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A REVIEW OF THE ELECTRO-SPARK DEPOSITION TECHNOLOGY

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Electro-spark deposition (ESD) technology is a new method for repairing and strengthening the surface of metal materials. This method has the advantages of simple equipment, convenient operation and wide application range. The alloyed coating has higher wear resistance, good corrosion resistance, excellent friction performance and other special properties, so it has better practical value and wide application prospect. This paper introduces the characteristics and principle of electro-spark deposition technology, analyzes the research status of this technology and points out the future development direction of this technology.

***Key words**: electro-spark deposition (ESD); surface; coating; special properties*

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1. Introduction

The electro-spark deposition (ESD) technology is that the material to be deposited is used as the electrode, the electrode is operated on the surface of the substrate, the pulse frequency of the power supply is 100Hz-6000Hz and a high-density current (10^5-10^6A/cm^2) is instantaneously (10^{-6} to 10^{-5}s) passed through the power supply, produce high temperature of 5000 ~ 25000℃ in a very small scope, make the material in the discharge area ionize with high energy, the electrode transfers to the surface of the substrate at a high speed and diffuses to the surface of the substrate, thus forms the deposit coating with metallurgy combination [1-3]. The process can really realize the metallurgical bonding of the coating and the substrate and simultaneously can keep the temperature of the substrate at room temperature and prevent the thermal deformation of the substrate metal[4]. This process can be used not only for the repair of local areas of parts, but also for surface coating [5-7]. The thickness of a single layer of deposited metal is limit, the electro-spark deposition is carried out again and again on the previous deposited layer, and finally a deposited layer with a certain thickness is obtained. Because the electric spark discharge of the latter deposit layer will make the former deposit metal re-melt, and the micro-cracks in its surface layer will also be eliminated, so only the last surface deposit layer has micro-cracks. At the end of deposition, the deposited layer is slightly higher than the required size of the workpiece, and the remaining layer can be grinded to eliminate the micro-cracks on the surface layer.

2. The characteristics of the electro-spark deposition technology

The electro-spark deposition technology can effectively improve the physical and chemical properties, mechanical properties and tribological properties of the surface of mechanical parts, so that the surface of mechanical parts has high hardness, high wear resistance, high fatigue strength, high corrosion resistance and oxidation resistance, high temperature resistance, ablation resistance and other special properties [8-10]. Widely used in tools, molds, cutting tools, agricultural machinery, military, medicine, automotive, food, mining, metallurgy, aerospace, nuclear industry, marine vessels, turbines, electric power generation, electrical transmission and other industries of mechanical parts of the surface strengthening and the surface repair of failure parts, especially for precision parts of the surface strengthening and local material addition manufacturing [11-13]. Compared with other surface treatment technologies, electro-spark deposition has the following advantages.

(1) No temperature rise or very low temperature rise in parts, no change in organizational structure and performance, parts will not anneal and deform.

(2) Fast heating and rapid cooling can easily obtain fine crystal and even amorphous structure. When the material is heated and cooled rapidly, it is easy to obtain fine grain structure, even amorphous structure under high temperature gradient, so as to improve the mechanical properties, wear resistance and corrosion resistance of the material surface.

(3) The ESD coating and the substrate are metallurgically bonded and the bonding strength is high.

(4) The ESD coating is dense and has good uniformity.

(5) Only a small amount of pre-treatment and post-treatment is needed and sometimes even no need. The final machining allowance of the deposited layer is small and the subsequent machining cost of a workpiece is saved.

(6) The ESD device is simple and convenient to carry and operate. It is suitable for online repair (good equipment mobility), which is very important for the repair of large workpieces or online equipment.

(7) Wide application range, suitable for all conductive, fusible metal and ceramic materials.

(8) The surface of the deposition layer is orange peel-like with a large number of tiny pores and pits, which is quite beneficial to the lubrication of the workpiece (Figure 1).

(9) There are some other advantages of electro-spark deposition, such as economic and practical, safe and environmental protection, easy to automate. It can be used in places that can't be seen, such as inner holes and grooves of parts.

