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Study of the VAC of the EPCTT process with varying electrode parameters

Nowadays the treatment of machine parts, instruments is one of the actual topics in the modern world. One of the modern processing method is chemical-thermal treatment of parts, in which there is an increase of hardness in the surface part to increase wear resistance, while the core of the part remains in a ductile state for resistance to shock loading. The solution to this problem could be the electrolytic plasma chemical-thermal treatment of the parts. This method has a number of advantages over traditional methods, such as cost-effectiveness and speed of processing. In the present work the influence of changes in technological parameters on the volt-ampere characteristics of electrolyte-plasma chemical-thermal treatment unit is presented. A solution of soda ash (Na_2CO_3), urea (CH_4N_2O) in distilled water was used as an electrolyte. According to the results of the study current-voltage diagrams were plotted by varying the diameter of the anode (D=90; 110;130 mm) and the distance between the electrodes (L=50;70; 90 mm). According to the analysis, in the voltage range of 180-220 V, with anode diameter D=110 mm and electrode spacing D=70 mm, a more stable vapor-gas envelope is formed. It was found that by changing the anode diameter, respectively the ratio of active and passive electrodes we can significantly influence the formation of stable vapor gas shell and establishment of the optimum mode of treatment of parts.

Keywords: electrolytic-plasma chemical-thermal treatment, volt-ampere characteristic, electrodes, vapor-gas shell, anode.

Introduction

The problem of increasing the hardness and wear resistance of machine parts, tools and equipment is a very urgent task in modern industry and mechanical engineering. The modern manufacturing industry has many solutions to this issue. The physical and chemical state of the parts surface has a significant impact on the equipment operability. The chemical-thermal treatment (CTT) is one of the actual solutions of this issue. This process can produce a hardened layer on the surface of steel by diffusing the atoms of various chemical elements into the atomic-crystalline lattice of iron by heating the steel parts in an environment enriched with these elements. Surface hardness increases in the surficial part, while the core of the part remains in a ductile state. The surface hardness provides increased wear resistance, while the ductile core provides resistance to impact loading of the parts [1].

There are traditional methods of chemical-thermal treatment of steels such as detail treatment in a gas environment, in a solid environment, etc. All of these methods are complicated by the fact that such treatment takes a lot of time, energy resources and is difficult to perform.

Currently, another method of chemical heat treatment is electrolyte-plasma chemical heat treatment of steels used in mechanical engineering. This method of part treatment is one of the effective methods that allow improving the required physical and mechanical properties of parts in much less time, compared to traditional chemical heat treatment processes, which require somewhat more time for processing [2].

During EPCTT, the area around the active electrode is heated by a current flowing through the electrolyte, leading the electrolyte to a "boiling-evaporating" state, which contributes to the "gaseous formation" process. Further heating of the gaseous state leads to the separation of free electrons from the particles followed by the formation of positive ions with free electrons. The free electrons are current conductors, and form a plasma layer on the surface of the cathode (detail) in the area of the "vapor-gas shell" (VGS), where the conversion of electrical energy into heat occurs. The plasma layer appears as a glow discharge, and can heat the steel to a temperature of up to 2000°C. [3, 4].

As a result of the high temperature, the surface of the detail is saturated with evaporation elements from the electrolyte in the VGS, due to thermal decomposition of components and electrochemical reactions on the surface of the detail, through diffusion [5].

During EPCTT, the establishment of stable VGS depends on such parameters as the ratio of the areas of the active and passive electrodes, shape, electrolyte parameters (composition, concentration, volume, flow rate), and the distance between the electrodes [6].

The stability of VGS in the treatment process provides the system with a stable temperature and a steady flow of the treatment process. The author's work [7] previously studied the behavior of the system VAC during EPCTT of details. And there were distinguished zones of electrolyte boiling, VGS formation zone, VGS steady state zone, etc. During the study of these works we concluded that the VAC has a direct influence on the selection of the parts treatment mode. However, to date, in spite of the vast knowledge base, this issue has not yet been fully explored.

In accordance with the above facts, the purpose of this research work is to study the change of VAC in the EPCTT process with varying the technological parameters (anode size and distance between the anode and cathode) of EPCTT.

