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ELECTROSPARK DEPOSITION IN REMANUFACTURING ENGINEERING, PROSPECT OF DEVELOPMENT AND APPLICATION

Du Xin
postgraduate student
Sumy National Agrarian University
Henan Institute of Science and Technology
ORCID: 0000-0002-1996-602X
e-mail: 51969926@qq.com

Ievgen Konoplianchenko
PhD, associate professor
Sumy National Agrarian University
ORCID: 0000-0003-4814-1796
e-mail: konopl_e@i.ua

Viacheslav Tarelnyk
doctor of science, professor
Sumy National Agrarian University
ORCID: 0000-0003-2005-5861
e-mail: tarelnik@i.ua

Abstract: *Electro Spark Deposition (ESD) technology is widely used in the preparation of surface coating of parts, remanufacturing and repair. It has been used widely in many industrial areas. The surfaces of mechanical parts are strengthened to improve properties by ESD technology. The article introduced firstly the development history and various terms of the ESD technology. Secondly, it was shown that the working principle of ESD and the work process of ESD. With the development process of ESD deposition equipment, three types of vibrating electrodes were figured. Thirdly, the characteristics of ESD were summarized. Then it introduced the latest research progress of ESD technology on the hotspots of research and new fields of application. Discoveries and new theories in materials provide greater scope for exploration in ESD research. For example, fusion coating of amorphous structure and in-situ reaction in the cemented carbide, multi-layer composite process and multiple materials composite coating, high entropy alloy, nanostructure coating, and biological coating. Researchers had optimized the machining process to improve the surface quality of ESD. At present, the research hotspots are in the ESD of the subsequent treatment process and the study of the composite process. These researches provide new ideas for ESD automation processing to obtain better surface quality. Finally, the paper addressed the current problems of ESD technology and provided an outlook on the research direction and future development of ESD technology.*

Keywords: *electro spark deposition, surface strengthening, remanufacture, coating, perspectives.*
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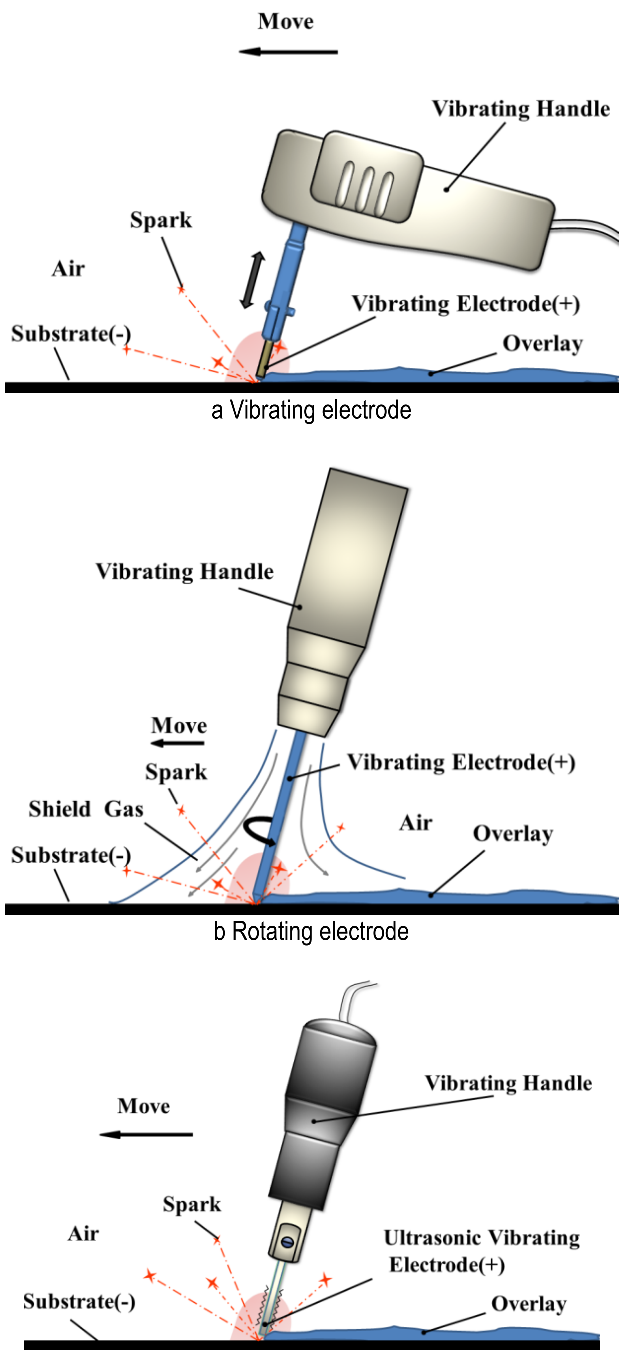
1 Introduction