However, there are also some shortcomings in the process, such as thin surface layer (generally less than 1 mm), slow deposition rate and low efficiency, so it is not suitable for large area and complex surface.

3. The research status of the electro- spark deposition technology

The electro-spark deposition can be used as a surface strengthening method to strengthen the surface with the requirements of wear resistance, corrosion resistance and oxidation resistance, or to repair the surface through deposition, and also to prepare various special functional coatings [14-16].

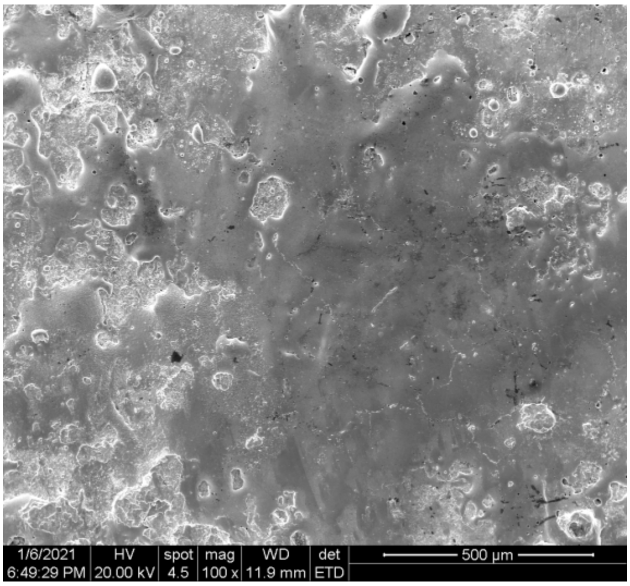

Fig. 1 The morphology of the ESD coatings surface

3.1 The research on the mechanism of electro-spark deposition

Since the theory of electro-spark deposition was put forward in 1943, the new technology of electro-spark deposition has been developed rapidly. With the development of the theory of electro-spark deposition, researchers have different views on the definition of this technology. Some scholars believe that electro-spark deposition is a process of surface strengthening by direct use of high energy density of electric energy. Through spark discharge, conductive materials as electrodes are infiltrated into the surface of metal workpieces to form alloyed surface deposits, which can improve the physical, chemical and mechanical properties of workpieces. Another part of researchers connect the electric spark deposition with the traditional electric arc welding, and think that the electric spark deposition is a kind of pulse electric arc micro-welding technique, which utilizes the short time big electric current pulse produced by the electric capacity discharge to form the high temperature plasma arc with the temperature as high as 5000~25000℃, melting or vaporizing the electrode material and transiting to the work piece.

Researchers put forward two theories to explain the mechanism of electric spark deposition discharge. One is the principle of non-contact discharge, the other is the principle of contact discharge. The physical process of non-contact discharge is that the electric field strength increases when the electrodes are close to each other, when the distance is close enough, the gap between the electrode and the workpiece is broken down to generate spark discharge, through the discharge channel, the electron beam bombards the surface of the anode and converts into heat energy, the surface of the anode is heated and melted to generate metal droplets. The droplets move from the front of the moving anode to the cathode and are heated in the process of separating from the anode, and the temperature rises until boiling and explosion occur, forming a large area of particle flow. The molten particles reach the cathode, adhere to the cathode and partially infiltrate into the surface of the cathode. The electrode moving behind these particles mechanically strikes the workpiece and moves upward away from the workpiece, leaving a layer of anode material on the cathode surface.

At the same time, some researchers also questioned the non-contact discharge theory, thinking that it cannot reasonably explain the discharge mechanism of electro-spark deposition, they think that under normal conditions, when the discharge voltage of electro-spark deposition cannot reach the air breakdown voltage, non-contact discharge mode is difficult to occur. For example, in iron cathode, the minimum breakdown voltage of air is 270V, while in electro-spark deposition, the bipolar voltage is less than 100V. Therefore, the theory of contact discharge is put forward, and the discharge process can be divided into three stages: (1) the formation stage of low voltage breakdown condition; (2) spark discharge stage; (3) separate that electrode from the workpiece. The condition of low voltage breakdown is that high current density is generated instantaneously under the condition of contact resistance discharge and the energy is highly concentrated, so that thermal emission and thermal ionization are generated, the concentration of free electrons, ions and other charged particles between electrodes is greatly increased, the number of collisions between electrons and atoms or molecules meeting the requirement of gas breakdown is realized and the gas low voltage breakdown condition is formed.

