МАТЕРІАЛОЗНАВСТВО

UDC 621.0.484.755 DOI: 10.30977/BUL.2219-5548.2024.107.0.21

EFFECT OF MAGNETIC FIELD ON MASS TRANSFER AT ESA

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Abstract. *The study analyzed the effect of magnetic field (value and direction) on mass transfer at electro-spark alloying (ESA). It was experimentally established the increase the productivity of ESA process by additional action of the magnetic field.*
Keywords: *electro-spark alloying, magnetic field, deposition, layer, electric discharge.*

Introduction

It is known that in order to make processing technologies more efficient, several processes are often combined in a single technological process. For example, using the anodic dissolution of metals, simultaneously with the abrasive action, there is an internal removal of the anodic dissolution products from the processing area, which contributes to stabilizing the process and increasing its technological indices [1].

Electrochemical and ultrasonic processing, or Laser can be also combined.

One of the complex methods is chemical processing by electroerosion, which in itself presents the combination of two processes: electroerosion and electrochemical dissolution, in which the tool-electrode is connected to the direct current generator, and the workpiece - to a pulse generator [1].

From other sources that talk about the application of electric and magnetic fields in the crystallization processes of metal alloys, also in thermomagnetic processing, it can be concluded that the application of auxiliary sources to technological processes contributes to their intensification and as a result to the improvement of the main technological indices, such as productivity, quality and processing precision [1–3].

In the present paper, some results are presented about the influence of the magnetic field on the electroerosion machining process, especially on the electro-spark alloying (ESA).

It is known that among the electrophysical methods of forming the coatings of metallic surfaces, it occupies a special place considering the multitude of its characteristic advantages. Among them can be mentioned the high adhesion of the coatings deposited on the workpiece surface, the possibility of depositing coatings from any conductive materials, the simplicity of the process and the low energy consumption for its implementation, etc.

But in the traditional version, the method does not satisfy the requirements regarding the productivity and quality of the deposited coatings [4–6].

It is known that when alloying with electric sparks, applying a certain type of current, either continuous or pulsating, passed through the volume of the electrodes, a substantial increase in the deposition on the cathode part is observed [2–6].

Some results of the experimental research carried out with the additional application of the magnetic field on the electrodes used at the ESA process are elucidated in this paper.

Materials and methods

From the experimental point of view, electrodes from materials more often used in the construction of machines were investigated, whose operating characteristics show the performance. Thus, nickel and silver rods with a diameter of 1 mm and length 30...35 mm, which were pointed at an angle of 15º, were used as anodes. Each electrode that was used for only one discharge was sharpened again. The cathodes featured rectangular shaped plates of St3 steel and M1 copper.

To carry out the ESA process, the following pulse generators were used: EFI-10M, MPD-103A, MPI-702ER and Elitron-22.

The material transfer to the cathode was determined by using the "ADV-200M" analytical balance.

The experimental investigations were carried out both with single and multiple discharges.

As for the magnetic field, it was obtained with the help of an electromagnet with the possibility of applying it to the ESA area both perpendicularly and parallel to the direction of the discharge current.

The induction of the magnetic field could be adjusted within the limits from 0 to 0.1 T with a step of 0.004 T.

The direction of the magnetic field induction vector $\vec{B}$ was set according to the discharge current $\vec{I}_d$ in the ESA process as follows (Fig. 1):

a) parallel to the discharge current;

b) coplanar with the discharge current;

c) perpendicular to the direction of the discharge current.

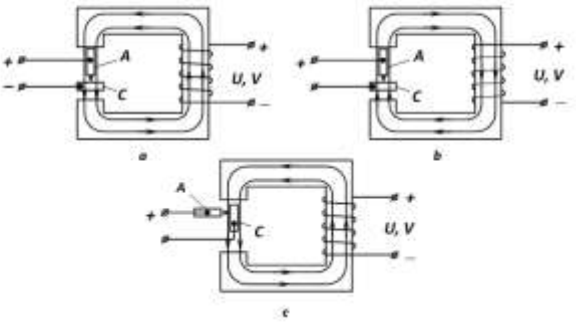

Fig. 1. Scheme of magnetic field imposition on the ASE zone: a – $\vec{B}\uparrow\uparrow\vec{I}_d$; b – $\vec{B}\downarrow\uparrow\vec{I}_d$; c – $\vec{B}\perp\vec{I}_d$

Results and their discussion

In the following, the results of unitary discharge research are presented in the case when the magnetic field induction vector is perpendicular to the direction of the discharge current (Fig. 2).

