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OPTIMIZATION OF ELECTRIC ARC METALLIZATION PARAMETERS TO IMPROVE THE PROPERTIES OF 30KhGSA STEEL COATINGS IN THE AUTOMOBILE INDUSTRY

This paper discusses the optimization of arc spraying parameters to improve the properties of 30KhGSA steel coatings, which are widely used in the automotive industry. The use of high-strength steels such as 30KhGSA is driven by the need to improve safety, energy efficiency and reduce emissions. The paper examines in detail the effects of compressed air pressure, temperature and other spraying parameters on the quality of the coatings. The use of the supersonic arc spraying method made it possible to obtain coatings with improved mechanical properties such as hardness, wear resistance and adhesion strength. The experiments were carried out using an electron microscope to analyze the cross-section of the coatings, as well as a profilometer to assess the surface roughness. The results demonstrate that increasing the compressed air pressure helps to reduce roughness and increase the hardness of the coating. The paper emphasizes the importance of optimizing the metallization parameters to improve the efficiency of protective coatings under high operating conditions in the automotive industry.

Key words: *arc spraying, coating, steel surfacing wire, wear resistance, adhesion, hardness.*

Introduction

The automotive industry is under increasing pressure to adopt advanced high-strength steels to meet the growing demand for improved safety, energy efficiency, and reduced emissions [1]. One such material that has attracted the interest of researchers and industry professionals is 30KhGSA steel, a high-strength, low-alloy steel characterized by unique chemical composition and microstructural features [2, 3]. Electric arc spraying, a thermal spraying method, has emerged as a promising method for applying protective coatings to these steel surfaces [3].

Damaged crankshafts, often caused by wear, can be restored to functionality using a variety of methods, including hard chrome plating. This process improves the surface hardness, wear resistance, and corrosion resistance of the crankshaft, thereby extending its service life. However, environmental and health concerns associated with chrome plating have led to the exploration of alternative coating methods, such as electric arc spraying. This method uses compressed air to deliver droplets of molten metal onto a substrate, creating a protective coating with the desired mechanical and tribological properties [4, 5]. The aim of this research is to study the effect of compressed air on the properties of 30KhGSA steel coatings obtained using electric arc spraying.

Materials and research methods

In the experiment, the EDM-5U electric arc metallizer shown in Figure 1 was used to obtain the coating. Steel grade 45 was used as a substrate, and the diameter of the 30KhGSA steel wire was 1.6 mm. Before spraying, the samples were sandblasted. The coating application modes are given in Table 1.

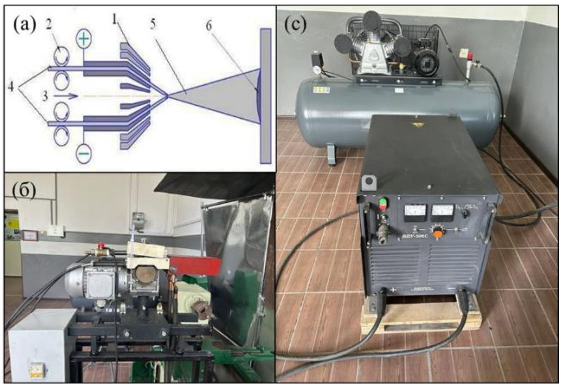

Figure 1 – a) Flow chart of electric arc metallization (1 – metallizer body; 2 – wire feed mechanism; 3 – air supply channel; 4 – electrode wires; 5 – electric arc with sprayed wire particles; 6 – sprayed coating) b) external view of the gun; c) external view of the source and compressor.

Table 1 – Modes of applying 30KhGSA coatings by electric arc metallization

Sample	Voltage, V	Current, A	Wire feed speed, cm/s	Compressed air pressure, atm	Spray distance, mm	Spray time, sec
№ 1	42	300	16	7	15	15
№ 2				8		
№ 3				9		

A JSM-6390 LV JEOL electron microscope was used to study the cross-section of the coatings. The roughness of the coatings was measured using an Anytester HY2300 profilometer. The microhardness of the created coatings was determined by the cross-section using a Vickers HLV-1DT microhardness meter with an indenter load of 0.2 N and a holding time of 10 seconds. The tribological properties of the coatings were studied using an Anton Paar TRB3 tribometer.