The electro spark deposition (ESD) technology is important in surface strengthening. It is frequently used in the field of surface engineering and remanufacturing engineering. ESD technology can improve the performance of the surface of metal materials(V. B Tarelnyk et al., 2019). It has been reasonably used in navigation, chemical industry, metallurgy, machinery, medicine, water conservancy, and other industries. The surfaces of mechanical parts are strengthened to improve friction reduction, corrosion resistance, anti-wear, and other properties. ESD can extend the service life on the surface of parts. The material is deposited in multiple layers and repaired to achieve the dimensional requirements of the parts on the surface defects of mechanical parts(V. B. Tarelnik et al., 2018). ESD technology can perform micro-arc welding on different kinds of materials of metal surfaces.

In 1943, Soviet scientists Mr. Lazarenko and Mrs. Lazarenko (1943) proposed the theory of the ESD strengthening process. In1950, the URI series of ESD surface strengthening machines were developed at the Central Institute of Electrical Sciences, and electro-spark machines entered the industrial application stage. Starting in the 1990s, engineers in TechnoCoat Co. Ltd. changed from vibrating to rotating electrodes(L. Zhang & Shao, 2017). The power of the equipment was increased to enable the overlay welding process. ESD is based on its application characteristics. It is also known as electro-spark alloying (ESA), pulse arc deposition (PAD), pulse electrode surfacing (PES), electro-spark hardening (ESH) and electro-discharge deposition. Through the effect of spark discharge, the conductive material of the electrode is fused and infiltrated into the surface of the metal substrate or part. It forms an alloyed surface layer which results in the improvement of surface properties.

2 The working principle of ESD

At a certain distance between the electrode and the substrate, the electric field strength produces electrical sparks. When the electrode and the substrate reach a certain distance, the electric field strength generates electric sparks. The electrode discharges instantaneously to the substrate in the form of a micro-arc, they form a discharge loop. While the discharge is highly concentrated in time and space, the arc generates high surface temperatures in the tiny area of the contact point, causing localized material melting or vaporization in the area. Liquid molten droplets are formed and deposited excessively at the contact point. The pressure generated during the discharge causes parts of the materials to be thrown away from the contact area and sputtered around to form long sparks. In short durations, pulsed currents deposit electrode material onto the surface of some base metal or alloy in the area(Konoplianchenko et al., 2018). One of the main advantages of the ESD process is that it uses very low heat transfer into the base metal. The coating is applied to the metal surface in a metallurgical bond by bringing the electrode into contact with it and melting it at close to ambient temperature. ESD is completed in a very short period of time, and it consists of three processes.1) Physicochemical process at high temperature and pressure.2) High temperature diffusion process ; 3) Rapid phase change process.



a Vibrating electrode

b Rotating electrode

c Ultrasonic vibration electrode

Fig.1 – Process diagram of electro spark deposition

When the positive side of the power supply is connected to the substrate, the melting of the substrate is stronger than that of the electrode. It causes the removal of the substrate material. When the cathode of the power supply is connected to the substrate, it causes the electrode material to be deposited on the surface of the substrate. The electrode material is melting on the metal surface and tends to adhere to the surface. In order to avoid electrode material sticking and Improve deposition efficiency, electrodes with different vibration sources were invented successively: 1) Vibrating electrode: 100~600 times per second vibration frequency; 2) Rotating electrode: no more than 200r/min; 3) Ultrasonic vibration electrode: 20,000~30,000 times per minute.