Materials and methods

As samples for the test we chose steel 20X which is widely used in industry for the manufacture of parts such as: bushings, gears, clutches, etc. which require high surface hardness and low core strength, parts operating in conditions of frictional wear [8]. The chemical composition of steel 20X (according to GOST 4543–71 following: C (0.17–0.24 %), Si (0.17–0.37), Mn (0.35–0.65), S to 0.04, P to 0.04, Ni to 0.25, Cr to 0.25, Cu to 0.25, As to 0.08, Fe ~98.

Before the experiment, the surface of the samples cut from bars of steel 20X (size 2 × 2 × 1 cm3) were polished on sandpaper with a grain size of P100 to P2000, followed by polishing with diamond paste size 0.25-0.5 microns and cleaned with ethanol.

Experimental works were carried out at the EPCTT unit assembled at Plasmascience LLP. Schematic diagram of the EPCTT unit is shown in Figure 1, which consists of a direct current source (1), electrodes (cathode (3) and anode (2)), an electrolyte bath (4), a valve (5) to control the electrolyte flow and a pump (6) to circulate the electrolyte.

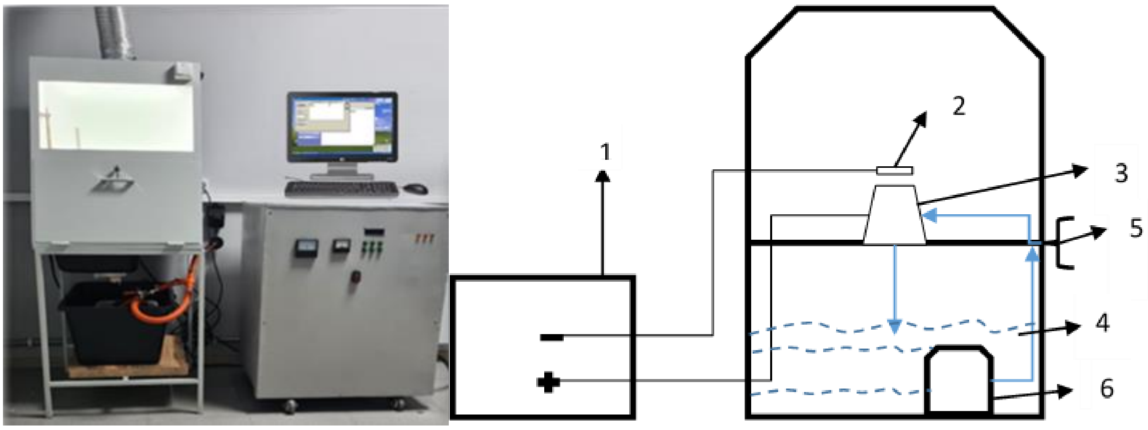

Figure 1. Schematic diagram of the electrolyte-plasma chemical and thermal treatment unit.

The EPCTT unit consists of a power source in the form of a powerful rectifier, which gives a maximum output value of 360V/100A in the form of direct current and electrodes (anode and active cathode). The cathode is a detail, the anode is presented in the form of a round plate having a group of holes for uniform distribution and passage of electrolyte (Fig. 2). The anode is located inside the electrolytic cell with a cover in the form of a truncated cone (Fig. 2). The cone has an upper hole with diameter D=25 mm for uniform feeding of electrolyte. Based on our previous studies [9], an aqueous solution (distilled water) of 10 % soda ash (Na_2CO_3) and 20 % carbamide (CH_4N_2O) (mass %) was used as an electrolyte, which is considered to be more efficient and optimal for the formation of stable plasma.

