Quality assurance in the process of machining of parts made of heat-resistant alloys with the help of abrasive electrochemical grinding

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Abstract. For the purpose of efficient treatment of heat-resistant alloys, an abrasive electrochemical part grinding method is proposed using an advanced abrasive wheel cleaning method by means of abrasive wheel contamination assessment. The process was researched and it was revealed that a parameter which is a ratio of cutting force against the ECT (electrochemical treatment) phase duration within one round of spindle revolution is versatile, which means it does not dependent on the EDM electrode cutting feed rate, the depth of treatment, and is an independent value.

1. Introduction
Application of advanced materials in the production process calls for revolutionary approaches to their treatment. Heat-resistant alloys are characterized by low thermal conductivity, which leads to a significant increase in the thermomechanical impact in the treatment area during edge cutting machining. It may result in micro cracks, burns and burrs, which act as stress concentrators reducing the fatigue strength of parts [1]. For this reason, treatment using conventional blade tools is done at low speeds with low productivity, which is unacceptable for mass production.

A study of existing treatment methods for solving the given problem has shown that the use of a combination of treatment methods with additional exposure to electric current, certain chemical substances and ultrasound has the highest potential. One such method is an abrasive electrochemical grinding (AECG) which is a combination of electrical and mechanical impact. This process is characterized by the removal of material with the help of two simultaneous processes: anodic dissolution, mechanical cutting by diamond grains and electroerosion action [2-4, 7, 8].

In the process of heat-resistant alloy treatment, an active adhesion of the workpiece material to the abrasive wheel occurs [9]. As a result, the thermomechanical effect in the cutting zone increases. The process is accompanied by burns, micro cracks and burrs. The reduction of the cutting depth and the increase in the number of passes leads to a decrease in the process performance. The use of high-quality cutting tools, efficient cooling and state-of-the-art equipment may not always guarantee the
required quality of the surface layer of the treated parts and the process performance. To increase the process performance, to improve the surface layer quality and to increase the fatigue strength of the treated parts, a timely cleaning of the cutting tool from the sticking material of the workpiece is required.

Currently, the following methods of cleaning and dressing of abrasive wheels are available [10]:

1. Electrochemical method. Electrochemical cleaning and dressing of the diamond edged wheel is normally done directly on the machine, while changing the polarity of the current, so that the tool becomes the anode and the metal bar becomes the cathode. The electrolyte is fed into the electrode gap.

2. The electroerosion method is effective for the dressing of profile tools. In this case, the wheel is the anode, and the cathode is also made in the form of a wheel or a rod (can be rotating type). The electrolyte is fed into the electrode gap.

3. Dressing with an abrasive stone made of green silicon carbide with C1-C4 hardness. The grain size and grain concentration is designed based on the diamond tool grain size. The treatment is carried out continuously with the supply of a large amount of coolant. However, it should be noted that wheel cleaning and dressing with an abrasive stone is characterized by a very high consumption of the stone and takes a lot of time.

4. Dressing with a loose abrasive. An abrasive tool can be cleaned and dressed by supplying an operating fluid containing abrasive powder.

5. Abrasive wheel rolling-off. Removal of chips, diamond grains and binder metal from the surface of the wheel is carried out with a round-shaped tool which is rotated by the diamond wheel. The given method is used very rarely because of low performance.

6. Dressing by means of grinding. It is done with the help of a dressing tool rotated by a separate drive rather than a diamond wheel which is used for the abrasive wheel rolling-off. The process is characterized by a low rotation speed of the dressing wheel. And the dressed wheel rotates at a normal operating speed. The disadvantage of the given method is that the dressing tool uses an additional rotation drive.

At each abrasive wheel dressing cycle, a thick abrasive layer is removed together with a binder metal which dramatically reduces the abrasive wheel life. In this regard, it is proposed to clean the cutting tool only upon accumulation of a large amount of waste.

To improve the treatment performance of parts made of heat-resistant alloys, a method of regular cleaning of the cutting tool was developed using additional inverted pulse power source, an additional cleaning EDM electrode and an additional nozzle (figure 1).