3 Features of ESD technology

ESD technology can effectively improve the physical properties, chemical properties, mechanical properties, and tribological properties in the surface of mechanical parts. It can also improve the hardness, wear-resistance, and corrosion resistance of mechanical parts. It has the following outstanding advantages.

1) Simple process and light equipment quality. The process is simple. ESD requires only a simple grinding and cleaning of the substrate surface. ESD is carried out on the surface at a uniform speed subsequently. ESD equipment consists of two parts: vibrating power supply and operating handle, sometimes the process needs protective gas. Because the equipment is simple, it is easy to carry on-site operation.

2) Extremely fast solidification and small thermal deformation. It is small in the heat deformation area of the substrate. The quality of the molten metal droplets is very small. The droplets cool in a very short time, the heat of the molten droplets is rapidly diffused, the heat will not be concentrated in the processing part of the workpiece, which does not change the microstructure and various properties of the substrate material of the parts, the amount of heat deformation about the workpiece has a limited influence.

3) Wide range of applications. ESD technology is not limited by the shape and size of the component substrate. It can deposit on the large surface and complex surface, but also can apply to parts local small area deposition treatment. It is suitable for all conductive, fusible metals and metal alloy materials.

4) Low maintenance cost and environmental protection. ESD technology consumes less energy, and the processing does not produce material splash or harmful gas, which prolongs the overall life of the machinery.

4 The recent research progress of ESD technology

ESD technology is widely used in various fields as a very promising surface engineering technology. With the development of modern technology, people have a deeper understanding of the strengthening mechanism of ESD technology, and ESD technology has been further developed. Researchers have done a lot of work in the development of ESD coatings. Based on the conventional alloy coatings, they have further researched and prepared new coating materials with better performance, improved surface quality and optimized the coating manufacturing process. Discoveries and new theories in materials provide greater scope for exploration in ESD research.

4.1 Electro spark deposition of cemented carbide

ESD of cemented carbide coating has the advantages of high hardness, high strength, wear resistance, corrosion resistance, oxidation resistance, and low expansion coefficient. It is widely used in cutting tools, gauges, metal molds, extractive tools, etc. ESD can rapidly deposit carbide materials on the metal surface and form amorphous alloys and ultrafine crystalline alloys to improve surface properties.

Wang (J. Wang et al., 2014) deposited WC-4Co ceramic carbide on cast steel material and used the surface wettability theory which combined with the microstructure of the surface. It was found that the surface generated tiny particles of Fe_2C, Si_2W, Fe_3W_3C, Co_3W_3C, and deposited into a thickness of 20 μm. Tarel'nik (V. V. Tarelnik & Kuchmii, 1997) used EG-4 graphite electrode to deposit on the surface of steel R6M5, and he found in situ reaction phenomena. You (You et al., 2007) used graphite electrode to deposit on the substrate surface of titanium alloy and generate in situ TiN coating. Its Vickers hardness was 5 times that of the substrate and reached 16 700 MPa $HV_{0.05}$. Zhang (P. Zhang et al., 2011) used TC4 as the electrode and 45 steel as the substrate. The deposition layer of TiN was generated by in situ reaction at a high temperature when nitrogen was used as the protective gas. The nano-hardness of the surface was 4 times that of the substrate.

4.2 Electro spark deposition of composite coatings

ESD technology has high discharge temperature and fast cooling, but it also has its shortcomings, such as the limited thickness of the deposited layer, the low surface quality of the deposited layer, and poor bonding strength of the deposited layer. In order to improve these shortcomings, the method of multi-layer metal deposition is usually used to achieve the effect of improving the surface properties. Alternatively, several materials are compounded into electrodes and deposited to improve the deposition efficiency.