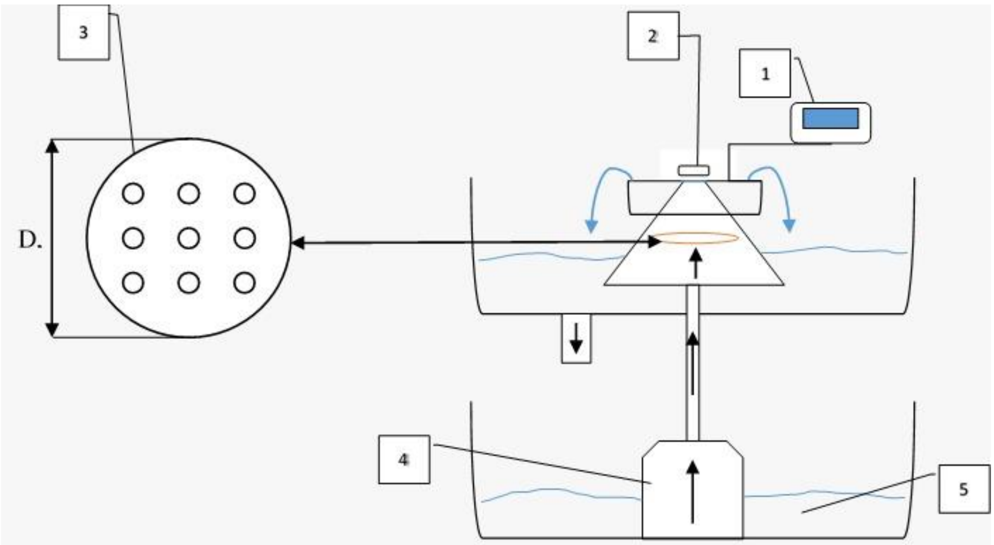

Figure 2. Schematic diagram of an electrolytic cell:
1 — thermocouple to measure the electrolyte temperature; 2 — cathode; 3 — anode;
4 — pump; 5 — bath with electrolyte

At the beginning of the experiment, the active electrode (cathode) was partially immersed in the electrolyte by 1-2 mm and a thermocouple was placed nearby to measure the electrolyte temperature near the active electrode. Then, voltages were applied to the electrodes from the constant power supply starting from 20 V up to 340 V, and the readings of amperemeter and voltmeter placed on the power supply were recorded. Based on the results of the data obtained during the experiment, a graph of the VAC was plotted.

Results and Discussion

1. Research of the VAC at different values of the anode diameter.

For heating the active electrode (cathode) to the temperature of stable EPCTT process flow, we need to choose the optimal size of the anode, contributing to the formation of stable VGS [10]. Table shows the values of varying parameters in the estimation of the VAC of the EPCTT process.

Table

Values of the varying parameters in the estimation of the EPCTT process's VAC

№	1	2	3
DiameterD, mm	86	110	130
DistanceL, mm	50	70	90

Based on the results of the experiment, we plotted the volt-ampere characteristics of the electrolyte, where we can observe the areas of voltage and current changes (Fig. 3).

The first region, the value of current changes proportional to the applied voltage (U=0-140V in Fig. 3) In this region, we can observe that the electrode and electrolyte temperatures in this region are less than the boiling point. As the voltage increases from 140 to 160V in the second region, we can observe an increase in the current up to the maximum value. In this area the electrolyte temperature increases near the cathode with the generation of vapor and the formation of a bubble layer. At the end of this region there is a sharp decrease and oscillation of the current. This is possible due to the instability of the system and rapid boiling of the electrolyte with the occurrence of separate current discharges. Rapid decrease of current value in this area is explained by formation of VGS, and steep jump of resistance in the system cathode-VGS-electrolyte. The third area at voltage values of 180-220V the current becomes constant, which forms a stable VGS around the cathode. As the voltage increases further, an abnormal discharge is observed, which leads to a rapid increase of current followed by an increase in temperature until the melting of the electrode [9, 11].

An important factor in EPCTT is the VGS area, we will observe the behavior of VGS by varying parameters such as anode diameter and the distance between the electrodes.

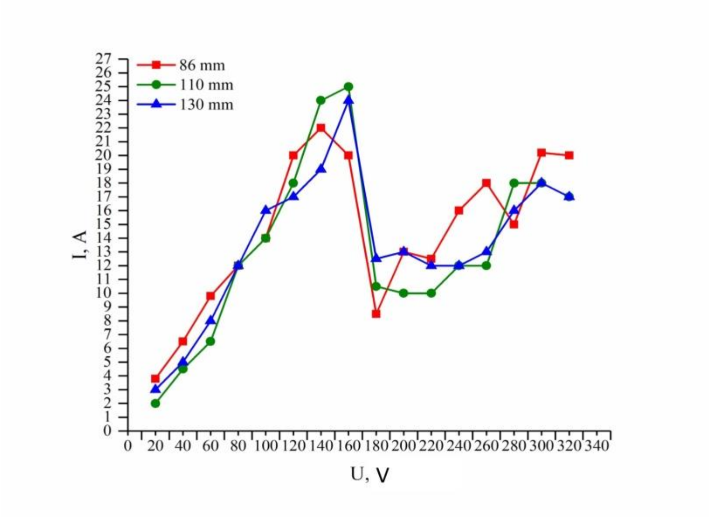

Figure 3: Graphic of volt-ampere characteristics as a function of anode size.