![Figure 1. Installation diagram of the cleaning EDM electrode on the machine.](image)

The research objective is to study the abrasive wheel cleaning efficiency by introducing an additional cleaning electrode with simultaneous control of the treatment process parameters.
2. Research materials and methods

During the study, samples made of VKNA-1V-VI intermetallic alloy (For the chemical composition, see table 1.) were used as the objects of treatment [5,6]. For the treatment, Napomar RP 0200 M1 flat grinding machine was used. It was upgraded to allow for AECG. The machine was equipped with Pulsar SMART 1000/12 process current source with a wide range of process capabilities.

An aqueous solution containing NaNO₃ (6%), NaNO₂ (0.5%), Na₂CO₃ (0.5%) and glycerin (2%) was used as the treatment electrolyte. The electrolyte density was equal to p=1.07–1.04 g/cm³. It was controlled by a hydrometer. As a tool for the electrochemical diamond grinding, an abrasive wheel based on a binder metal was used, AS20 160/125 100 M2-02 575 type.

The electrical parameters were recorded with the help of RIGOL-DS 1104 Z digital oscilloscope. The waste accumulation on the abrasive wheel was controlled without removing the wheel with the help of Mikmed-5.0 portable digital microscope.

| Table 1. Chemical composition of VKNA-1V intermetallic alloy. |
|------------------------------------------|
| Alloy | Chemical composition of the alloy, % wt. |
|      | Ni  | Al  | Ti  | Cr  | W   | Mo  | Hf  | C   |
| VKNA-1V Main | 8...9 | 1...3 | 5...6 | 2...4 | 2.5...4.5 | 0.35 | 0.04 |

Samples with a length of 60 mm, width of 5 mm, height of 20 mm were used for the treatment.

To assess waste accumulation on the abrasive wheel, an indirect parameter is proposed which is a ratio of the cutting force to the electrochemical processing phase (ECT) duration per a revolution of the spindle. It is then compared with a given value, where the ECT phase is the ratio of the short circuit duration to the spindle rotation period.

The AECG process flowchart with a simultaneous and regular cleaning of the abrasive wheel is given in figure 2 and figure 3. As the cutting tool becomes contaminated, control system 16 receives a signal about an increase in the thermomechanical effect in the area of treatment and reduction of the ECT phase, i.e. an increase in the indirect cleaning parameter.

![Figure 2](image-url)
The signal control algorithm during the cleaning process is shown in figure 4.

![Control Algorithm Diagram]

**Figure 3.** A control algorithm of the cutting tool cleaning system.

After that, the control system 16 activates the cleaning system consisting of an additional power supply 19 and a cleaning EDM electrode 18. Once the abrasive wheel is cleaned, the indirect parameter of the wheel contamination assessment is reduced, the control system turns off the cleaning system. The process is repeated as the tool is contaminated.

3. **Results and discussions**

The workpiece surface layer quality and the groove accuracy during the AECG is a product of many factors, such as material grade, operating feed speed, treatment depth, etc., the influence of which has also been researched in the given study. During the AECG, without regular wheel cleaning at low cutting feed rates (20 mm/min), the surface layer quality (figure 4a) meets the fatigue strength specification, as the modified layer is removed by means of material electrochemical dissolution of the workpiece. Meanwhile, the thermomechanical impact of abrasive grains and wheel wear is reduced (figure 5a). However, electrochemical dissolution leads to deterioration of treatment precision. The groove size (width) was 1.33 mm (figure 6a), with a permissible size of 1.25 mm.

With an increase in the cutting feed rate, the treatment precision increases. Here, the groove size (width) is 1.24 mm (figure 6b). However, the workpiece material is late to leave the cutting tool surface. Besides, short circuits occur. The electroerosion component increases (figure 5b), which leads to deterioration of the workpiece surface layer quality. A modified layer of 30-35 microns is formed (figure 4b).

![Sample Structural Study Results](image_url)

**Figure 4.** The sample structural study results upon AECG completion: a) at the cutting feed rate of 20 mm/min, 100x magnification: b) at the rate of 80 mm/min, 100x magnification.
Thus, treatment without regular wheel cleaning did not allow to simultaneously obtain the required surface layer quality and groove accuracy.