Maryam Kazemi (Kazemi et al., 2020) used HA/TiN dual-layer deposited on Ti-6Al-4V material to utilize the corrosion behavior and biocompatibility in dental and orthopedic implants. Chen (B. Chen, Fan, Tang, & Li, 2018) deposited two kinds of tungsten steel rods, Ti-6Al-4V and YG10, as electrode materials on the surface of H13 steel alternatively, and the microhardness and thickness of each deposited layer were significantly increased compared to the substrate. Tang (Tang, 2016) deposited Ti and B4C powder on 40Cr steel substrate by ESD to generate TiC-TiB2 composite coating, the coating has better tribological properties, which of wear resistance is five times that of the substrate.

4.3 Electro spark deposition of high entropy alloys

High entropy alloys are new alloy systems with five or more primary elements. A simple solid solution is formed in each principal element, and its lattice distortion leads to strong solid solution strengthening, which results in high strength, high hardness, and high corrosion resistance. ESD preparation of high entropy alloy coatings play with the high mixed entropy effect of multiple primary elements. Due to the fast solidification characteristics of ESD, it is easier to form simple face-centered cubic (FCC) or body-centered cubic (BCC) solid solution phases (Yong ZHANG et al., 2021). Due to the fast solidification characteristics of ESD deposition, it is easier to form simple face-centered cubic (FCC) or body-centered cubic (BCC) solid solution phases. And which forms fine grain organization. It plays the role of solid solution strengthening and fine grained strengthening, which is the benefit to obtain excellent performance coatings.

It plays the role of solid solution strengthening and fine grained strengthening, which is beneficial to obtain excellent performance coatings. Li (Li, Yue et al., 2013)prepared a multi-element high entropy alloy coating AlCoCrFeNi on AISI 1045 carbon steel substrate using ESD technique, and the substrate obtained has a simple BCC structure, the microhardness of the coating is 2 times higher than that of the substrate material, that the corrosion resistance of the coating is better than that of the substrate. Karlsdottir (Karlsdottir et al., 2019) used CoCrFeNiMo high entropy alloys electrode to generate the coating on the surface of the steel substrate, the layer had additive BCC and potentially σ phase. The surface of Vickers hardness is 593HV, and it had relatively high wear and corrosion resistance. Wang (Y. F. Wang et al., 2018) prepared the deposited layer of FeCoCrNiCu high-entropy alloys electrode on the surface of 45Mn2 alloy steel. The layer produced a simple FCC structure, and the deposited layer had good corrosion resistance.

4.4 Electro spark deposition of nanostructured coatings

The liquid metal is rapidly cooled above the crystallization temperature to below the crystallization temperature, which forms the amorphous alloy tissues. Some of the tissues reach ultrafine nano-crystals. Due to the significant increase in the number of grain boundaries, it emerges that some excellent new tissues and structures with good mechanical properties.

Zamulaeva (Zamulaeva, et al., 2008) utilized WC(8% Co) nanopowder deposited on Armco iron surface, The upper layer of coatings deposited with nanostructured material, which exhibit a uniform amorphous structure, higher wear resistance, and reduced friction coefficient. Gao (Y. Gao et al., 2012) utilized Ni-Cr alloy electrode to deposit on 3Cr2Mo (P20) steel substrate. The nano-crystalline structure in the upper part of the coating was found and increased the substrate wear resistance and corrosion resistance. Wei (Wei et al., 2017) used coarse-grained Fe_2B electrode to generate nanocrystalline Fe_2B coating on the surface of the substrate of AISI 1045 steel. The toughness of the coating was increased. Zhang (Yi Zhang et al., 2019) utilized Chromium carbide cermet ($Cr_3C_2$20%Ni5%Cr) powder alloy electrode deposited on Cr12MoV steel. In the nanocrystalline microstructure, the coating surface was strengthened.

