

Role of laser radiation in activating anodic dissolution under electrochemical machining of metals and alloys

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Abstract. The specific features of electrochemical dissolution of the 12X18H9T stainless steel, the OT-4 titanium alloy and the BK8 hard alloy in the sodium nitrate water solution exposed to 1.06 micrometer wavelength laser radiation were considered. It is found that depassivation of the anode surface is the main mechanism of laser activation in electrochemical dissolving of materials. It is established that the maximum efficiency of laser electrochemical machining is achieved at a pulse repetition frequency of 10 kHz laser radiation. It is connected with the photoactivation mechanism of electrolyte solution molecules, which increases their reaction capacity.

1 Introduction

Improving modern electrophysical technologies aims at increasing their efficiency in machining different metals and alloys. Introducing laser radiation in the machining zone is one of the perspective ways of intensifying the processes of anodic dissolving of current conducting materials. Different mechanisms of machining activation including those connected with laser radiation influence on the electrolyte are considered in investigations [1, 2]. Understanding the complex character of laser effect on the machining procedure providing different activation mechanisms, we tried to find the main mechanism and assess the influence of the laser radiation frequency on the process of anodic dissolving of the investigated materials.

2 Experimental Data

The 12X18H9T stainless steel, the OT-4 titanium alloy and the BK8 hard alloy were used as machined materials. The 10% sodium nitrate water solution electrolyte was chosen during the preliminary experiments [3]. Investigations on studying the anodic behavior of materials in laser radiation were conducted on the experimental installation, the design of which is described in [4]. It should be noted that this installation is unique and allows us to use laser radiation in a wide range of the wavelength (1.32; 1.06; 0.63; 0.53; 0.32 and 0.26 micrometers) by changing the pulse repetition frequency in the range from 1 Hz to 30 kHz.

The influence of laser radiation with a wavelength of 1.06 micrometer and the average power density of $1.05 \cdot 10^6$ W/m² chosen according to the results of mathematical modelling presented in [5] was studied during the investigation. The condition that the used

value of the average power density does not result in boiling the electrolyte was observed. The peculiarities of the electrochemical cell construction providing the introduction of laser radiation in the machining zone are presented in [6].

The perspective of using laser radiation for intensifying the electrochemical machining of investigated materials is shown in [7-9].

The investigation of the material anodic behavior was conducted using the potentiodynamic and potentiostatic methods by the IP-Pro M potentiostat-galvanostat.

3 Results of the Research and Discussion

Each material used in the investigation has limitations under electrochemical dissolving in the chosen electrolyte. It is confirmed by the data of potentiodynamic investigations characterizing the anodic behavior of the materials under electrochemical machining (ECM) in 10% sodium nitrate water solution (Fig. 1).

Small values of the current density determining the low speed of the anodic dissolving of the investigated materials can be explained by insufficient anion activity of the electrolyte used and the formation of passivating films of different chemical composition on the anode surface. In introducing the laser radiation in the electrochemical system it is possible to realize the following mechanisms of the activation process of anodic dissolving:

- Heat activation,
- Effect of light-hydraulic effect,
- Influence on passivating films,
- Photoactivation of electrochemical and chemical processes.

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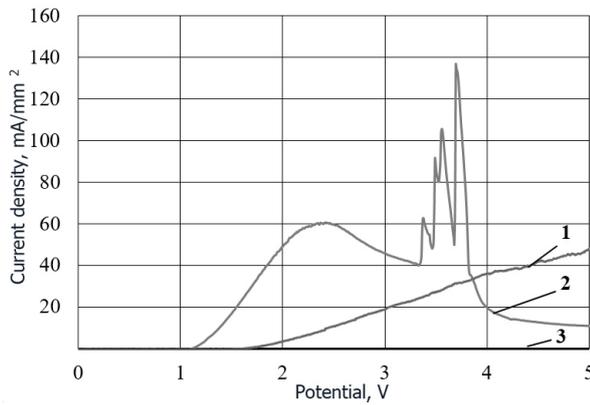


Fig. 1. Potentiodynamic curves during ECM in 10% NaNO₃ water solution: 1 – 12X18H9T stainless steel; 2 – BK8 hard alloy; 3 – OT-4 titanium alloy.

The results of the laser electrochemical machining (LECM) of the investigated materials are presented as polarization curves in Fig. 2-4.

