UDK 620.22: 620.186 DOI: 10.18372/0370-2197.2(107).20145

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IMPROVING THE WEAR RESISTANCE OF STRUCTURAL STEELS BY ELECTROSPARK DEPOSITION

The advantages of the electrospark deposition method in forming wear-resistant coatings on steel parts have been analyzed, and the main requirements for electrode materials for forming coatings with high hardness, wear resistance, and crack resistance have been identified. The aim of this work was to assess the wear resistance of electrospark coatings made from high-carbon steel U10 (DIN: 1.1645) and high-speed steel R18 (DIN: 1.3355) on structural steels in an abrasive environment. It was found that for uncoated structural steels, weight loss due to abrasion decreases with increasing material hardness. This is caused by improved abrasion resistance in steel 45 due to a higher proportion of iron carbides, and in medium-alloy steel 30ХГСА due to deposition carbide-forming elements such as manganese and chromium. The enhancement in wear resistance of structural steels with electrospark coatings is substantiated by the more effective resistance of hardened surface layers under abrasive particle impact, which is due to the formation of coatings with a high content of Fe carbides (U10 and R18 coatings), W, Cr, and V carbides (R18 coatings). The possibility of controlling structural effects and phase composition of modified surface layers of structural steels by applying electrospark coatings with the required level of tribotechnical properties has been demonstrated.

Key words: *structural steels, coating, friction, abrasive, electrospark deposition, wear resistance, carbides.*

Introduction. The use of resource-saving technologies for strengthening iron-carbon alloys to improve their wear resistance under abrasive conditions is a relevant direction aimed at increasing the service life of machine parts subject to abrasive wear during operation.

The work [1] states that the only way to resolve or significantly reduce the severity of the abrasive wear problem is the use of optimal materials that combine sufficiently high wear resistance with acceptable cost. This goal is achieved using two approaches: based on the tribological approach, the mechanisms of abrasive wear processes are identified to build their numerical or analytical models; based on the materials science approach, the dependence of material wear resistance on their microstructure and properties is determined. The dependencies of wear resistance on composition, structure, and properties remain qualitatively valid under any abrasive wear conditions, making it possible to recommend specific materials for use.

The relevance of electrospark doposition (ESD) methods for increasing the wear resistance of parts remains high in many industries related to the development of high-performance machinery and advanced technologies.

Electrospark deposition (ESD) is used to strengthen the surface of a part or to restore damaged or worn components, which significantly saves time and costs and extends the service life of machines and mechanisms. The ESD method allows the deposition of materials with improved properties—such as high hardness, strength, corrosion resistance, etc.—onto component surfaces [2]. This is especially important in conditions where parts are subject to intensive wear, such as in the aviation and automotive industries.

The reduction in material and energy consumption in the ESD process contributes to lowering emissions and waste, which aligns with modern environmental standards. The development of new materials and high-efficiency technologies makes ESD even more relevant for improving wear resistance and enabling new possibilities for part enhancement.

Review of Publications and Analysis of Unresolved Issues. Structural steels are widely used in the manufacturing of various components, mechanisms, and constructions in mechanical engineering (e.g., bushing bearings, seals, piston rods, chains, hinges, bolts, shafts, etc.). Wear, fatigue, corrosion, and other processes lead to the premature failure of steel components [3]. Various surface engineering methods – such as surface treatment and coating deposition—are frequently employed to improve surface properties of steel parts and extend their service life.

The main methods for obtaining wear-resistant coatings include thermal spraying, plasma electrolytic/micro-arc oxidation, electroplating, physical and chemical vapor deposition (PVD and CVD), among others [4].

Due to increasing environmental protection requirements, some methods that require additional expensive operations – such as wastewater treatment and hazardous waste disposal—are becoming less relevant. Preference is given to alternative and environmentally friendly methods for applying wear- and corrosion-resistant coatings, which is an important scientific and technological task. The ESD method is environmentally clean and has a number of advantages: low cost, relative simplicity, ease of process automation, high adhesion strength of the coating, and the ability to locally treat parts [5].

The key properties required for wear-resistant coatings on steel parts include high hardness, wear resistance, resistance to cracking, and others. An important distinguishing feature of the ESD method is the absence of significant heating of the substrate to which the protective coating is applied. This eliminates the formation of heat-affected zones in the substrate, which otherwise would lead to internal stresses, coating cracking, and decreased physical and mechanical properties of the coating [6].