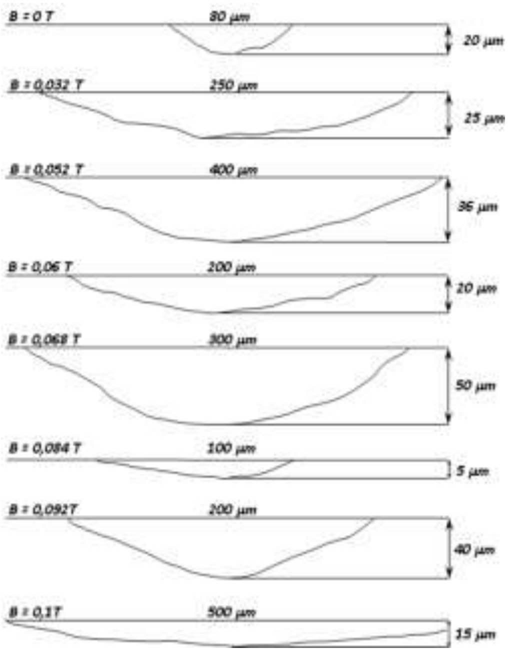

Fig. 2. Profilograms of the craters obtained as a result of unitary discharges depending on the induction of the magnetic field: $\vec{B}\perp\vec{I}_d$; the discharge energy is 0.12 J; the magnetic field variation range is from 0 to 0.1 T

The profilograms of the craters following solitary discharges for the „steel-nickel" pair show us that when the induction of the magnetic field increases the quasi-regular oscillation of their dimensions takes place. An analogous effect is also observed for the diamagnetic pair: the anode – silver, the cathode – copper.

Thus, in the result it can be considered that the mechanism of the influence of the magnetic field on the ESA process consists in the effect of focusing the electron beam, which basically forms the discharge current and later influences the anode erosion process, and as a result the cathode mass change.

However, since the chance factor is high for unitary discharges, the results for the multiple action of the spark discharge were performed and analyzed.

The evaluation of the increase in the mass of the cathode under the multiple action of the spark discharge for the same values of the discharge energy 0.12 J and the change of the magnetic field induction from 0 to 0.1 T also confirms the existence of the quasi-regular oscillation and the stability of the effect of the influence of the magnetic field on the mass transfer at spark discharge (Fig. 3).

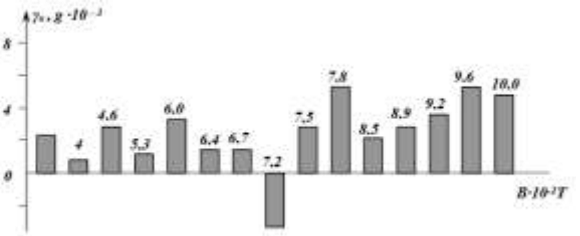

Fig. 3. Histograms variation of the St3 cathode mass alloyed with a Ni anode on the time in a magnetic field as a function of the induction value when the discharge energy changes from 0.12 J to 5 J

Such phenomena also occur when the discharge energy varies for a fixed value of the magnetic field induction. Figure 4 shows the results of the experiments obtained at ESA in magnetic field with induction B=0.068 T and B=0.1 T for a variation within wide limits of the discharge energy from 0.12 J to 5 J by changing the voltage on the condenser battery within the limits of 27 and 160 V.

In the range U=27...33 V and 84...100 V, the influence of the magnetic field can be clearly observed: the maximum increase of the cathode mass for 0.068 T and the minimum for 0.1 T.

In the range U=45...80 V and 120...160 V for both values of the magnetic field induction, the increase in the mass of the cathode is practically the same, that is, even in the case of the discharge energy variation for constant values of the magnetic field induction, the stability of the quasi-regulated oscillation effect is also observed for the amount of eroded mass transferred to the cathode.

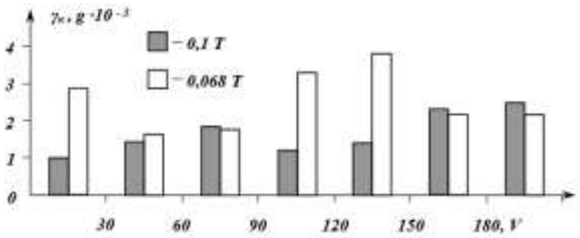

Fig. 4. Histograms of the change in the mass of the St3 cathode alloyed with a nickel anode in the magnetic field for two fixed values of the magnetic field induction B = 0.1 T and B = 0.068 T at the variation of the discharge energy value from 0.12 J to 5 J

Another possible phenomenon, which can occur under the focused influence of the magnetic field - the asymmetry of the singular spots of the discharges – is observed in the contactless alloying process for the case when the magnetic field and the discharge current are perpendicular (Fig. 5).