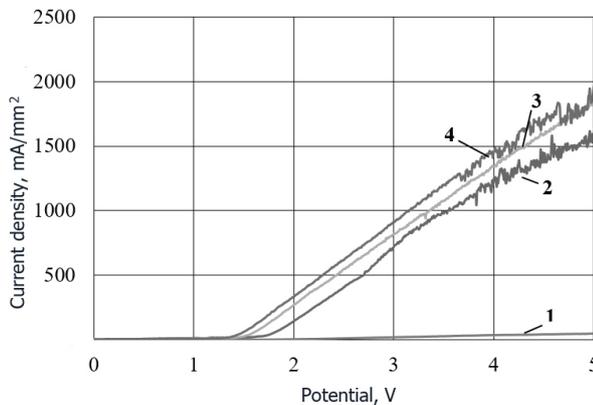


Fig. 2. Potentiodynamic curves for 12X18H9T stainless steel: 1 – during ECM; 2, 3, 4 – during LECM at pulse repetition frequencies: 2-2.5 kHz; 3-5 kHz; 4-10 kHz.

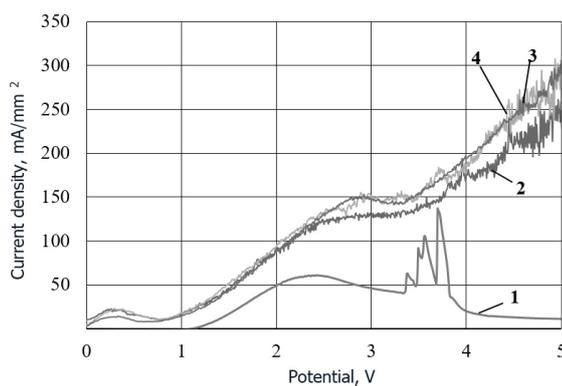


Fig. 3. Potentiodynamic curves for BK-8 hard alloy: 1 – during ECM; 2, 3, 4 – during LECM at pulse repetition frequencies: 2-2.5 kHz; 3-5 kHz; 4-10 kHz.

The analysis of the obtained results shows that introducing laser influence in the zone of electrochemical machining results in a significant activation of the anodic dissolving process, increasing the values of the current density by tens of times. It is more likely that all the mechanisms of activation mentioned above are involved to a different extent in

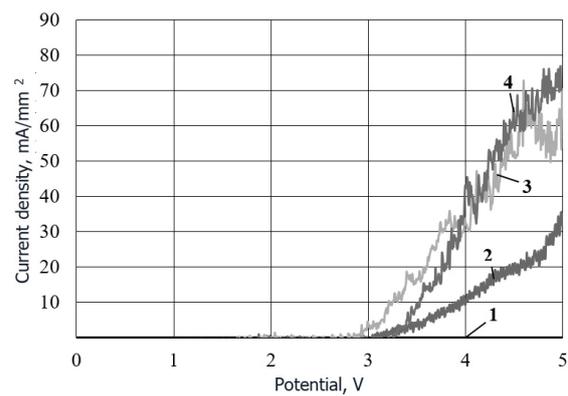


Fig. 4. Potentiodynamic curves for OT-4 titanium alloy: 1 – during ECM; 2, 3, 4 – during LECM at pulse repetition frequencies: 2-2.5 kHz; 3-5 kHz; 4-10 kHz.

laser intensification of anodic dissolving. It is known that the main limitation in processes of electrochemical dissolving of metals and alloys is considered to be the appearance of passivating phenomena. Elimination of these limitations during LECM is confirmed by the data of polarization investigations using the potentiostatic method. The fall in the current density during the entire process (Fig. 5–7) does not happen for all the investigated materials during LECM, which shows the absence of passivating limitations in machining.

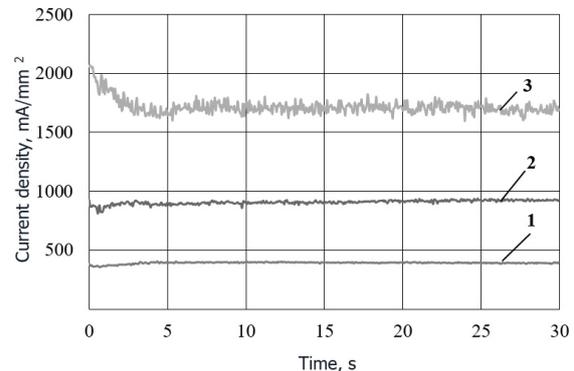


Fig. 5. Potentiostatic curves for 12X18H9T stainless steel during LECM with 10 kHz pulse repetition frequencies at potentials: 1-2 V; 2-3 V; 3-5 V.

