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Mining machine parts restoration by laser surfacing

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Abstract

Introduction. *The main reason for mining equipment failure is parts wearing out. Their effective repair requires advanced process flows. In the aircraft industry, for example, nickel-based alloys are widely used due to good mechanical properties. They should be considered for mining machine parts repair.*

Methods of research. *Chrome-nickel-based (Inconel 718) and chrome-molybdenum-based (38ChMA) and chrome-phosphorus-based (42ChPhA) powders were used to form coatings by laser surfacing using Optomec LENS 450 system. The adhesive strength of the deposited layer to the surface of the part, Vickers hardness (HV) and tribological properties of samples during dry sliding friction were determined. Structure was studied by the metallographic analysis with a scanning electron microscope.*

Research results. *The adhesive force of an Inconel 718 layer deposited on 38ChMA and 42ChPhA steel is higher than that of a sample of 38ChMA plus 38ChMA and a sample of 42ChPhA plus 42ChPhA. The microhardness of the deposited layers of Inconel 718 and the part surface from 38ChMA or 42ChPhA have similar values (about 520 HV). The fracture of samples with a deposited layer of Inconel 718 is of a ductile nature, and the fracture of samples with a deposited layer of 38ChMA or 42ChPhA is of a brittle nature. The worn out surface morphology for deposited 38ChMA and 42ChPhA materials is similar.*

Conclusion*. The possibility of repairing mining machine parts made of 38ChMA and 42ChPhA steel by laser surfacing is shown. The deposited layers of Inconel 718 alloy have good mechanical and tribological properties. The wear resistance of parts with deposited Inconel 718 material is on average 1.7 times higher than after surfacing with 38ChMA and 42ChPhA steel.*

Keywords: *parts restoration; wear resistance; mechanical properties; surfacing; steel; hardness.*

Introduction. Mining machines operate in harsh conditions. They are exposed to temperature changes, corrosion, and wear resulting in serious mechanical damage to the surfaces of parts, such as micropitting and scoring, which lead to equipment failure [1]. Machine parts work surface wearing out is the main reason for mining equipment failure. A damaged part is often replaced with a new one, which leads to a serious waste of material resources and increased operating costs.

The feasibility of equipment repair is explained by the growing fleet of mining machines, spare parts production problem, especially for imported equipment under the EU sanctions, and phasing out obsolete equipment with the remaining need for spare parts. Therefore, the main goal of machinery repair industry is to save material resources and reduce equipment repair time by increasing the efficiency of repair flow processes.

Advanced flow processes [2, 3] which ensure improved efficiency include electric arc welding [4], electron beam welding, electrospark deposition [5], plasma spraying [6], laser surfacing [7, 8], supersonic spraying [9], using concentrated energy fluxes [10], etc. Each method has advantages and disadvantages.

The present research focuses of the technology of restoring the parts surfaces by laser surfacing. Layers obtained by laser surfacing have a minimal heat affected zone and a low mixing ratio of the deposited material and the material of the part, which ensures higher dimensional accuracy and good mechanical properties. Laser surfacing is also characterized by high adhesive strength to the surface of the part compared to such methods as high velocity oxygen fuel spraying and plasma processing [11]. When restoring parts by laser surfacing, two process flows are used: depositing the material the part is made from, or depositing other material that can improve the physical and mechanical properties of the surface [7, 8].

After applying the first option to heavy duty parts (gears, turbine blades), the restored part mechanical properties cannot become better than those of the new one. So, to restore and improve the part surface properties, the second option should be applied. For laser surfacing, the alloys stronger and harder than the material of the part being restored can be considered. In the aircraft industry, for example, nickel-based alloys are widely used due to good mechanical properties [12, 13]. They should be considered for mining machine parts repair as well.

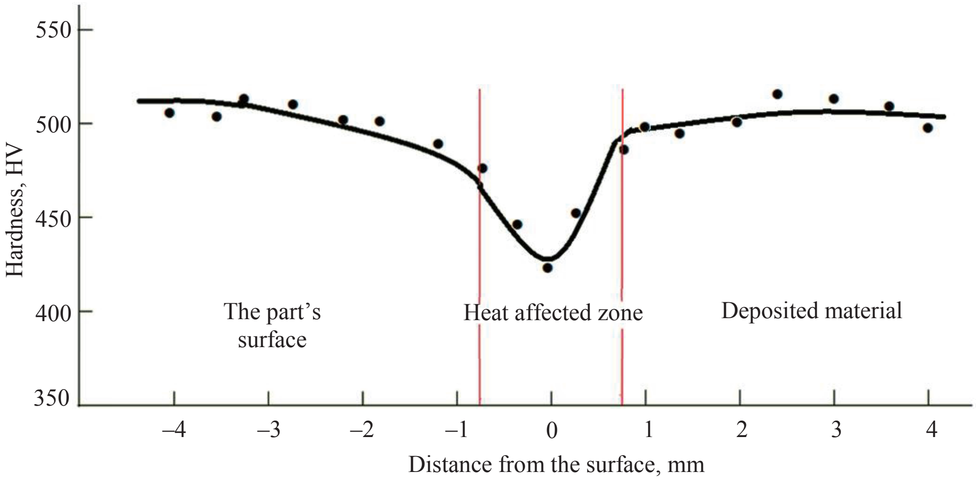

Figure 1. Hardness distribution along the depth of the sample
Рисунок 1. Распределения твердости по глубине образца