According to the presented Figure 3 at the anode diameter D=86 mm, we can observe on the section 180-200V the instability of VGS. We can assume that due to low value of current VGS is thinned, which is accompanied by decrease of system resistance and electric discharges with splashing of electrolyte, which cools the cathode, occur. Based on our observations, the vapor-gas shell becomes unstable, there appear current surges and electrolyte splashing, which are also described in the works of the authors [10].

In the second case, at anode diameter D=110 mm, we observe in the area of VGS formation at voltages of 180-200 V the stability of the system, which is explained by the steadiness of VGS.

The results of the experiment with the anode D=130 mm at a voltage range of 180-200V showed that the VGS is stable, but the value of the current is high, due to which the sample is heated, causing partial melting the surface of the sample part.

2. Study of the anode's VAC varied with the anode-cathode distance.

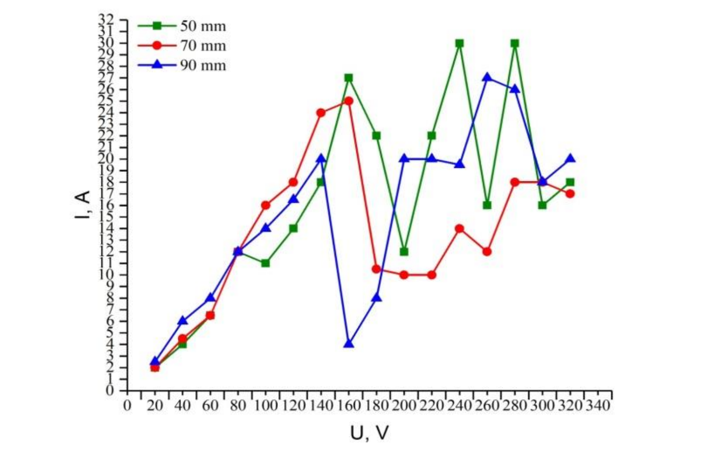

Figure 4: Graph of volt-ampere characteristics as a function of the distance between the anode and cathode.

In Figure 4 we can observe the inversely proportional dependence between parameters of current strength and distance between electrodes: in a zone of 140-160 V voltage at distance L=50 mm we see a steep increase in current, and with increasing distance to L=90 mm we see a steep decrease in current strength. According to the literature analysis we suppose that in the first case during boiling and bubbling of bubble layer the cathode surface is bombarded with arc discharges of high energy due to short distance between the electrodes and small resistance path which makes useful energy of the system very high which leads to strong discharge of system with the following burst of discharges. Strong discharges, in their turn, constantly destabilize the system by disrupting the VGS.

Thereby, considering the system at values of L=90 mm due to the large distance between the electrodes, the current passes a larger resistance path, and the system does not have enough energy for strong discharges, which leads to a decrease in the current strength. Further we observe that with increasing voltage the energy of the system increases, and at 200 V, there is enough energy to create and maintain VGS.

At the value of distance L=50 mm we observe in the voltage range of 180-200 V a stable area of VGS formation, with the current parameter satisfying the requirements of VGS stability.

Also during the experimental work, when measuring the temperature of the electrolyte with a thermocouple, we observed that the temperature changes linearly up to the value of 160V from room temperature 24℃ to 90℃ boiling point of the electrolyte. According to the analysis of the VAC diagram of the EPCTT process, the resistance value in the electrolyte decreases and the conductivity increases with increasing temperature.