In [17], the formation mechanism of micro-nano coating was described, the main reason for the improvement of hardness and wear resistance of cladding layer were analyzed. The addition of nanocrystalline hard phase and focused on the formation reason of nanocrystalline structure in micro-nano coating. The metal surface layer was quenched at ultra-high speed in the cladding process of rapid cooling and rapid heating.

In another report [18], the phenomenon of arc drift in spark discharge during the study of automatic strengthening of electric spark was observed and explained this phenomenon by using the principle of welding arc. But there are essential differences between welding arc and electric spark deposition arc. Welding arc is continuous discharge, but electric spark deposition arc is intermittent discharge controlled by high frequency pulse.

Single point gap discharge, single point contact discharge and continuous discharge with rotary electrode tests were conducted in order to study the discharge mechanism of electro-spark deposition with rotary electrode, as in research [19]. The voltage and current waveform between the electrode and substrate in discharge process were collected and analyzed. The results show that the medium between electrode and substrate can be broken down and result in gap discharge under certain voltage and gap conditions. Contact discharge mainly consists of two stages: short circuit discharge and gap discharge. The contact state between electrode and substrate is complicated and variable in the process of electro-spark deposition with rotary electrode. During the discharge process, there exists not only non-contact discharge phenomena, but contact discharge and short circuit discharge phenomena. Most of them are contact discharge phenomena.

At present, the research on the mechanism of electro-spark deposition is still continuing.

3.2 The research on the electro-spark deposition equipment

In 1944, the former Soviet Union made the world's first electric spark perforating machine according to the deposition process proposed by Lazarenko and his wife. In 1950, the former Soviet Union Central Institute of Electrical Science developed the yHP series of electro-spark deposition equipment and also developed the he series of electro-spark deposition equipment. In 1964, the Institute of Applied Physics of the Academy of Sciences of Moldavia of the former Soviet Union developed 3H series equipment according to the theory of deposition technology of Lazarenko and his wife and widely used in industrial departments. The Kishinev Experimental Factory of the Institute of Applied Physics of the Academy of Sciences of Moldavia produced the new equipment for electro-spark deposition using thyristors and transistors in the 1970s which has greatly improved the quality of deposited layers and manual operability. According to records, in 1978 to 1979, the former Soviet Union used 37 such sedimentation equipments to save about 400000 rubles.

European and American countries began to study and use this deposition process in the 1950s and mostly used in mould parts while Japan began to study and use it in the 1960s. These devices are typically manually operated devices with a power of within 200W. After entering the 1990s, Japan's electro-spark deposition technology has been great development, they developed the SparkDepo deposition equipment power is bigger, can obtain a more uniform coating, coating thickness also increased a lot and the current use of SparkDepo Model 300 electro-spark deposition equipment. ASAP (Advanced Surface And Processs Inc.) of the United States is the authority on the spark deposition, is the most advanced spark deposition system manufacturers and it has also the successful applied ESD to the aviation, marine, military, medical, automotive and food processing industries.