Research objective. The possibility of using these alloys to repair mining machinery parts made of alloy steel using laser surfacing is not sufficiently reflected in literature. It is therefore necessary to consider such alloys application in mining machinery repair.

Materials and experimental procedures. *Materials.* To consider the possibility of using laser surfacing for mining machinery repair, 38ChMA (chrome-molybdenum-based, carbon ~ 0.38%) and 42ChPhA (chrome-phosphorus-based, carbon ~ 0.42%) steel parts were chosen. To form deposited coatings, a nickel-based alloy Inconel 718 (GOST standard 5632) and 38ChMA and 42ChPhA steel powders were used. Microstructure and mechanical properties, namely microhardness, adhesive strength, wear resistance of materials after spraying with Inconel 718, 42ChPhA and 38ChMA alloy powders were compared with the original materials from 38ChMA and 42ChPhA steel.

Experimental procedure. Surfacing was carried out with an Optomec LENS 450 system, which included a laser, pneumatic system of powder delivery. Cylindrical rods of 38ChMA and 42ChPhA steel (30 mm long, 10 mm in diameter) were selected as test samples. Powders of 38ChMA, 42ChPhA and Inconel 718 steel were used for surfacing. Before surfacing, the samples were cleaned with acetone. The adhesive strength of the deposited layer to the part was determined with a MIM 2-20-2 universal tension tester under the crosshead speed of 0.2 mm/s. The Vickers hardness test was carried out on the sample cross-section with an ITV-30-AM hardness tester under a load of 50 N with a holding time of 15 s. Measurements were carried out with 0.5 mm spacing, each test was repeated five times. Fractographic analysis of the deposited part fracture surfaces was carried out with a VEGA LMS scanning electron microscope by TESCAN with an Xplore30 attachment for energy dispersive analysis by Oxford Instruments.

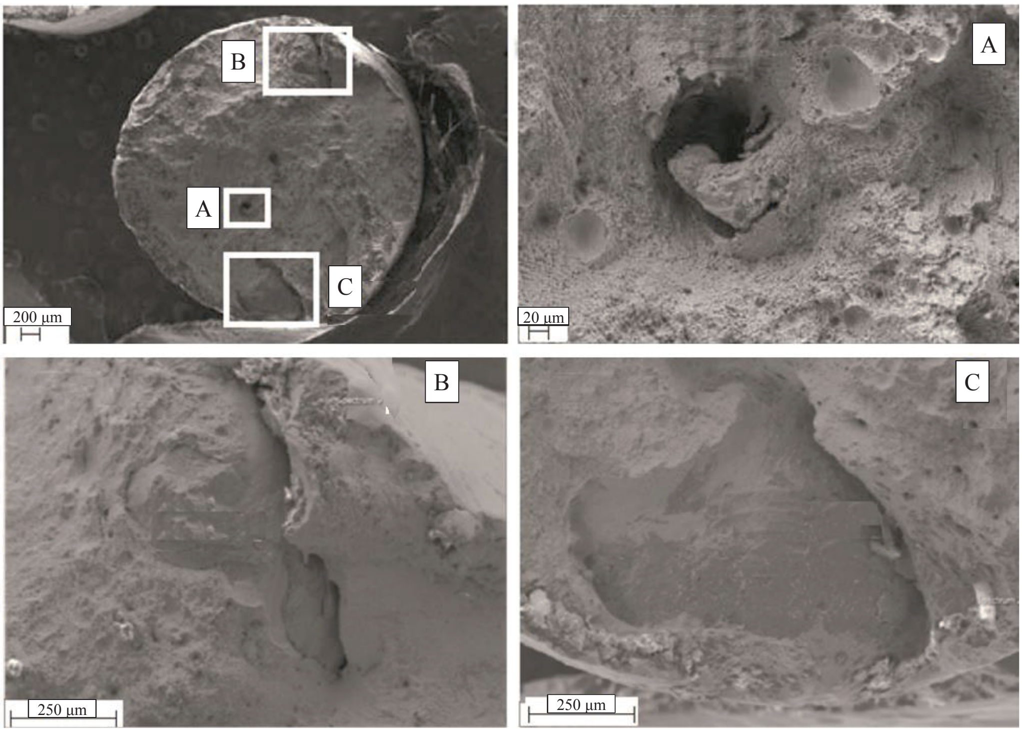

Figure 2. Analysis of fracture surface of EDS for Inconel 718
Рисунок 2. Анализ поверхности излома для ХН45МВТЮБР