The effectiveness of the ESD method for applying protective coatings is based on the use of high-quality electrode materials. For example, wear tests on stainless steel Cr18Ni10Ti strengthened with ESD coatings (ESC) made from refractory metals and graphite showed that all ESCs demonstrated higher wear resistance than the original Cr18Ni10Ti steel [7]. X-ray structural analysis revealed the formation of molybdenum, tungsten, titanium carbides, titanium nitride, and a nickel-titanium intermetallic on the surface of the alloyed steel, increasing microhardness by 4.9 to 8 times and wear resistance by 1.63 to 29 times.

In work [8], local strengthening of the surface layer of parts to a depth of 10–40 μm was established, as well as an increase in the surface hardness of steel with a sorbite structure to HV 600–650 during electrospark deposition with tungsten and chromium. It was determined that the wear resistance of parts strengthened by ESD increases by 1.3 times compared to the initial state.

Work [9] notes that among eutectic alloys recommended for ESD coatings based on their physical and mechanical properties, the main materials belong to the Fe-Mn-C-B system alloyed with various additives to enhance hardness, corrosion resistance, and wear resistance. However, a disadvantage of these systems is the appearance of harmful impurities such as sulfur, oxygen, phosphorus, and others during the synthesis of such coatings. These impurities significantly reduce the operational characteristics of the coatings due to increased brittleness.

As mentioned in [10], traditional electrode materials for ESD are metals and their alloys—for improved adhesion, homogeneity, and coating thickness—and carbide composite materials mainly based on tungsten and titanium compounds—for increasing surface hardness. Recently, there has been a trend toward using composite electrode materials based on non-metallic refractory superhard compounds such as B_4C, AlN, Al_2O_3, etc., but their high brittleness limits their use.

Thus, the selection of electrode material composition is crucial for the tribological and mechanical properties of the coatings and their service life. In this study, the choice of electrode material was based on obtaining ESD coatings on structural steels that would provide high anti-wear performance in an abrasive environment.

The aim of this work was to assess the wear resistance of electrospark coatings (ESCs) on structural steels in abrasive conditions.

Experimental Equipment and Research Methodology. For the research, the following materials were selected: alloyed structural steel 30ChGSA and high-quality carbon structural steels 30 and 45 in the normalized condition. ESCs were applied using the “Елітрон -22” unit with a constant short-circuit current of 1A. High-carbon steel У10 and high-speed steel Р18 were used as electrode materials. In the initial state, all the studied steels had a ferrite-pearlite structure; the ESCs formed were characterized by a discrete structure (Fig. 1).

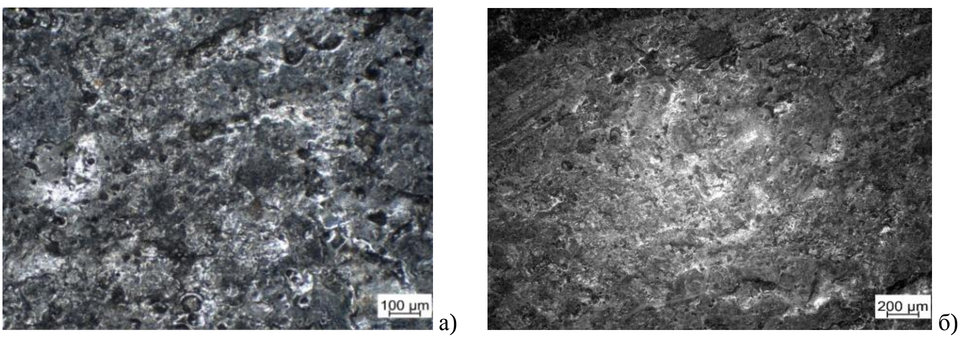

Fig. 1. Surface image of electrospark coatings formed from У10 steel electrodes (a) and P18 steel electrodes (b) on structural steel 45.

The abrasive wear tests were conducted using a methodology analogous to the ASTM G65 Abrasive Wear Test (abrasive – quartz sand (SiO_2) with a grain size of 500 μm; rubber wheel rotation speed – 0.158 m/s; load – 44.1 N; test duration – 20 minutes) [11].

The weight loss due to wear was measured using Axis ANG200C precision scales (class 2, with a resolution of 0.0001 g).

Research Results and Their Analysis. Microstructural analysis of ESCs revealed that, after friction testing, the coatings were characterized by island-like distribution with varying local layer thicknesses (from approximately 40 μm to 3–6 μm) (Fig. 2). The coatings produced using U10 and R18 steels showed high adhesive and cohesive strength, which was visually assessed based on the uniformity of the coating structure and the absence of cracks or chipping both in the coating and at the coating-substrate interface.