To guarantee the optimal value of the thermomechanical impact depending on the cutting tool contamination, treatment with a regular wheel cleaning was carried out.

The dependence of the cutting force on the groove length (electrochemical treatment (ECT) phase duration) and the grinding depth was studied (figure 7). At the stage of cut-in into the workpiece, the cutting force increases. As the abrasive wheel moves out of the workpiece, the cutting force decreases. Studies have shown that as the grinding depth increases (figure 8), the abrasive wheel becomes greasy faster and the time needed for the wheel to clean up by means of electrochemical component is not enough. It results in an additional increase in the cutting force.

In case of continuous grinding at one depth (5 mm), the abrasive wheel becomes greasy with each pass which also leads to an increase in thermomechanical impact on the treated material figure 8.

Studies have shown that as the wheel becomes contaminated, the intensity of the electrochemical impact decreases. At high speeds and depths it ceases, while the contribution of the thermomechanical impact increases. This leads to burns. figure 9 shows the results of studies of the cutting tool contamination.
Figure 7. The dependence of the cutting force on the groove length at various grinding depths (hn).

Figure 8. Dependence of the cutting force on the treatment duration, pass 1, 2, 3; consecutive passes.

Figure 9. Photos of the abrasive wheel surface: a) new wheel; b) contaminated wheel; c) after cleaning using electroerosion method; d) after cleaning using the proposed method.

Figure 10 shows the metallographic study results of the sample surface upon completion of AECG using the proposed cleaning method. Treatment was done at the operating voltage of \( U = 8 \text{V} \) and the current of \( I = 150 \text{A} \). The cutting feed rate was equal to 80 mm/min. The grinding depth - 5 mm. An
additional cleaning electrode was supplied with a voltage of 15V and an average current of 10A. The electrode gap was equal to 0.05 mm. A concurrent cleaning of the diamond wheel was used. The cleaning duration was equal to 2.5 minutes. Treatment roughness was equal to Ra 0.32. There was no modified layer on the surface layer of the sample.

![Figure 10. The sample structural study results upon AECG completion with the cleaning rate of 80 mm/min, 100x magnification.](image)

Studies have shown that if the proposed regular cleaning method of the abrasive wheel is used, the surface layer quality and the accuracy of the treatment parameters meet the requirements. The groove size (width) is 1.25 mm.

The studies have shown that in order to maintain the cutting properties of the grinding wheel and to reduce its wear, cleaning in the process of treatment must be done by feeding a reverse polarity pulse through the auxiliary electrode during the period of time when the value of the grinding wheel contamination assessment parameter is higher than the set value.

4. Conclusion
A number of studies were made on the surface layer quality of the samples made of VKNA-1V VI heat-resistant intermetallic alloy with varied cutting feed rate. The studies have shown the increase in the cutting rate leads to a degraded quality of the surface layer. A defective layer of 30-35 microns is formed, which is unacceptable.

Also, a study was made to determine the degree of contamination of the abrasive wheel depending on the cutting feed rate. The studies have shown, that if the cutting feed rate increases, there is not enough time for the abrasive wheel to get rid of contamination by means of electrochemical dissolution. The rate of the electroerosion component increases, which reduces the quality of the surface layer of the workpiece.

Besides, a number of studies were made to determine the dependency of the accuracy ratio on the cutting feed rate. The studies have shown, that if the cutting feed rate is equal to 80 mm/min, the groove width in terms of depth meets the specification, but at the same time a modified layer is formed, which is unacceptable. At low cutting feed rates of 20 mm/min, due to active electrochemical dissolution, the groove gets broken up by depth.

The studies have shown that in order to maintain the cutting properties of the grinding wheel and to reduce its wear, cleaning in the process of treatment must be done by feeding a reverse polarity pulse through the auxiliary electrode during the period of time when the value of the grinding wheel contamination assessment parameter is higher than the set value.

AECG method was developed which guarantees a set value of the thermomechanical action. Besides, the given method allows to effectively clean the surface of the tool.

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