The research of electro-spark deposition technology in China started very early and the research of electro-spark deposition equipment began in the 1950s, but due to the theoretical knowledge and technical conditions at that time, this technology was not applied in a large area. In 1977, Suzhou Electro-machining Machine Tool Research Institute developed D9 series of deposition equipment which has been widely used in the deposition strengthening and surface repair of dies, measuring tools and mechanical parts and achieved good economic benefits. In the 1990s, with the progress of science, this enhancement technology has been further developed. Xi'an Qing'an Group Co Ltd of Aviation First Group has developed the ZS-116 type electro-spark deposition equipment which is characterized by a wide range of deposition current and can be used for a variety of electro-spark deposition processes. Some institutions of higher learning and scientific research units in China have done a great deal of work on the development of the deposition equipment and have developed a series of new-type electro-spark deposition equipment. For example, some scientific research units such as Tsinghua University have developed the pulse electric spark deposition equipment. Because a set of control circuit is designed on this series equipment, the discharge energy is greatly increased, thus the quality and thickness of the deposition layer are improved and the surface roughness is reduced. The Institute of Metal Research of Chinese Academy of Sciences has developed the 3H-ES series of electric spark surface strengthening and repairing machine, high energy micro-arc pulse cold welding processing equipment which is characterized by small thermal effect, no deformation of the workpiece, metallurgical bonding between the deposit and the substrate and on-line surface deposition and repair, thus greatly saving production costs. At present, the DZ-4000Ⅲ electric spark surfacing machine produced by the Institute of Surface Engineering Technology of China Academy of Agricultural Mechanization Science and Technology is widely used.

The electro-spark deposition equipments and the parameters (model, power, voltage, capacitance and frequency) are shown in Table 1.

Table 1 The parameters of the electro-spark deposition equipments

Model	Power, W	Voltage, V	Capacitance, μF	Frequency, Hz
Elitron22A	500	15-70	360	---
Elitron52A	3500	35-210	120-2040	---
Depo150	500	50/100/150	---	60-1400
Depo300	2000	50/100/150	---	60-2000
DZ-4000III	4000	20-200	30-420	1300-6000
SZ-08	1500	20-100	---	50-500
SZ-HCS07	3800	20-100	---	50-500
SW1500	1500	20-100	---	50-500
VC400DHF	1500	20-100	---	50-500

3.3 The research on the electro-spark deposition process

The equipment and process of electro-spark deposition have a significant impact on the efficiency and quality of deposition. There are many process parameters affecting the electro-spark deposition which are systematically studied and classified as follows [20-22]:

(1) Electrode and its movement. Electrode materials (material composition, density, microstructure), manufacturing technology (machining, powder metallurgy, 3D printing), shape, speed of movement, specific deposition time, contact force, cycle times, deposition angle and so on [23-25]. According to the application, the electrode materials used can be divided into three categories. The first is wear resistance material that include hard carbides (carbides of W, Ti, Cr, Ta, Mo, Hf, Zr, Nb, V, etc.), hardfacing alloys (Stellite, high nickel chromium alloy), Ti, Zr, Ta and other borides, intermetallic compounds and cermets. The second is corrosion resistance material that include stainless steel, special alloys (Hastelloy, Inconel, etc.), intermetallic compounds of Fe, Ni and Ti with Al, multicomponent alloys FeCrAlY, NiCrAlY, CoCrAlY. The third is repair or modification material that include nickel-based or cobalt-based superalloy, noble metals such as Au, Ag, Pt, Ir, Pd and Rh, refractory metal such as W, Mo, Ta, Re, Nb and Hf and alloys thereof and alloys of Fe, Ni, Cr, Co, Al, Ti, Cu, Zr, Zn, V, Sn and Er [26-28]. Because the electrical resistivity, melting heat, thermal conductivity, ductility, wetting angle and other characteristics of materials are very different and considering the instability of the electro-spark deposition process, the influence of process parameters on the preparation and performance of coatings is uncertain.

(2) Substrate material. Material, surface roughness, cleanliness, shape, temperature.

(3) Power supply. Electric spark energy and frequency, voltage, current, capacitance, discharge time of electric spark, inductance.

(4) Environment. Gas or liquid composition, fluid properties, gas flow rate and mode, temperature.

(5) Electro-spark deposition composite process. Sometimes it cannot achieve the desired effect by using a single electro-spark deposition technology for deposition, some scholars combine the electro-spark deposition technology with other processes to achieve better results [29,30]. And other process combined with that electro-spark deposition technology include magnetron sputter, ultrasonic treatment, laser treatment, chemical heat treatment, shot peening treatment and rolling treatment [31-33].