The adhesion strength of the coatings was assessed using the pin method [6]. The essence of the method is that when a load is applied, the coating is torn off from the substrate, while the force required for tearing is recorded. To assess the adhesive strength using the pin method, samples were prepared (see Fig. 2) consisting of a pin and a substrate equipped with a gripping device with a hole and a fastener for fixing the pin. The sample design used a washer with a hole in which a pin was installed so that its end surface was flush with the outer plane of the washer. The coating was applied to the common surface of the end of the pin and the washer. To prevent the pin from falling out during spraying, it was fixed with a screw. The pin was torn off the substrate using a universal tensile testing machine WDW-100 kN. The adhesion strength was determined as the ratio of the maximum force at which the coating was torn off to the area of the end of the pin.

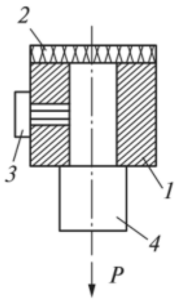

Figure 2 – Testing the adhesion strength of coatings using the pin method:
a) Schematic diagram of the manufactured sample: 1 – substrate (45 steel); 2 – coating; 3 – retainer; 4 – pin

Results and discussion

Figure 3 shows the scanning electron microscope (SEM) images showing the cross-sections of the coatings produced by the supersonic arc metallization method. It can be seen from Figures 3a, b, c that the coating thickness varies. With increasing compressed air pressure, the effective spraying efficiency decreased, probably due to the decrease in particle size. The coating thickness values are given in Table 2. It can also be seen that with increasing compressed air pressure, the coatings become denser and less porous.

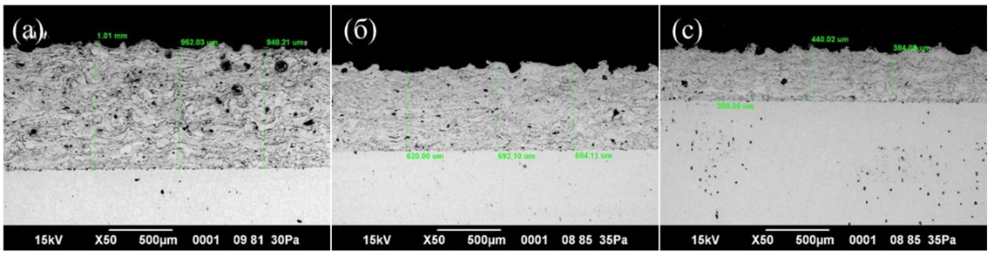

Figure 3 – SEM images of cross sections of samples

Table 2 – Coating thickness

Sample	№ 1	№ 2	№ 3
Coating thickness, μm	966,78±22,21	665,4±30,27	401,36±25,77

Studies have shown that the surface roughness of coatings produced by supersonic arc metallization (SAM) decreases with increasing compressed air pressure. The roughness was measured using the Ra parameter, which is the arithmetic mean deviation of the surface profile. According to the data, an increase in pressure contributes to a decrease in the Ra index: for sample № 1 it is 20,054 μm, for sample № 2 – 19,16 μm, and for sample № 3 – 14,358 μm. This is due to the fact that an increase in pressure increases the kinetic energy of the coating particles, which leads to their stronger impact on the substrate and a denser, more uniform distribution of the material. A higher particle velocity improves their sintering and merging both with each other and with the substrate, which reduces the number of microvoids and irregularities. In addition, more efficient spraying at increased pressure contributes to a uniform distribution of particles and the formation of a smooth surface with smaller height deviations [7-10].

Figure 4a shows that the hardness of the coatings obtained by the supersonic arc metallization method is higher than that of steel 45. With an increase in compressed air pressure, the hardness of the coatings also increases. It should be noted that the steel wire of the 30KhGSA brand used for spraying has a higher hardness compared to steel 45, amounting to 289 HV and 204 HV, respectively. It is noteworthy that the hardness of the coatings exceeds the hardness of the original wire. Sample № 1, processed at a compressed air pressure of 7 atm, has a hardness of 309,33±13,89 HV; sample № 2, at a pressure of 8 atm – 314,2±12,1 HV; and sample № 3, at a pressure of 9 atm – 331±10,32 HV.

The increase in the coating hardness compared to the original 30KhGSA wire after supersonic arc metallization is explained by the fact that upon contact with the substrate, the metal particles are subjected to rapid cooling due to a cold jet of compressed air, which contributes to their instantaneous hardening [11, 12]. The increase in hardness with increasing compressed air pressure is due to the fact that with greater kinetic energy, the density of the coatings increases. The density of the sprayed metal depends on the speed of the particles before impact and their dispersion: the smaller the particle size, the higher the hardness, and the dispersion increases with increasing compressed air pressure.