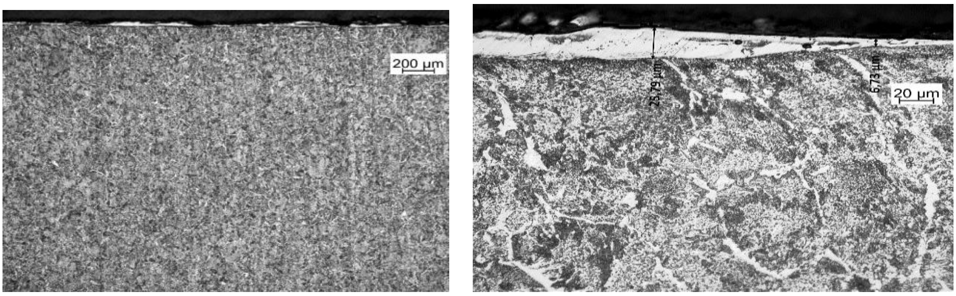

Fig. 2. Microstructure fragments of steel 45 (cross-section) with an ESC of P18 steel applied

The weight loss due to wear of the studied materials is shown in Fig. 3. It was established that for uncoated structural steels, wear in abrasive conditions decreases with increasing material hardness. For steels 30, 45, and 30ChGSA with respective hardness values of HB 150, 165, and 200, the weight loss amounted to 0.052 g, 0.041 g, and 0.033 g.

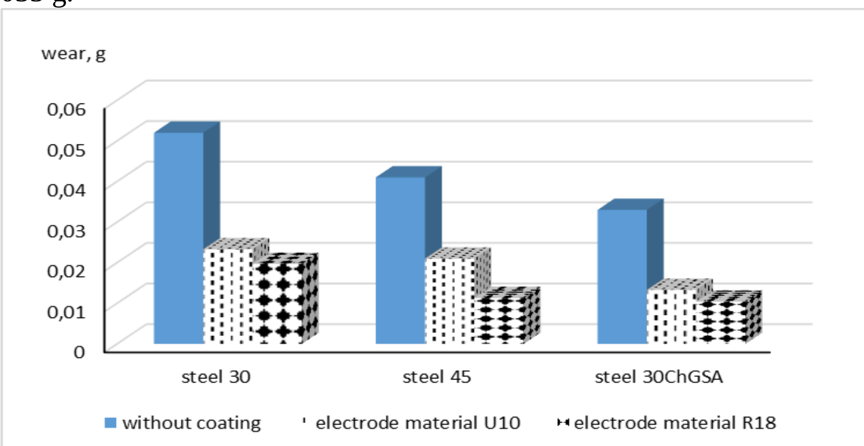

Fig. 3. Weight loss of structural steels and ESCs in abrasive conditions.

Thus, the increase in carbon content in steel 45 compared to steel 30 leads to an increase in strength, hardness, and resistance to abrasive wear due to the greater proportion of iron carbides in its structure (Table 1).

Table 1

Chemical composition (%) of the investigated structural steels

C	Si	Mn	Ni	S	P	Cr	Cu	As
Steel 30 (DSTU 7809:2015)								
0.27-0.35	0.17-0.37	0.5-0.8	<0.3	<0.04	<0.035	<0.25	<0.3	<0.08
Steel 45 (DSTU 7809:2015)								
0.42-0.5	0.17-0.37	0.5-0.8	<0.3	<0.04	<0.035	<0.25	<0.3	<0.08
Steel 30ХГСА (DSTU 7806:2015)								
0.28-0.34	**0.9-1.2**	**0.8-1.1**	<0.3	<0.025	<0.025	**0.8-1.1**	<0.3	-

The highest wear resistance under abrasive conditions was observed in the medium-alloy steel 30ChGSA, which is attributed to the presence of deposition elements such as manganese and chromium. These elements exhibit high chemical affinity for carbon and act as carbide-forming agents. The deposition elements Mn and

Cr, present in the steel up to 1.1% (see Table 1), dissolve in cementite, replacing some iron atoms and forming alloyed cementite of the types $(Fe, Mn)_3$ C and $(Fe, Cr)_3$ C. It should be noted that manganese is also known to increase steel strength without significantly reducing its ductility, while silicon - present in steel 30ChGSA up to 1.2% – promotes the formation of fine-grained structure and enhances strength.

According to Taylor's model [1], the maximum resistance to plastic deformation (τ_{max}) is determined by the stress required to allow edge dislocations to pass through their maximum interaction positions. Given that allowable shear stresses are often derived using strength theories and expressed through allowable tensile stresses, we accept $\tau_{max} \approx 0.6[\sigma]$. Accordingly, for steels 30, 45, and 30ChGSA, τ_{max} is estimated at 170, 220, and 420 MPa, respectively (Fig. 4). Thus, the increased resistance to plastic deformation of steel 30ChGSA compared to the other investigated steels contributes to its improved wear resistance under abrasive particle indentation or scratching.