The research scope of electro-spark deposition by scholars is narrow and the thickness of deposition layer is often used as the basis for evaluating performance and selecting process parameters. So the research of electro-spark deposition mostly focused on how to determine the relationship between process parameters and deposit thickness and how to increase the deposit thickness, and the research of deposition process parameters mainly focused on the limited ceramic or cemented carbide deposition materials, spark capacitance, voltage, frequency and specific deposition time. There are obvious deficiencies in the research of deposition materials, electrode motion and automatic control.

In [34], NiCrAlY coatings with different Al contents on GH4169 superalloy by electro-spark deposition were prepared. There was a coating thickness limit for the NiCrAlY coating with high Al content. The coating thickness could be further increased by coating again after annealing treatment. The low aluminum content NiCrAlY coating was not applied to the limit thickness after being applied to the 130 layers. Different element content of the alloy coating on the thickness of the coating is also a great impact.

In another paper [35], a new method of ESD is proposed to improve the wear resistance of copper alloysurface. TiN strengthened coating is formed on the surface of QAl9-4 aluminum bronze rotating workpiece by the reaction of titanium cluster electrode with nitrogen under the action of electric spark discharge heat. The results show that a uniform and continuou TiN coating was formed on the surface of copper alloy. The surface of the TiN coating is composed of refined grain structure and compact structure. The electrode wire has a strong grinding pin coating effect on the surface of the coating, which significantly reduces the roughness of the coating surface. The sum of the titanium and nitrogen atomson the surface of the coating layer and the end of the electrode wire is more than 90%. The coating is mainly composed of TiN hard phase with a thickness of about 85μm. The microhardness of the coating can reach $890HV_{0.05}$, which is about 4.8 times of the substrate ($185HV_{0.05}$). There is an alloying metallurgical bonding layer between the coating and the substrate. The friction coefficient of the coating is 0.125-0.2, which is much smaller than that of the substrate (0.23-0.35) and the fluctuation is small. The wear rate of the TiN coating is about 49.6% of that of the substrate. The TiN coating has better antifriction and wear resistance than the substrate.

In other work [36], electro-spark deposition process was used to prepare the Mo_2FeB_2-based cermet coatings in Ar and in air. The DZ2000 electro-spark deposition equipment was used to prepare the coatings and the specific process parameters were as follows: capacitance 360μF, voltage 150V, frequency 1800Hz, deposition rate 2min/cm^2 and argon gas flow rate 5L/min. The coating prepared in air is oxidized severely, and has a rougher surface and non-uniform thickness. Both of the coatings are composed of amorphous phase and martensitic phase while more amorphous phase is involved in the coating produced in Ar. The coating prepared in Ar has better wear resistance, whose wear mass is about 1/7 that of the coating produced in air. The abrasion mechanism of the two coatings is fatigue wear and abrasive wear and the coating produced in Ar is mainly fatigue wear, whereas the coating prepared in air is primarily abrasive wear.

In [37], In order to investigate the effects of pulse energy on microstructure and properties of Mo^2FeB^2-based ceramet coatings, three kinds of coatings were prepared under different pulse energy (1.35J, 6.41J and 17.81J) by electro-spark deposition. The results show that all the coatings are consisted of amorphous, martensite and Fe_3B. The content of amorphous phase is the lowest when the pulse energy is 17.81J. The splash area of single spot and the quantity of cracks on the coatings surface increase with the pulse energy increasing, while the thickness variation is limited. Metallurgical bonding to the substrate is formed in all the coatings. The coating deposited at pulse energy of 6.41J has a maximum peak microhardness of $1395HV_{0.05}$, the minimum mean friction coefficient (0.313) in the steady state and the minimum wear mass (0.7mg) after 1h of abrasion, indicating its better friction and wear performance.