Figure 4b shows the results of determining the friction coefficient. The obtained values are as follows: steel 45 – 0,472; sample № 1 – 0,538; sample № 2 – 0,528; sample № 3 – 0,523. These results demonstrate that with an increase in compressed air pressure, it is possible to improve the wear resistance of the coatings. With an increase in compressed air pressure, the average pore size decreases, which helps to improve the antifriction properties of the coatings.

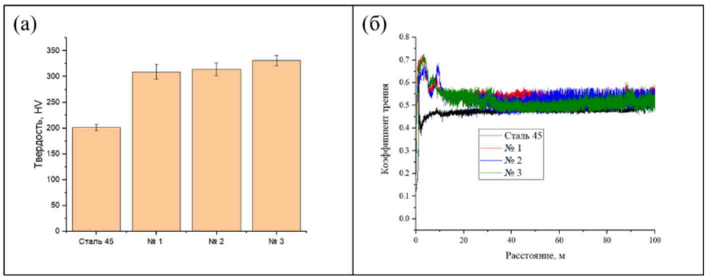

Figure 5 – Results of tribomechanical tests of coatings: hardness (a); coefficient of friction (b)

When testing the adhesion strength of the coatings using the pin method, an adhesive rupture occurred in all samples, indicating the presence of a clear interface between the substrate and the coating. This means that the adhesion strength between the coating and the substrate was lower than the cohesive strength of the coating particles. Table 5 presents the results of the study of the adhesion strength of the coatings, which show that with an increase in compressed air pressure, the adhesion strength increases. Sample № 3, sprayed at a compressed air pressure of 9 atm, demonstrated the best results. This is due to the fact that higher pressure contributes to an increase in the kinetic energy of the particles, which leads to a stronger penetration of the coating particles into the surface of the substrate.

Table 3 – Results of coating adhesion strength tests

Samples	Coating adhesion strength, MPa
№ 1	15,43±2,11
№ 2	18,55±1,65
№ 3	22,32±0,95

Conclusion

This study examined the influence of various parameters of the supersonic arc metallization process on the properties of protective coatings made of 30KhGSA steel. Particular attention was paid to changing the compressed air pressure and its effect on the mechanical and tribological properties of the coating, such as hardness, adhesion and wear resistance. The results confirm that optimization of metallization parameters can significantly improve the performance characteristics of coatings, making them suitable for use under high load conditions, which is especially important for the automotive industry.

Based on the analysis, the following conclusions were made:

1. Increasing the compressed air pressure during spraying significantly improves the quality of the coating. With increasing pressure, the porosity and roughness of the coating decreases, and the density and homogeneity of the distribution of particles on the substrate surface increases.

2. The maximum mechanical properties of the coating, such as hardness and wear resistance, were achieved at a compressed air pressure of 9 atm. This pressure also ensured the best results in terms of the adhesive strength of the coating, which is due to the increased kinetic energy of the particles and their stronger penetration into the substrate.

3. Experiments confirmed that increasing the compressed air pressure increases the speed of the particles, which leads to better fusion of the coating particles with the substrate and a decrease in the number of microvoids. This improves the mechanical properties of the coating and its resistance to wear and corrosion, which is especially important for parts subject to high loads.

4. The results of the work show that optimizing the parameters of supersonic arc metallization can significantly improve the performance characteristics of the coatings. This opens up prospects for further application of this method in the restoration and protection of parts such as crankshafts and transmission components operating in difficult conditions. The results obtained can be used to optimize the parameters of the supersonic arc metallization process in order to improve the characteristics of protective coatings in mechanical engineering and other industries.

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АВТОМОБИЛЬ ӨНЕРКӘСІБІНДЕГІ 30ХГСА БОЛАТ ЖАБЫНДАРЫНЫҢ ҚАСИЕТТЕРІН ЖАҚСАРТУ ҮШІН ЭЛЕКТР ДОҒАЛЫҚ МЕТАЛДАНДЫРУ ПАРАМЕТРЛЕРІН ОҢТАЙЛАНДЫРУ

Бұл мақалада автомобиль өнеркәсібінде кеңінен қолданылатын 30хгс Болат жабындарының қасиеттерін жақсарту үшін электр доғасын металдандыру параметрлерін оңтайландыру қарастырылады. 30ХГСА сияқты жоғары беріктігі бар болаттарды пайдалану қауіпсіздікті, энергия тиімділігін арттыру және шығарындыларды азайту қажеттілігіне байланысты. Мақалада қысылған ауа қысымының, температураның және басқа бүрку параметрлерінің жабын сапасына әсері егжей-тегжейлі қарастырылады. Дыбыстан жоғары доғалық металдандыру әдісін қолдану қаттылық, тозуға төзімділік және жабысқақ беріктік сияқты жақсартылған механикалық қасиеттері бар жабындарды алуға мүмкіндік берді. Тәжірибелер жабындардың көлденең қимасын талдау үшін электронды микроскопты, сондай-ақ бетінің кедір-бұдырын бағалау үшін профометрді қолдану арқылы жүргізілді. Нәтижелер Сығылған ауа қысымының жоғарылауы кедір-бұдырдың төмендеуіне және жабынның қаттылығының жоғарылауына ықпал ететінін көрсетеді. Мақала автомобиль өнеркәсібінде жоғары пайдалану жағдайында қорғаныс жабындарын қолдану тиімділігін арттыру үшін металдандыру параметрлерін оңтайландырудың маңыздылығын көрсетеді.