Conclusion

In the present work, we studied and investigated the VAC of the EPCTT process by changing the diameter of the anode and the distance between the electrodes. Based on the analysis of the obtained results we can make the following conclusions:

1. It was found that by changing the anode diameter and the ratio between the active and passive electrodes respectively we can influence essentially to the formation of stable VGS and establishment of the optimal mode of detail treatment.

2. It was revealed that decreasing the distance of active and passive electrodes leads to the growth of useful energy, which contributes to the formation of stable VGS.

Therefore, by changing the above-mentioned parameters of the EPCTT unit we can select the optimal mode for treatment and hardening of parts.

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Электродтардың параметрлерін өзгертудің ЭПХТӨ тәсілінің ВАС-қа әсерін зерттеу

Қазіргі әлемде машиналар мен құралдардың бөлшектерін өңдеу өзекті тақырыптардың бірі. Өңдеудің заманауи әдістерінің бірі — бөлшектерді химиялық-термиялық өңдеу, онда тозуға төзімділікті арттыру үшін беткі бөлікте қаттылық жоғарылайды, ал бөліктің өзегі соққы жүктемесінің тұрақтылығы үшін тұтқыр күйде қалады. Бұл мәселенің шешімі ретінде электролиттік-плазмалық химиялық-термиялық өңдеуді қарастыруға болады. Осы әдіс дәстүрлі әдістерге қарағанда бірқатар артықшылықтарға ие, мысалы: үнемділік және өңдеу жылдамдығы бойынша. Жұмыста технологиялық параметрлердің өзгеруінің электролиттік-плазмалық химиялық-термиялық өңдеу қондырғысының вольт-ампер сипаттамаларына әсері қарастырылған. Электролит ретінде тазартылған суда кальцийленген сода (Na_2CO_3), карбамид (CH_4N_2O) ерітіндісі қолданылды. Зерттеу нәтижелері бойынша анодтың диаметрі (D=90;110;130 мм) және электродтар арасындағы қашықтық (l=50;70;90 мм) өзгерген кезде тоқтың кернеуге тәуелділігі графиктері салынды. Талдауға сәйкес 180-220 В кернеу аралығында d=110 мм в анодының диаметрі және D=70 мм электродтар арасындағы қашықтық кезінде неғұрлым тұрақты бу-газ қабығы пайда болады. Анодтың диаметрін, сәйкесінше белсенді және пассивті электродтардың арақашықтығын өзгерту арқылы біз тұрақты бу-газ қабығының түзілуіне және бөлшектерді өңдеудің оңтайлы режимін орнатуға айтарлықтай әсер ете алатынымыз анықталды.

Кілт сөздер: электролиттік-плазмалық химиялық-термиялық өңдеу, вольт-ампер сипаттамасы, электродтар, бу-газ қабығы, анод.

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Изучение ВАХ процесса ЭПХТО при варьировании параметров электродов

В современном мире обработка деталей машин, инструментов является одной из актуальных тем. Одним из современных методов обработки является химико-термическая обработка деталей, при которой происходит повышение твердости в поверхностной части для повышения износостоикости, а сердцевина детали остается в вязком состоянии для стойкости при ударной нагрузке. Решением данной проблемы может оказаться электролитно-плазменная химико-термическая обработка деталей. Данный способ имеет ряд преимуществ перед традиционными способами, такими как экономичность и скорость обработки. В настоящей работе рассмотрено влияние изменений технологических параметров на вольт-амперные характеристики установки электролитно-плазменной химико-термической обработки. В качестве электролита использовали раствор кальцинированной соды (Na_2CO_3), карбамида (CH_4N_2O) в дистиллированной воде. По результатам исследования были построены графики зависимости тока от напряжения, при варьировании диаметром анода (D=90; 110; 130 мм) и расстоянием между электродами (L=50; 70; 90 мм). Согласно анализу в интервале напряжения 180–220 В, при диаметре анода D=110 мм и расстоянии между электродами D=70 мм формируется более устойчивая парогазовая оболочка. Установлено, что, изменяя диаметр анода, соответственно соотношение активного и пассивного электродов, мы можем существенно повлиять на образование стабильной ПГО и установление оптимального режима обработки деталей.

Ключевые слова: электролитно-плазменная химико-термическая обработка, вольт-амперная характеристика, электроды, парогазовая оболочка, анод.

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