4.5 Electro spark deposition of biological coatings

ESD has used materials with good biocompatibility and corrosion resistance for medical applications, such as titanium alloy and stainless steel. It is required that environmental protection, non-toxic and non-allergic reactions in blood and tissue fluids. It has high strength and hardness. It is commonly used in healing bone defects and injuries. Currently, titanium alloys and ceramic materials based on calcium phosphate compounds are used in medicine, such as hydroxyapatite (HA).

Jiang (Jiang et al., 2011) used silicon as an electrode material to prepare an intermediate layer in TA2 material, which prevented oxidation of titanium plates and ensured the bond strength of cast titanium porcelain. Boshitskaya (Boshitskaya et al., 2014) deposited $TiAL_3$ or TiN-3AlN layer on VT-6 titanium alloy. Then, laser fusion of a subsequent hydroxyapatite layer was used to create biocoating, which had high corrosion resistance and biocompatibility. Durdu (Durdu et al., 2017) utilized Ti6Al4V material deposited on the surface of St35 steel and then after micro-arc oxidation (MAO) treatment to generate hydroxyapatite (HA). HA-based bioceramic coatings were formed. Esmaeili (Esmaeili et al., 2021) utilized $Fe_{37}Cr_{15}Mo_2B_{26}C_7Nb_3Si_3Al_6Mn_1$ was used as an electrode and deposited bioceramic coatings on the surface of 316 stainless steel by ESD technology. And the biocompatibility of the coatings was analyzed.

5 Optimization of the ESD process

Researchers had optimized the machining process to improve the surface quality of ESD, reduce micro-cracking and improve surface wear resistance. In particular, a lot of researches have been conducted on ESD voltage, pulse frequency, discharge capacitance, deposition time, duty cycle, protective gas flow, and metal surface wetting angle. At present, the research hotspots are in the ESD of the subsequent treatment process and the study of the composite process. These researches provide new ideas for ESD automation processing to obtain better surface quality(V. B Tarelnyk et al., 2019).

5.1 Composite coating of Laser processing

ESD deposition produces the problem such as surface micro-cracking, it is useful that Laser processing improved other properties such as tribological properties of ESD coatings(V. B. Tarelnyk et al., 2020). Radek (Radek & Bartkowiak, 2010) used the WC-Co-Al_2O_3 electrode which was made of nanostructured powder and deposited on the surface of C45 carbon steel, then laser surface melting was performed. Better surface quality can be obtained. The micro-cracks or pores of the laser-modified outer layer could not be observed. The surface micro-hardness increased from 784 $HV_{0.04}$ to 843 $HV_{0.04}$, the critical force adhesion of the coating increased from 6.33 N to 8.94 N. Gao (Y.-x. Gao & Wang, 2021)used alloy powder Ni-based alloy deposited on the surface of P20(3Cr2Mo) steel substrate, and the surface was remelted by a JHM-1GY-300D type pulsed laser welding machine to obtain a uniform distribution of ultrafine grains. The surface quality and surface hardness were improved, and the wear resistance had been nearly doubled. And the surface wear was analyzed mainly as abrasive wear.

5.2 Composite processing about Ultrasonic machining and EDM machining

ESD coupled with ultrasound can yield better surface quality of the coating. The discharge gap was effectively improved, so the coating grain size was refined, cracks in the coating, and bubbles inside the coating were reduced.

The electrode was incorporated into ultrasonic (C. Chen, Tang, & Xu, 2011), Chen used die steel 718 as the electrode to deposit on the surface of H13 substrate. it was studied that the effect of processing process parameters on the surface deposition thickness. Zhao (Zhao et al., 2019) used copper-based NiCrBSi powder electrodes to generate coatings on ASTM 1045 steel, which has good continuity and few defects. The coating has good continuity and few defects, and the introduction of ultrasound makes the metal powder to be uniformly dispersed and melted and results in better coating quality. Ultrasonic technology has strict requirements for electrode size and material. Although the surface remanufacturing of the mold is more restricted, it has good performance in surface fine-machining.