In the present study [38], the effects of process parameters (voltage, nitrogen flux and specific strengthening time) on the microstructure and wear resistance properties of TiN coatings prepared by electro-spark deposition (ESD) were investigated systematically. The microstructure of the coatings was characterized for thickness (TOC), content of TiN (CON) and porosity (POC). A statistical model was developed to identify the significant factors affecting the microstructure and wear resistance of the coatings. The results show that the voltage and nitrogen flux present significant effects on majority of the evaluation indexes such as TOC, friction coefficient (COF) and wear mass loss, while the specific strengthening time has a significant effect on POC and a small effect on the other indexes. The optimal process parameters were obtained as follows: voltage 60V, nitrogen flux 15L/min and specific strengthening time 3 min/cm^2. The variation of wear mass loss by the variation of the voltage and nitrogen flux is attributed to the change of wear mechanisms of TiN coatings. The main wear mechanism of TiN coating prepared under optimal process parameters is micro-cutting wear accompanied by micro-fracture wear.

The most recently [39], aiming at the defects such as pores, microcracks, loose surface structure, poor continuity and poor surface quality in the ESD layer, a machining method of "ESD-remelting and rolling" was proposed. The results show that the electrode has great extrusion and rolling effect on the deposited surface during remelting and rolling. Remelting and rolling can effectively eliminate the defects such as pores, microcracks and loose microstructure in the sediment layer. In addition, this process can refine the grain size and improve the continuity and integrity of the layer. It is considered that the rotating electrode has a remarkable effect on grinding the surface of the deposited layer. The results show that the roughness value of remelting and rolling coatings is 76.3% of the conventional ESD coating, which indicate the surface quality of the deposition layer is improved.

In order to determine the temperature field of WC-12Co coating, mathematical model of heat conduction was established by utilizing suitable heat source and the thermal boundary conditions [40]. Numerical simulation was carried out by commercial finite element code ANSYS, and iso-surface, the temperature distribution curve and temperature variation curve were derived. The areas of melting and gasification zone were measured by setting of contour lines of temperature field. Furthermore, the influence of process parameters on the areas of melting and gasification zone was researched and the optimized process parameters were predicted. To verify the prediction, electro spark deposition experiments were carried out and the optimized process parameters were determined.

Through the optimization of different process parameters, analysis of the various parameters on the deposition layer quality and deposition efficiency to obtain stable and reliable process parameters in order to achieve quality and efficiency of double excellent is one of the research direction of the electro-spark deposition process scholars and experts.

3.4 The research on the surface characteristics of electro-spark deposition

Electro-spark deposition technology can effectively improve the physical and chemical properties, mechanical properties and tribological properties of the surface, so that the surface has high hardness, high wear resistance, high fatigue strength, high corrosion resistance and oxidation resistance, high temperature resistance, ablation resistance and other special properties.

The composite coatings of the tin bronze surface that was formed by alternately ESD applying the soft antifriction material of silver, copper and babbitt B83. The investigation of the tribological properties of the coatings in dry friction show that the lower resistance is exhibited by the composite coatings deposited using the soft antifriction material. The surface friction coefficient of the composite coatings is 55.6% of the tin bronze substrate. The surface of wear traces were analysed in order to understand the friction and wear resistance mechanisms of the coatings. The wear scars of the tin bronze substrate with and without the soft antifriction composite coatings after tribological testing are shown in Fig. 2 and Fig. 3. It was found from analysis of wear scars in Fig. 2 that the wear mechanism of the tin bronze substrate is dominated by severe ploughing wear and fatigue delamination. A lamellar structure can be distinguished on the surface of the worn tin bronze substrate. This can be responsible for low friction under these conditions. However, it can be seen in Fig. 3 that the soft antifriction composite coatings may effectively restrain fatigue delamination, showing plastic deformation, abrasive wear and slight polishing.