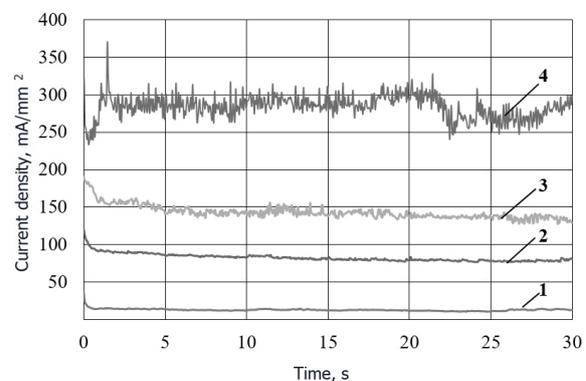


Fig. 6. Potentiostatic curves for BK8 hard alloy during LECM with 10 kHz pulse repetition frequencies at potentials: 1-1B; 2-2 V; 3-3V; 4-5 V.

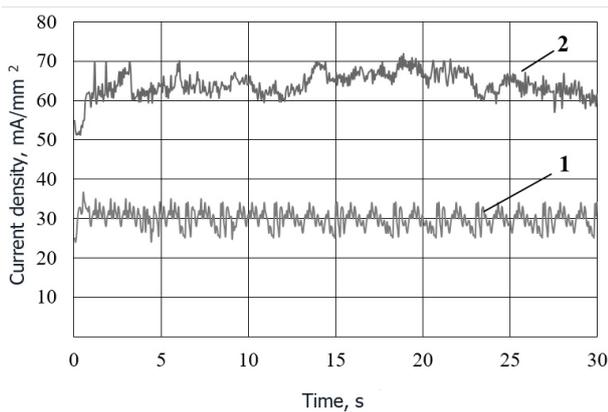


Fig. 7. Potentiostatic curves for OT-4 titanium alloy during LECM with 10 kHz pulse repetition frequencies at potentials: 1–4 V; 2–5 V.

Otherwise, the decrease in the current density during machining would be observed in forming different types of passivating films on the anode surface.

The analysis of the polarized investigation results presented in Fig. 2–4 shows that maximum efficiency in activation of anodic dissolving is achieved at a pulse repetition frequency of 10 kHz. The further frequency increase results in reducing the current density in the whole range of potentials and for all the investigated materials. The importance of pulse repetition frequency of laser radiation in intensifying the electrochemical machining procedure can be obtained by analyzing possible activation mechanisms. It is known that heat activation increases with the increase in temperature but heat effect decreases with increasing the laser radiation frequency under other equal conditions. Therefore, the intensification of the heat mechanism by increasing the frequency characteristic of radiation is impossible.

Intensification of anodic dissolving under laser influence on the ECM process takes place due to the action of light-hydraulic effect that eliminates passivation limitations. The appearance of acoustic shock waves in conducting laser radiation through liquid results in the deformation effect on the objects in the machining zone. The action of light-hydraulic effect under LECM results in destroying the films of different type on the anode surface. The increase in the pulse repetition frequency does not lead to strengthening the mentioned mechanism because the strength of the light-hydraulic effect increases in reducing the frequency characteristic if the average power density is constant. It is also unlikely that the increase in the pulse repetition frequency of laser radiation will provide the increase in the speed of anodic dissolving under the influence of radiation directly on passivating films. The maximum effect from the action of the mentioned activation mechanism in machining different materials would be observed at different frequencies, optimal for dissolving oxide films of a certain chemical composition.

Acceleration of electrochemical and chemical processes is also possible due to selective ionization of electrolyte solution molecules by stepwise photoactivation. It results in excitation of solution atoms and molecules, reducing the height of the energy barrier

of the chemical reaction with their participation [10]. As a result, the reaction capacity of the solution anions as well as the velocity of anodic dissolving increases. Ionization selectivity is provided by choosing the frequency characteristic of laser radiation. In spite of the fact that materials of different types are used in investigations, the greatest value of the current density is observed at one value of pulse repetition frequency of laser radiation. This fact proves that the maximum photoactivation of 10% NaNO₃ water solution molecules is achieved at a frequency of 10 kHz.

4 Conclusions

1. The results of the investigations show the efficiency of laser intensification of ECM for 12X18H9T stainless steel, BK8 hard alloy and OT-4 titanium alloy. The data of polarization investigations of the material anodic behavior prove the increase in the current density by tens of times in introducing laser radiation in the ECM process. The main factor in using all the mechanisms of the anodic dissolving activation process under LECM is the depassivation of the machined material surface in the zone of laser action.