6 Conclusion

Electro spark deposition technology has been developed for more than 70 years and has received a lot of attention from researchers and scholars because of its small investment, easy operation, and remarkable effect. The technology has made great progress, but there is still a need to solve the problems ， such as the limited thickness of deposited layer, large surface roughness, relatively low productivity, unstable strengthening process, reliability needs to be improved, etc. The existence of these problems has limited the promotion and application of the technology.

ESD is one of the hot spots in remanufacturing engineering, which has a great prospect of development and application. To reduce the problems of ESD technology and further improve the performance of deposited coatings, its future development may be carried out in the following aspects: 1) strengthening the research on the mechanism of ESD deposition; 2) process research to improve the thickness and surface finishing of ESD deposition; 3) intelligence and automation of ESD process; 4) exploring more application areas of ESD.

References:

1. Boshitskaya, N., Podchernyaeva, I., Lavrenko, V., Uvarova, I., & Yurechko, D. (2014). Combined functional biocoatings on the VT-6 alloy. *Powder Metallurgy and Metal Ceramics, 52*(9-10), 551-559. doi:https://doi.org/10.1007/s11106-014-9559-5

2. Chen, B., Fan, X., Tang, X., & Li, D. (2018). Microstructure and Properties of YG10/CD750 Double Electrode Alternating Deposition Electro-spark Deposition Coating. *Hot Working Technology*, 04. doi:http://10.14158/j.cnki.1001-3814.2018.04.041

3. Chen, C., Tang, Y., & Xu, Y. (2011, 2011-10-22). *Ultrasonic ESD deposition device and its process research.* Paper presented at the Proceedings of the 14th China Special Processing Academic Conference.

4. Durdu, S., Korkmaz, K., Aktuğ, S. L., & Çakır, A. (2017). Characterization and bioactivity of hydroxyapatite-based coatings formed on steel by electro-spark deposition and micro-arc oxidation. *Surface and Coatings Technology, 326*, 111-120. doi:https://10.1016/j.surfcoat.2017.07.039

5. Esmaeili, A., Ghaffari, S. A., Nikkhah, M., Ghaini, F. M., Farzan, F., & Mohammadi, S. (2021). Biocompatibility assessments of 316L stainless steel substrates coated by Fe-based bulk metallic glass through electro-spark deposition method. *Colloids and Surfaces B-Biointerfaces, 198*. doi:https://10.1016/j.colsurfb.2020.111469

6. Gao, Y.-x., & Wang, J.-b. (2021). Effects of Laser Remelting on Microstructure and Wear Properties of Ni -Based Coating Prepared by Electrospark Deposition. *Meterials Profection, 54*(1), 54(51): 112-115, 120. doi:https://10.16577/j.cnki.42-1215/tb.2021.01.019

7. Gao, Y., Zhao, C., & Yi, J. (2012). Microstructure and Properties of Ni-Cr Alloyed Coating Prepared by Electrospark Deposition Processes. *Journal of Materials Engineering 2*(3), 74-78.

8. Jiang, T., Hu, J., & Zhou, J. (2011). Effect of Middle Layer by Electro-spark Deposition Technology on Bonding Strength of Porcelain and Cast Pure Titanium. *Journal of Oral Science Research, 27*(04), 277-280. doi:http://10.13701/j.cnki.kqyxyj.2011.04.007

9. Karlsdottir, S. N., Geambazu, L. E., Csaki, I., Thorhallsson, A. I., Stefanoiu, R., Magnus, F., & Cotrut, C. (2019). Phase Evolution and Microstructure Analysis of CoCrFeNiMo High-Entropy Alloy for Electro-Spark-Deposited Coatings for Geothermal Environment. *Coatings, 9*(6), 406. doi:https://doi.org/10.3390/coatings9060406

10. Kazemi, M., Ahangarani, S., Esmailian, M., & Shanaghi, A. (2020). Investigation on the corrosion behavior and biocompatibility of Ti-6Al-4V implant coated with HA/TiN dual layer for medical applications. *Surface Coatings Technology, 397*, 126044. doi:https://doi.org/10.1016/j.surfcoat.2020.126044

11. Konoplianchenko, I., Tarelnyk, V., Antoszewski, B., Martsynkovskyy, V., Belous, A., Gerasimenko, V., & Vasilenko, O. (2018). *Mathematical modeling a process of strengthening steel part working surfaces at carburizing thereof by electroerosive alloying method*.