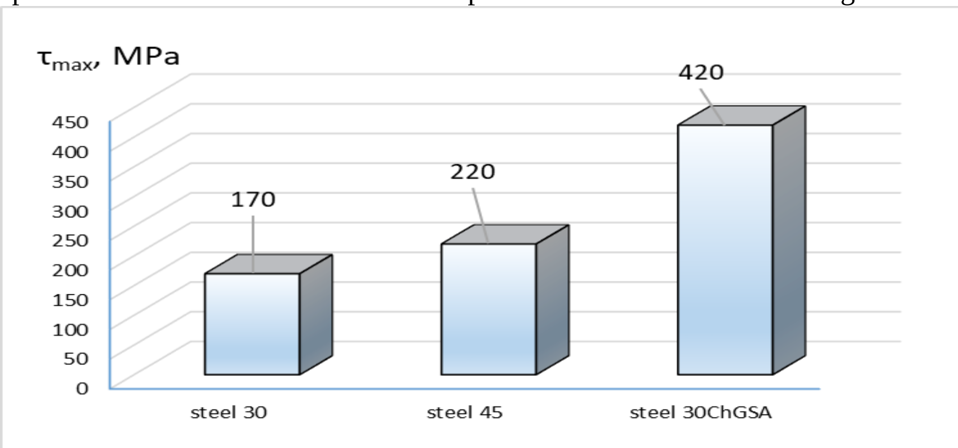

Fig. 4. Estimated allowable shear stresses for structural steels.

The application of ESCs provides a significant improvement in the wear resistance of the studied steels under abrasive conditions (see Fig. 3). In particular, the ESC based on У10 steel reduced the weight loss of steels 30, 45, and 30ChGSA by 2.2, 1.95, and 2.48 times, respectively. The ESC based on P18 steel demonstrated even more effective resistance of the strengthened surface layers under the impact of abrasive particles – weight loss of steels 30, 45, and 30ChGSA was reduced by 2.63, 3.62, and 3.17 times, respectively.

The improvement in wear resistance of the studied steels due to ESC application is explained by the strengthening of the surface layers through the formation of coatings containing a higher share of carbides of Fe (for ESCs made from U10 and R18 steels), and W, Cr, and V (for ESC from R18 steel).

Conclusions

1. Experimental results have proven that the increased resistance to abrasive wear of steel 45 is due to a higher proportion of iron carbides in comparison to steel 30.

2. The highest wear resistance under abrasive conditions was observed in the medium-alloy steel 30ChGSA, attributed to the presence of deposition carbide-forming elements such as manganese and chromium.

3. The wear resistance of structural steels under abrasive particle exposure is significantly enhanced by applying ESCs made from U10 and R18 steels, which contain an increased amount of carbides.

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Стаття надійшла до редакції 20.05.2025

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ПІДВИЩЕННЯ ЗНОСОСТІЙКОСТІ КОНСТРУКЦІЙНИХ СТАЛЕЙ ЕЛЕКТРОІСКРОВИМ ЛЕГУВАННЯМ

Проаналізовано переваги методу електроіскрового легування при формуванні зносостійких покриттів на сталевих деталях та визначені основні вимоги до матеріалів електродів для формування покриттів з високою твердістю, стійкістю до зносу, відсутністю тріщиноутворення. Мета роботи полягала в оцінці зносостійкості електроіскрових покриттів високовуглецевої сталі У10 та швидкоріжуючої сталі Р18 на конструкційних сталях в абразивному середовищі. Встановлено, що для конструкційних сталей без покриття ваговий знос в абразивному середовищі зменшується по мірі зростання твердості матеріалу, що спричинено зростанням стійкості до абразивного зношування сталі 45 за рахунок збільшення частки карбідів заліза, а для середньолегованої сталі 30ХГСА за рахунок легуючих карбідоутворюючих елементів марганцю та хрому. Обгрунтовано підвищення зносостійкості конструкційних сталей при нанесенні електроіскрових покриттів за рахунок більш ефективного опору поверхневих зміцнених шарів за умов впливу абразивних часток, що обумовлено формуванням покриттів з високою часткою карбідів Fe (електроіскрові покриття з сталі У10 та Р18), W, Cr, V (електроіскрове покриття з сталі Р18). Показана можливість управління структурними ефектами та фазовим складом поверхневих модифікованих шарів конструкційних сталей нанесенням електроіскрових покриттів з необхідним рівнем триботехнічних властивостей.

Ключові слова: конструкційні сталі, покриття, тертя, абразив, електроіскрове легування, зносостійкість, карбіди.

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