2. Change in laser radiation frequency characteristic influences the efficiency of ECM intensification. It is shown that the maximum value of the current density for a group of machined materials in sodium nitrate electrolyte is achieved at a pulse repetition frequency of 10 kHz.

Thus, selecting the frequency of laser radiation, we can obtain maximum photoactivation of electrolyte solution molecules, which provides the increase in their reaction capacity.

References

1. N. P. Gaar, Kh. M. Rakhimyanov, *Puti intensifikacii jelectrohimicheskoy razmernoj obrabotki (Ways for intensification of electrochemical dimensional machining)*, Polzunov's almanac, Barnaul, I.I. Polzunov Altai State Technical University **4**, 191-192 (2008) (in Russian).
2. N. P. Gaar, Kh.M. Rakhimyanov, *Possible ways for intensification of dimensional electrochemical machining (DECM)*. IFOST. Novosibirsk- Tomsk, Russia, June 23-29, 2008, Proceedings of the third international forum on strategic technologies, Novosibirsk, Novosibirsk State Technical University 106-107 (2008)
3. N. P. Gaar, A. I. Zhuravlev, B. A. Krasilnikov, A. A. Loktionov, Kh. M. Rakhimyanov, *Method of selection electrolyte for laser-electrochemical treatment*, *Obrabotka metallov (tehnologiya, oborudovanie, instrumenty)* **55**, 18-21 (2012) (in Russian)
4. N. P. Gaar, A. I. Zhuravlev, A. A. Loktionov, K. Kh. Rakhimyanov, Kh. M. Rakhimyanov, *Anodic behavior of titanium alloy OT-4 with electrochemical stripping in the conditions of laser influence*,

- Obrabotka metallov (tehnologiya, oborudovanie, instrumenty) **51**, 11–13 (2011) (in Russian)
5. N. P. Gaar, A. I. Zhuravlev, B. A. Krasilnikov, A. A. Loktionov, K. Kh. Rakhimyanov, Kh. M. Rakhimyanov, *Dimensional electrochemical machining of firm alloy BK8 in the conditions of laser influence*, Obrabotka metallov (tehnologiya, oborudovanie, instrumenty) **50**, 3–7 (2011) (in Russian)
 6. N.P. Gaar, *Anodnoe povedenie nerzhavejushhej stali 12H18N9T v uslovijah lazernoj aktivacii pro-ces-sa jelektrohimicheskoj razmernoj obrabotki (Anode behaviour of "12X18H9T" stainless steel in the conditions of laser activation of electrochemical dimensional machining process)*, Proceedings of the All-Russian Scientific Conference of Young Scientists "Science. Technology. Innovation", Dec. 3-5, **Part 2**, Novosibirsk, Novosibirsk State Technical University, 262-264 (2010) (in Russian)
 7. N. P. Gaar, A. I. Zhuravlev, B. A. Krasilnikov, A. A. Loktionov, Kh. M. Rakhimyanov, *Installation for studying materials under of laser-electrochemical treatment combined radiation*, Obrabotka metallov (tehnologiya, oborudovanie, instrumenty). **56**, 30-32 (2012) (in Russian)
 8. N. P. Gaar, Kh. M. Rakhimyanov, *Matematicheskoe modelirovanie pri lazernoj termoaktivacii jelektrohimicheskoj razmernoj obrabotke (Mathematical simulaion during laser thermoactivation of electrochemical dimensional machining)*, Modern technological systems in machine-building (MTSM-2006). Collection of repots abstracts of international scientific-technical conference, Barna-ul, I.I. Polzunov Altai State Technical University, 45-47 (2006) (in Russian)
 9. N. P. Gaar, Kh. M. Rakhimyanov, *Jelektrohimicheskaja jachejka dlja issledovanija intensifikacii JeHRO lazernym izlucheniem (Electrochemical cell for investigation of DECM intensification by laser radiation)*, Proceedings of the first Russian Scientific-Technical Conference, Modern ways for machine-building and auto-transport development in Kuzbass, Oct. 24-25, Kemerovo, Kuzbass State Technical University, 251-254 (2007) (in Russian)
 10. V.S. Letokhov, *Selektivnoe dejstvie lazernogo izluchenija na veshhestvo (Selective action of laser radiation on material)*, Uspekhi fizicheskikh nauk, Vol. **125**, issue 1. 57–94 (1978) (in Russian)