Fig. 5. Traces of singular discharges, obtained for the fixed size of the gap (0.5 mm): a – B=0 T; b – B=0.068 T; c – B=0.086 T. Discharge energy is 0.14 J

As can be seen from the figure, in the absence of the magnetic field the discharge trace is symmetrical (Fig. 5, a); for B=0.068 T - the trace is asymmetric (Fig. 5, b); and for B=0.086 T the tendency to restore symmetry is observed (Fig. 5, c).

Thus, it can be considered that the mechanism of the influence of the magnetic field on the material transfer process during the spark discharge really consists in the effect of focusing the electronic spot, but obtaining a real image of the appearance of the focus in the discharge channel requires theoretical research for the case of the combined influence of electric and magnetic fields.

The degree of manifestation of the focusing effect of the electronionic fascicle, as established, depends on the size and direction of the magnetic field induction, and this, respectively, must influence the intensity of the transfer of the anode material to the cathode.

Figure 3.10 shows the histogram, which shows the amount of erosion of the nickel anode during spark discharge for different values and directions of the magnetic field induction.

As can be seen from this histogram, in the case when the direction of the magnetic field induction vector is to the discharge current, i.e. $\vec{B}\uparrow\uparrow\vec{I}_d$, and for the value of the magnetic field induction equal to 0.07 T, the erosion of the nickel anode and the increase of the cathode mass reach the maximum value (Fig. 6, column 4).

If we change the direction of the field action by 180º, i.e. for $\vec{B}\uparrow\downarrow\vec{I}_d$, then the maximum erosion of the anode will occur in the case of B=0.067 T (Fig. 6, column 5).

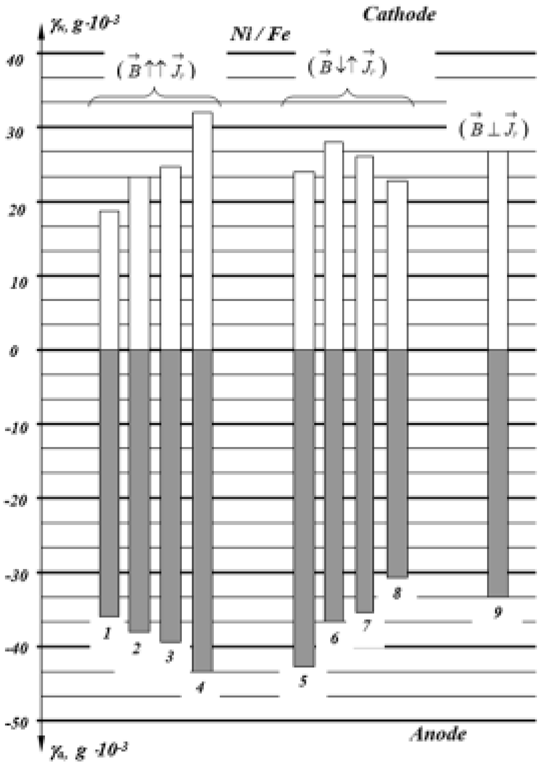

Fig. 6. The histogram of the erosion of the anode from Ni and the increase in the mass of the cathode from St3 depending on the intensity and direction of the magnetic induction vector, EFI-10M set-up, regime no. 3: 1 – B = 0 T; 2 – B = 0.04 T; 3 – B = 0.06 T; 4 – B = 0.07 T; 5 –B=0.067 T; 6 – B=0.07 T; 7 –B=0.074 T; 8 – B = 0.086 T; 9 – B = 0.07 T

In order to better understand the phenomena occurring in this case, we will use the notion of transfer coefficient, which expresses the ratio between the amount of eroded anodic mass and the amount of this material, transferred to the cathode.

In other words, the coefficient $K_t=\gamma_k/\gamma_a$ shows which part of the eroded material from the anode is deposited on the cathode. Thus, for the case of ESA of steel St3 with nickel electrode we have (see Fig. 6):

– for $\vec{B}\uparrow\uparrow\vec{I}_d$: K_t=0.74;

– for $\vec{B}\uparrow\downarrow\vec{I}_d$: K_t=0.79;

– for $\vec{B}\perp\vec{I}_d$: K_t=0.7.

As it is seen from Figure 6, the amount of eroded material does not always define the effectiveness of the formation of superficial layers on the cathode. So, for ASE when $\vec{B}\perp\vec{I}_d$, the transfer coefficient has a minimum value of 0.7, and the higher transfer (K_t=0.79) is observed in the case of overlapping of the magnetic field, which corresponds to the discharge current vector, i.e. when $\vec{B}\uparrow\downarrow\vec{I}_d$.