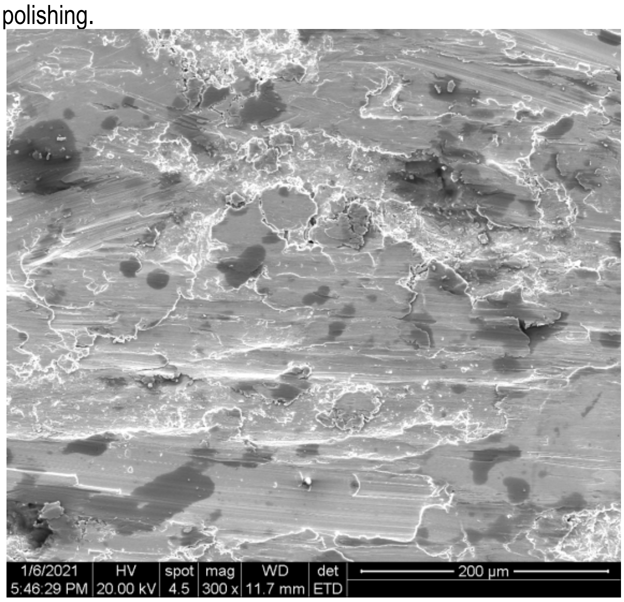

Fig. 2 The wear scars of the tin bronze substrate after tribological testing

Plastic deformation and abrasive wear dominated on the relatively soft composite coatings. The initial surface microgeometry was changed during load application and its surface became smooth with fine shallow scratches observed after the wear test. After the smooth surface was formed, the friction and wear stabilised.

In [41], indium, tin, copper and silver soft wear-resistant coatings were deposited on the axial surface of Babbitt alloy by electrospark deposition technology, which can reduce the requirements for the assembly standards of friction units and reduce the formation of SnSb crystals on the surface of Babbitt alloy.

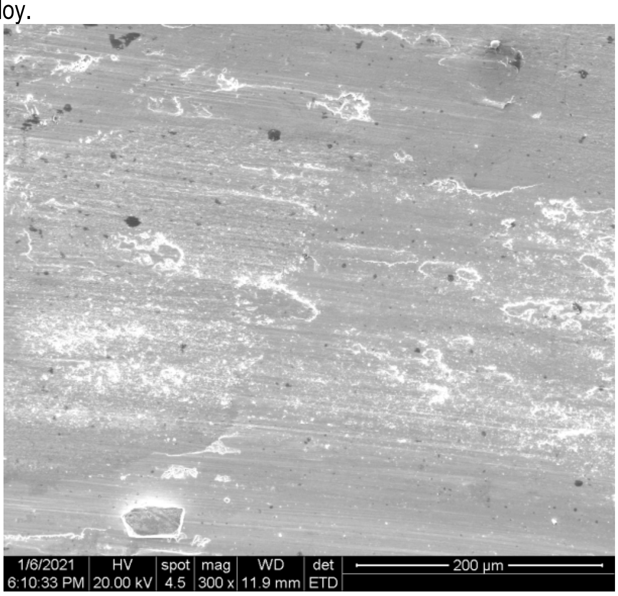

Fig. 3 The wear scars of the tin bronze substrate with the composite coatings after tribological testing

In other research [42], a new method was proposed to improve the surface properties of titanium alloy TC4 by synthesizing TiN coating with flexible titanium electrode. In that process, the flexible titanium electrode and the titanium alloy TC4 surface are subjected to electric spark discharge, nitrogen is introduce into a processing area through the interior of the titanium electrode at the same time, and the TiN coating is generated on the surface of a workpiece by utilizing the electro spark discharge energy. The results show that the TiN strengthening coating is prepared on the surface of TC4 workpiece and the coating is compact, uniform and continuous.

WC-Cu coating was deposited on the surface of C45 carbon steel by using laser technology and electro-spark deposition technology and good anti-corrosion effect was obtained [43].

In another report [44], the tribological properties of electro-spark deposited bronze were studied, Molybdenum, chromium, composite t15k6 and bronze on C45 steel under boundary lubrication conditions. The results showed that the molybdenum coating was the most stable, but the bronze coating had a lower friction coefficient in low load applications.

In more recent work [45], it was found that a metallic glass coating was uniformly formed on the stainless steel substrate. The samples with optimized coating were shown to exert lower cytotoxicity, better cell attachment, and higher blood compatibility than the stainless steel substrates.

In other work [46], the impact of laser modification on the morphology and mechanical properties of carbide/copper coatings produced by electro-spark treatment was analyzed. The laser beam machining of ESD coatings led to the homogenization of chemical composition, fragmentation of the structure, and elimination of microcracks. Laser processing proved to have a positive effect on improving the adhesion of coatings and reducing their porosity. This paper also presents a simulation model of heat transfer processes for the case of laser radiation impact on a WC-Cu coating. The developed numerical model, describing the influence of laser treatment on the distribution of temperature fields in the heated material (at a given depth) is of significant importance in the development of treatment technologies. Laser-modified ESD coatings perform anti-wear and protective functions, which enable their potential application in means of transport such as rolling stock.

