance during micro-cutting is and the greater the specific productivity of the tool from this abrasive is.

However, it should be noted that the above data are related to the wear resistance of abrasive grains in the tool and not to the durability of the tool itself. In response to this problem and also for operational quality control of an abrasive tool at the stages of its design, as well as production, the development of an appropriate methodology and means for its practical implementation is required.

4 Theoretical Part

As a result of the analysis of the methods for express evaluation of abrasives wear resistance and correlation values with operational indicators, the possibility of practical application of the method of relative wear resistance implemented using the "Schlif-2" unit designed by Volzhsky Research Institute of Abrasives and Grinding has been established. According to the existing method, $22 \times 22 \times 5$ mm samples from a grinding wheel were cut out from the cutting part of the grinding wheel with a diamond disk. A suspension ($10 \div 15$ drops) consisting of a mixture of water and glycerin and boron carbide in a ratio of 1:1 with an average particle size of ~ 160 μm was applied on the counterface from the modified cast iron. The choice of boron carbide powder was due to the need to fulfill the requirement that the hardness of the abrading body should be 1.5–2 times higher than the hardness of the abradable. Micro-hardness of boron carbide is 39 GPa, and of corundum is 22 GPa.

Since abrasive tool wear during grinding is implemented by abrading abrasive grains (finish grinding), and by tearing them out of the binder or chipping (rough grinding), it is not known a priori that the ratio of these processes is due to both factors. The cutting edges of boron carbide particles with a grain size of 160 μm are much larger, both local micro-volumes of the instrument grains, and smaller in most cases, the sizes of its grains, since for a significant number of grinding wheels, an abrasive grain (electrocorundum, silicon carbide) with an average size of more than 160 microns is used. The weight of the boron carbide particles established after numerous experiments is $0.04 \div 0.012$. The contact pressure is 0.01; the test time is 300 s [10, 21].

The wear of the samples was determined by the amount of the change in the height of the $22 \times 22 \times 5$ mm bar before and after the experiment, measured using a microcator with an accuracy of ± 0.5 μm. According to the data [10], there is a linear relationship between the sample wear and grinding wheel wear with a correlation coefficient of 0.86–0.92, which allows us to recommend this method for express evaluation of the tool quality of a made of abrasive materials for grinding operations.

In the course of experimental studies, it was found that with a decrease in the samples' hardness, the wear increases and practically does not depend on the grain of the abrasive. To clarify the reasons for this fact, studies have been conducted. The "Schlif-2" unit was upgraded by connecting the electric motor drive to the wattmeter, which allowed us to fix the energy consumption during wear of each sample during 300 s. Due to the fact that the strength of abrasive grains and abrasive powder sample (boron carbide) is greater than Al_2O_3 (corundum) and SiC (silicon carbide), and even more so of the binder, the most likely scenario for the process development should be considered as tearing out Al_2O_3 or SiC grains. The abrasive grain retention force in a binder depends on a number of factors: volume fraction in the grain circle, binder and pore, grain size, tensile and compressive strength of the binder material, the amount of binder bridges per abrasive particle, and its protrusion magnitude above the binder.

According to the test results, the volume of the worn part of the sample and the amount of energy consumed during 300 s were recorded (E). By dividing the energy E by the volume of the worn layer of the sample, the value of the specific energy of destruction was determined. It has been established that with an increase in the volume of the binder, the specific energy of destruction of the sample increases (Fig. 1).

As follows from Fig. 1, with an increase in the amount of binder from 20 to 35%, the specific fracture energy of the composite increases in ~ 3 times. Analysis of the grain size of the sample wear products indicates a decrease in the grain content of the main fraction (250 μm) and an increase in the fine fraction. These data indicate a transition from wear of the sample due to the tearing of the abrasive grains to micro-cleaving.

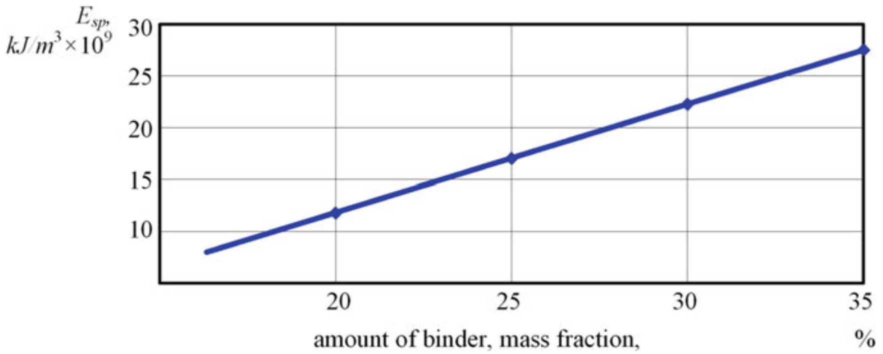

Fig. 1 Dependence of the specific crushing energy of abrasive sample on the quantity of binder (grain material Al_2O_3, main fraction size 250 microns)

Comparison of the specific wear energy of the samples of grinding wheels obtained by express analysis and the actual grinding process indicates a linear relationship between them with a correlation coefficient of ~ 0.84.

5 Conclusions

On the basis of the conducted research, a method of express control of the most important characteristics of the grinding wheel wear resistance has been developed. It has been established that there is a direct linear relationship between the wear of the grinding wheel in the actual process and the sample wear determined by the express method. The determination of the energy indicators of the process of wear by the express method can be useful in designing new tools for the given conditions of their operation, in particular, if it is necessary to reduce energy costs.

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