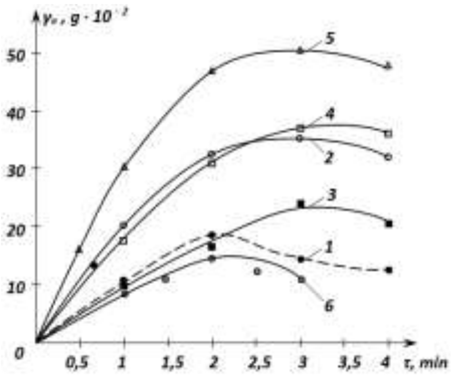

Fig. 7. The variation of the mass increase of St3 steel cathode over time depending on the value of the magnetic field induction, the anode tool-electrode – Ni, the discharge energy is 0.3 J: 1 – B = 0 T; 2 – B = 0.069 T; 3 – B = 0.075 T; 4 – B = 0.081 T; 5 – B = 0.086 T; 6 – B = 0.091 T

At the ESA of the steel piece with nickel electrode the amount of anode material transferred to the cathode in a unit of time (in 2 min) for a magnetic field induction value equal to 0.069 T is twice bigger than at the ESA in the same regime in the absence of a magnetic field (Fig. 7).

But with the increase of the field intensity by only 0.004 T, the amount of transferred material decreases approximately by 2 times and becomes comparable to the same as in the case of ESA without the field.

When applying the magnetic field with an induction equal to 0.07 T on the ESA area for the copper-silver pair (Fig. 8), the discharge channel focusing, and respectively, the discharge channel compressing take place.

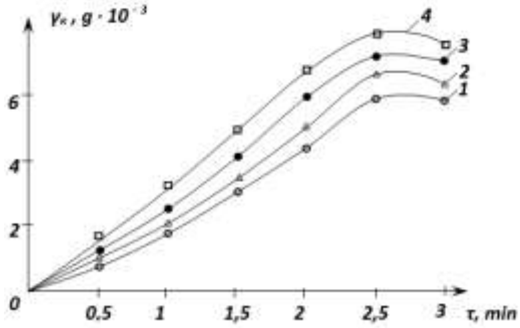

Fig. 8. The change of the cathode mass over time depending on the value of the magnetic field induction. Cathode – copper, anode – silver, set-up – EFI-10M: 1 – B=0.072 T; 2 – B=0.076 T; 3 – B=0 T; 4 – B=0.07 T

Because of this, a larger amount of the eroded mass is transferred to the surface of the cathode. However, with the increase in the intensity of the magnetic field, the defocusing of the electron-ion fascicle takes place, as a result of which a considerable part of the ionized particles are thrown out of the ESA area, which leads to a considerable reduction in the growth of the cathode mass.

Conclusions

1. The mechanism of the influence of the magnetic field on the material transfer process during the spark discharge consists in the effect of focusing the electrode spot.

2. The degree of manifestation of the focusing effect of the electron-ion fascicle depends on the size and direction of the magnetic field induction, and this respectively influences the intensity of the transfer of the anode material to the cathode.

3. The value of imposed magnetic field induction depends on the nature of the part and the electrode material used in ESA.

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Вплив магнітного поля на масообмін у процесі ЕІЛ

Анотація. Постановка проблеми. *У дослідженні проаналізовано вплив магнітного поля (величина та напрямок) на масообмін під час електроіскрового легування (ЕІЛ). Експериментально встановлено квазірегулярні коливання масообміну від інструмента-електрода до заготовки-катода за умови додаткової дії на процес магнітного поля.* ***Мета:*** *підвищити продуктивність ЕІЛ за допомогою додаткової дії магнітного поля та встановити цілі параметри (напрямок і значення) процесу.* ***Методика.*** *Дослідження спрямовані на вплив напрямку та величини індукції магнітного поля на процес ЕІЛ для інтенсифікації масообміну для найбільш корисних матеріалів у конструкції машин.* ***Наукова новизна.*** *Залежності масообміну для досліджуваних матеріалів показали, що магнітне поле певних величин і напрямків викликає вогнища плазмового каналу, що впливає на продуктивність або якість процесу.* ***Практична значущість.*** *Знайдено залежності масообміну та інтенсивності утворення шару осадження на катоді в процесі ЕІЛ від величини та напрямку індукції магнітного поля, прикладеного до зони розряду.*

Ключові слова: *електроіскрове легування, магнітне поле, осадження, шар, електричний розряд.*

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