12. Lazarenko, B., & Lazarenko, N. (1943). About the inversion of metal erosion and methods to fight ravage of electric contacts.

13. Li, Q., Yue, T. M., Guo, Z., Lin, X. J. M., & A, m. t. (2013). Microstructure and corrosion properties of AlCoCrFeNi high entropy alloy coatings deposited on AISI 1045 steel by the electrospark process. *Metallurgical and Materials Transactions A, 44*(4), 1767-1778. doi:https://doi.org/10.1007/s11661-012-1535-4

14. Radek, N., & Bartkowiak, K. (2010). Performance properties of electro-spark deposited carbide-ceramic coatings modified by laser beam. *Physics Procedia, 5*, 417-423. doi:https://doi.org/10.1016/j.phpro.2010.08.163

15. Tang, J. (2016). Mechanical and tribological properties of the TiC–TiB2 composite coating deposited on 40Cr-steel by electro spark deposition. *Applied Surface Science, 365*, 202-208. doi:https://doi.org/10.1016/j.apsusc.2015.12.198

16. Tarelnik, V. B., Paustovskii, A. V., Tkachenko, Y. G., Martsinkovskii, V. S., Belous, A. V., Konoplyanchenko, E. V., & Gaponova, O. P. (2018). Electrospark Graphite Alloying of Steel Surfaces: Technology, Properties, and Application. *Surface Engineering and Applied Electrochemistry, 54*(2), 147-156. doi:http://doi.org/10.3103/s106837551802014x

17. Tarelnik, V. V., & Kuchmii, A. N. (1997). Electroerosion hardening of metal-cutting tools for machining corrosion-resistant steels. *Chemical and Petroleum Engineering, 33*(1), 100-102. doi:http://doi.org/10.1007/bf02416796

18. Tarelnyk, V. B., Gaponova, O. P., Konoplianchenko, Y. V., Martsynkovskyy, V. S., Tarelnyk, N. V., & Vasylenko, O. O. (2019). Improvement of Quality of the Surface Electroerosive Alloyed Layers by the Combined Coatings and the Surface Plastic Deformation. I. Features of Formation of the Combined Electroerosive Coatings on Special Steels and Alloys. *Metallofizika I Noveishie Tekhnologii, 41*(1), 47-69. doi:http://doi.org/10.15407/mfint.41.01.0047

19. Tarelnyk, V. B., Konoplianchenko, I. V., Gaponova, O. P., Tarelnyk, N. V., Martsynkovskyy, V. S., Sarzhanov, B. O., . . . Antoszewski, B. (2020). Effect of Laser Processing on the Qualitative Parameters of Protective Abrasion-Resistant Coatings. *Powder Metallurgy and Metal Ceramics, 58*(11-12), 703-713. doi:http://doi.org/10.1007/s11106-020-00127-8

20. Wang, J., Zhang, Z., Yan, N., LI, G., TANG, M., & FENG, Z. (2014). Interface behavior of WC-4Co coating by electro-spark deposition. *The Chinese Journal of Nonferrous Metals, 24*(11), 2849-2855. doi:https://doi.org/10.19476/j.ysxb.1004.0609.2014.11.021

21. Wang, Y. F., Yan, H., Juan, L. I., Sun, S. Y., Song, Z. J., & Shi, Z. Q. (2018). Microstructure and Corrosion Resistance of FeCoCrNiCu High-entropy Alloy Coating Prepared by Electro-spark Deposition. *Transactions of the China Welding Institution, 39*(07), 121-124+134. doi:https://doi.org/10.12073/j.hjxb.2018390188

22. Wei, X., Chen, Z., Zhong, J., Wang, L., Hou, Z., Zhang, Y., & Tan, F. (2017). Facile preparation of nanocrystalline Fe2B coating by direct electro-spark deposition of coarse-grained Fe2B electrode material. *Journal of Alloys Compounds, 717*, 31-40. doi:https://doi.org/10.1016/j.jallcom.2017.05.081

23. You, T., Huang, D.-W., Liu, S.-B., Liu, H.-Y., Zhang, C.-H., Su, G.-Q., & Wang, M.-C. J. F. (2007). Research of Surface Carburizing on Titanium Alloys by Electrospark Deposition *Foundry*(03), 239-241.