4. The future research direction of the ESD deposition technology

The electro-spark deposition technology is a new technology with special strengthening effect and unique technical value which has great potential in the future. The application of electro-spark deposition in the prevention, protection and repair of surface coatings has obvious effect on improving production efficiency and reducing cost.

At present, the scientific research worker has done the massive research work in the electro-spark deposition technology mechanism research, equipment development and application and has obtained many research results, but along with the modern industry development of the high speed and heavy load, the mechanical components service condition is worse, the surface damage form and the degree are complex serious day by day. Electro-spark deposition technology need to be applied in a wide range. But also the problem of thin deposition layer, large surface roughness, low deposition efficiency, poor process stability and reliability need to be solved. The existence of these problems greatly limits the expansion of the application field of this technology, so the future research direction of electro-spark deposition technology will mainly focus on the following aspects:

(1) To strengthen the research on the mechanism of electro-spark deposition technology which will play an important role in guiding the basic research, equipment manufacturing and application development of ESD. At present, the existing mechanism of electro-spark deposition still has great limitations, including the mechanism of electro-spark deposition discharge and electrode material transfer mechanism. Scholars have not yet reached a unified conclusion on this which requires researchers to further overcome the difficulties and form a complete theoretical system as soon as possible to support the promotion and application of electro-spark deposition technology.

(2) The new types of electro-spark deposition automatic equipments are needed to develop and improve the quality and stability of the coating and the deposition efficiency.

(3) Strengthen the research of ESD process parameters. The strengthening process of different electrode and matrix materials, multi-electrode strengthening process, the strengthening process of multi-electrode materials on the same surface and composite strengthening process were studied.

(4) The research of coating materials is mainly focused on cemented carbide and ceramic materials, but other materials with excellent performance are also worth to be studied.

(5) Combining other technologies with the electro-spark deposition technology and developing the composite treatment

technology to prepare the deposits with excellent performance may become the preferred process in the process of the development of this technology. Electro-spark deposition technology combines with ultrasonic technology, nano-technology, laser technology, plasma technology, magnetron sputtering, chemical heat treatment, thermal spraying, electroplating, brush plating, chemical plating, physical meteorology deposition, ion implantation and other technical means to deposit coatings with better performance. Electro-spark deposition technology combines with computer simulation, artificial neural network, fuzzy control, expert system, intelligent control, pattern recognition, genetic algorithm, ant colony algorithm, particle swarm algorithm and other advanced technologies to promote the continuous progress of electro-spark technology.

5. Conclusions

The electro-spark deposition technology can make the surface have high hardness, high wear resistance, high fatigue strength, high corrosion resistance and oxidation resistance, high temperature resistance, ablation resistance and other special properties. It is believed that with the development of this new surface treatment technology, more and more people will devote themselves to the research of this technology and this technology will be widely used and play an important role in surface treatment. The research on the new technology of electro-spark deposition is an innovative and challenging research work which not only enriches the connotation of electro-spark deposition, but also has great significance for improving the processing and application level of advanced composite materials.

Notes

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Огляд технології електроіскрого легування

Технологія електроіскрового легування – це новий метод відновлення та зміцнення поверхні металевих матеріалів. Перевагами цього методу є просте обладнання, зручність експлуатації та широкий діапазон застосування. Леговане покриття має більш високу зносостійкість, хорошу стійкість до корозії, відмінні характеристики тертя та інші особливі властивості, тому має кращу практичну цінність і широку перспективу застосування. У цій роботі ознайомлюються з характеристиками та принципом технології електроіскрового легування, аналізується стан досліджень цієї технології та вказується напрямок подальшого розвитку цієї технології.

***Ключові слова**: електроіскрове легування; поверхня; покриття; особливі властивості.*

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