Түйін сөздер: *электр доғасын металдандыру, қаптау, Болат беткі сым, тозуға төзімділік, адгезия, қаттылық.*

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ОПТИМИЗАЦИЯ ПАРАМЕТРОВ ЭЛЕКТРОДУГОВОЙ МЕТАЛЛИЗАЦИИ ДЛЯ УЛУЧШЕНИЯ СВОЙСТВ ПОКРЫТИЙ СТАЛИ 30ХГСА В АВТОМОБИЛЬНОЙ ПРОМЫШЛЕННОСТИ

Аннотация: *В статье исследуются параметры электродуговой металлизации для оптимизации свойств защитных покрытий из стали 30ХГСА, которая играет ключевую роль в автомобильной промышленности благодаря своей высокой прочности и низкой легированности. В условиях растущих требований к повышению безопасности, энергоэффективности и снижению вредных выбросов, такие материалы становятся всё более востребованными. Основное внимание уделяется влиянию давления сжатого воздуха на качество покрытий, наносимых методом сверхзвуковой дуговой металлизации. Эксперимент проводился с использованием стали 45 в качестве подложки и проволоки 30ХГСА диаметром 1,6 мм. Для оценки влияния различных режимов металлизации были проанализированы такие параметры, как напряжение, ток, скорость подачи проволоки, давление сжатого воздуха и расстояние распыления. В качестве методов исследования использовались электронный микроскоп JSM-6390 LV JEOL для анализа поперечных сечений покрытий, профилометр Anytester HY2300 для оценки шероховатости и трибометр Anton Paar TRB3 для изучения трибологических характеристик. Полученные данные показали, что увеличение давления сжатого воздуха приводит к значительному уменьшению пористости и шероховатости покрытия, повышению его твердости и износостойкости. Особенно важным результатом стало улучшение адгезионной прочности покрытия при давлении 9 атм, что связано с более плотным и равномерным распределением частиц. Исследования также показали, что повышение кинетической энергии частиц способствует лучшему слиянию покрытия с подложкой и увеличению эксплуатационных свойств покрытия, таких как стойкость к износу и коррозии. Эти результаты подчеркивают значимость оптимизации параметров сверхзвуковой дуговой металлизации для создания высокоэффективных защитных покрытий, применяемых в условиях интенсивных нагрузок, что особенно актуально для деталей автомобильных двигателей и трансмиссий.*

Ключевые слова: *электродуговая металлизация, покрытие, стальная наплавочная проволока, износостойкость, адгезия, твердость.*

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ОТЕЧЕСТВЕННОЕ ПРОИЗВОДСТВО МАЛОГАБАРИТНОЙ СПЕЦТЕХНИКИ (МИНИ-ТРАКТОРЫ, МИНИ-ФРОНТАЛЬНЫЕ ПОГРУЗЧИКИ)

Аннотация: *В данной статье рассматривается производство малогабаритной спецтехники, в частности мини-тракторов и мини-погрузчиков. Основное внимание уделено актуальности использования таких машин в условиях ограниченных пространств и специфики малых хозяйств. Приведены ключевые аспекты разработки и проектирования мини-техники, обсуждаются используемые материалы и производственные процессы. Описаны результаты исследований по эффективности малогабаритной техники в сельскохозяйственной и строительной сферах, их экономическая выгода, экологическая безопасность и практическая ценность. На основе проведённых исследований делаются выводы о необходимости и перспективах развития малогабаритной спецтехники как эффективного решения для малого бизнеса и частных хозяйств и снижения импортозависимости Республики Казахстан.*

В статье также рассматриваются экономические выгоды малогабаритной техники, связанные с сокращением эксплуатационных затрат, повышением производительности и адаптацией к нуждам малого бизнеса и частных хозяйств.

Авторы приводят результаты исследований, демонстрирующие эффективность использования малогабаритной техники в различных отраслях экономики, включая