24. Zamulaeva, E. I., Levashov, E. A., Kudryashov, A. E., Vakaev, P. V., & Petrzhik, M. I. (2008). Electrospark coatings deposited onto an Armco iron substrate with nano- and microstructured WC–Co electrodes: Deposition process, structure, and properties. *Surface and Coatings Technology, 202*(15), 3715-3722. doi:https://doi.org/10.1016/j.surfcoat.2008.01.008

25. Zhang, L., & Shao, J. (2017). Research Status and Development Trend of Electro-spark Surface Deposition Technology. *Equipment Manufacturing Technology*(8), 76-79,.

26. Zhang, P., Zhang, E.-L., Ma, L., & Cai, Z.-H. J. Z. G. X. X. (2011). Processing Properties of TiN Ceramic Coating Prepared by In-situ Synthesis Electric Spark Deposition. *Journal of Academy of Armored Force Engineering, 25*(4), 74-79.

27. Zhang, Y., Chen, Z., Wei, X., Wang, L., Hou, Z., & Yang, W. (2019). Microstructure and Properties of Chromium Carbide Based Metal-Ceramic Coatings Prepared by Electro-Spark Deposition. *Rare Metal Materials and Engineering, 48*(2), 601-607.

28. ZHANG, Y., LI, L., CHANG, Q., WANG, X.-m., ZHAO, Y., ZHU, S., . . . GAO, X.-w. (2021). Research Status and Prospect of Electro-spark Deposition Technology. *Surface Technology, 50*(1). doi:https://doi.org/10.16490/j.cnki.issn.1001-3660.2021.01.012

29. Zhao, H., Gao, C., Wu, X.-y., Xu, B., Lu, Y.-j., & Zhu, L.-k. (2019). A novel method to fabricate composite coatings via ultrasonic-assisted electro-spark powder deposition. *Ceramics International, 45*(17), 22528-22537. doi:https://doi.org/10.1016/j.ceramint.2019.07.279

Ду Сінь, *Сумський національний аграрний університет, Україна; Хенаньський інтитут науки і технологій, Китай*
Конопля́нченко Є.В., *Сумський національний аграрний університет, Україна.*
Тарельник В.Б., *Сумський національний аграрний університет, Україна.*

Електроіскрове осадження в відновлювальному машинобудуванні, перспективи розвитку та застосування

Технологія електроіскрового легування (ЕІЛ) широко використовується при підготовці поверхневого шару деталей при відновленні та ремонті. Вона широко використовується в багатьох промислових процесах. Поверхні деталей машин зміцнюються для поліпшення властивостей за допомогою технології ЕІЛ. У статті представлена історія розвитку та термінологія технології ЕІЛ. Приведено принцип та процес роботи ЕІЛ. Розглянуто конструкції різних типів вібраційного обладнання. Наведені узагальнені характеристики процесу ЕІЛ. Представлено останні досягнення розвитку технології

ЕІЛ в існуючих та нових областях застосування. Наведено нові напрями застосування ЕІЛ. Розглануто покриття, що сформоване плавленням аморфної структури та реакція на місці в цементованому карбіді, багатошаровий композитний процес та композитне покриття з багатьох матеріалів, сплав з високою ентропією, покриття наноструктурою та біологічне покриття. В статті розглянуто існуючі проблеми технології ЕІЛ, перспективні напрямки досліджень та майбутній розвиток технології ЕІЛ.Ключові слова: електроіскрове легування, поверхневе зміцнення, відновлення, покриття, перспективи.

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