The samples tribological properties were determined under dry sliding friction with an AI 5018 pin-on-disk tribometer in accordance with GOST standard 23.21080. The sliding speed was 0.52 m/s (200 rpm) on a zirconium ceramic (ZrO_2) disk under a constant load of 160 N. Wear tests were carried out on cylindrical samples (Ø10 mm × 30 mm). The pin was fixed and brought into contact with the surface of a rotating disk 50 mm in diameter. Each wear test was carried out for a total slidepath of 300 m. Before testing, the sample surface was ground using abrasive paper and polished with a cloth coated with НОМ АСМ 20/14 diamond paste. After polishing, the surfaces were washed in acetone. Each test was repeated three times and the average value was taken.

The pin weight before and after testing was measured to determine the mass loss Δm, kg, after each testing stage by formula: $\Delta m = m_1 - m_2$, where m_1 and m_2 is the sample mass before and after testing, kg. The wear rate, mm^3/m, was determined by formula: $I_v = \Delta m / (\gamma L)$ where γ is the density of the material under study, kg/m^3; L is the slidepath, m. The dimensionless wear coefficient K was calculated by the Archard formula [14]: $K = I_v H / F_{load}$ where H is the material hardness, HV; F_{load} is the axial load imposed on the test sample end, N.

Research results. *Adhesive strength test of the deposited layer*. Four types of samples were tested. The samples behavior during testing is similar, the fracture is located in the deposited part of the materials. So, the adhesive force of the deposited layer was higher than the tensile strength of the deposited materials. Hence, the adhesion force of an Inconel 718 layer deposited on 38ChMA steel (average value 645 MPa) is higher than that of a 38ChMA layer deposited on 38ChMA steel (average value 637 MPa). The adhesive force of an Inconel 718 layer deposited on 42ChPhA steel (average value 714 MPa) is higher than that of a 42ChPhA layer deposited on 42ChPhA steel (average value 590 MPa).

The highest value of the adhesive force of an Inconel 718 sample deposited on 38ChMA is 786 MPa, which is lower than the tensile strength of the wrought Inconel 718 alloy (1000~1200 MPa).

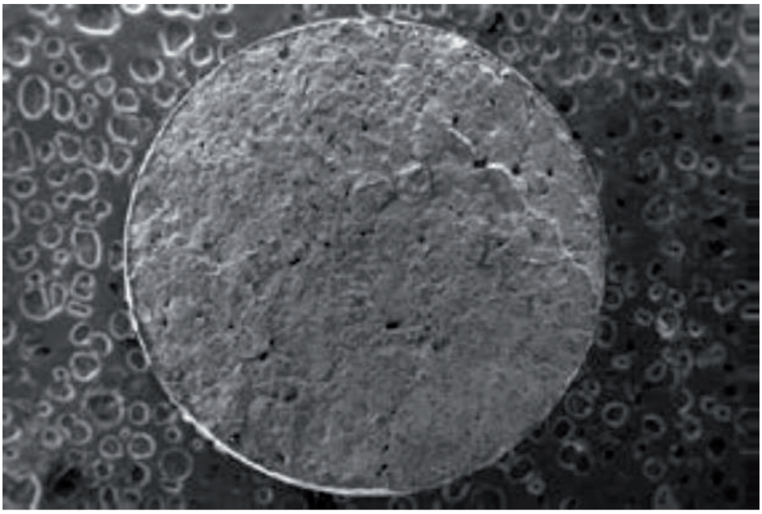

Figure 3. Steel fracture surface
Рисунок 3. Поверхность излома стали

A low value of the adhesive force can be explained by two reasons: the formation of residual stresses and the presence of pores and cracks. Since in course of material surfacing some gas remains in the chamber and dissolves in molten metal, pores are formed during hardening. Pores affect the properties of the deposited layers and lead to stress concentration, which causes the microcracks. Moreover, in course of surfacing, metals oxidize in air, and unmelted powder particles can cause cracks in the deposited layer. In course of surfacing, high temperature gradients tend to develop from the surface into the depth of the part. The related differential thermal compression creates high stresses in the deposited layer. When the deposited layer is cooled from the crystallization temperature to the surrounding temperature, residual stresses also arise in the coating [15].

Microhardness test result. The result of the deposited sample microhardness test is shown in Figure 1. The boundary between the deposited layer and the surface of the part was taken as the reference point 0 along the x axis. Hardness was measured from the outer surface into the depth of the sample on a cross-section with 0.5 mm spacing. The microhardness of the Inconel 718 deposited layers and the surface of the part have similar values (about 520 HV).

Deposited layer fracture. The general view of the surface of a part with a deposited layer of Inconel 718 indicates ductile fracture (Figure 2). There are several interesting features to note on the surface of the sample. Firstly, at high magnification (Figure 2, A), incompletely melted powder can be seen, which forms a cavity. This may be a result of excess powder introduced into the smelting bath during surfacing. A significant number of micropores can also be seen in the structure of the cavities. Secondly, the composition analysis shows that in course of surfacing, oxides were formed as a result of reaction with oxygen. Aluminum and oxygen account for a higher mass fraction compared to other elements, which indicates the presence of aluminum oxides which caused cracks (series 1, Figure 2, B) on the fracture surface (series 2, Figure 2, C).

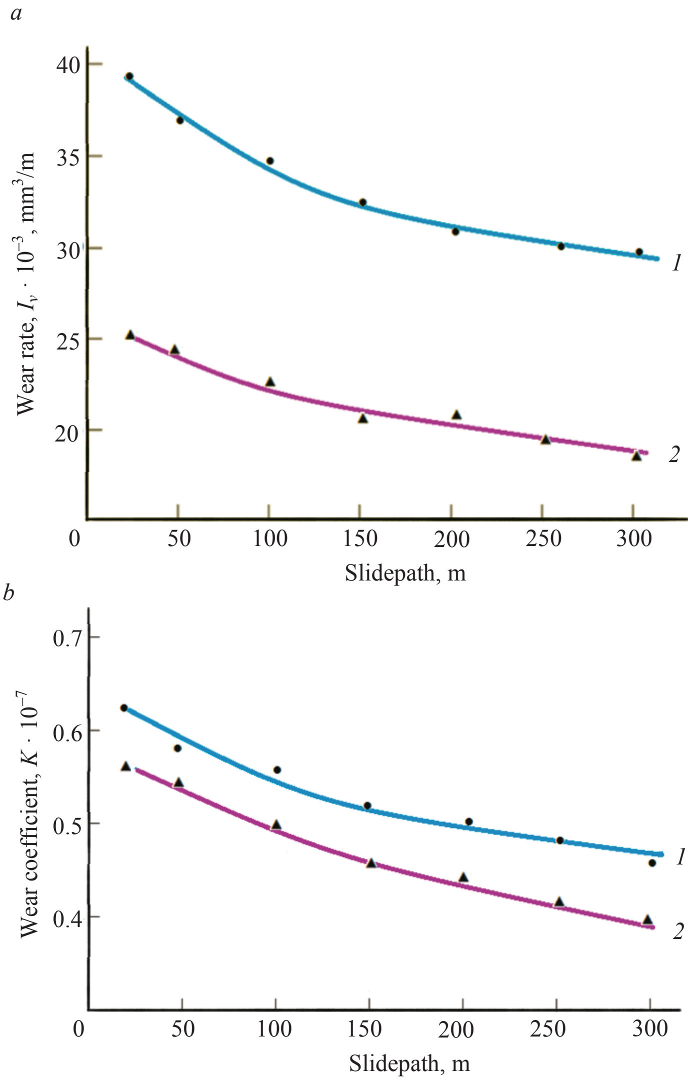

Figure 4. Wear rate depending on the sliding distance – *a*; wear coefficient versus sliding distance – *b*: *1* – 38ChMA; *2* – Inconel 718
Рисунок 4. Интенсивность износа от пути скольжения – *a*; коэффициент износа от пути скольжения – *b*: *1* – 38ХМА; *2* – ХН45МВТЮБР

From the results of the test determining the adhesive force of the layer deposited on the surface of the part, it follows that Inconel 718 samples fracture is of a ductile nature, which is associated with austenitic nickel-chromium-based alloying elements of the Inconel 718 alloy. While the 38ChMA samples fracture is of a brittle nature because of martensite embrittlement caused by high cooling rates. The average elongation of the

38ChMA and 42ChPhA deposited layers made up 2.3%, which is significantly lower than that of the Inconel 718 deposited layer (14%). The tensile strength of the 38ChMA and 42ChPhA deposited layers is also lower than that of Inconel 718, which is associated with incompletely melted powder particles and significant porosity of the layer. Despite the fact that the Inconel 718 fracture surface had defects, such as micropores and oxides, their effect on the layer properties was not as significant as that of 38ChMA.

On the other hand, the 38 ChMA deposited layer fracture surface looks smooth and even, which indicates brittle fracture (Figure 3). Significant porosity was found due to no fusion between layers in course of surfacing. Moreover, multiple unmelted spherical powder particles can be seen. A higher carbon content was also found, which can form cementite and, in turn, is responsible for cracks initiation [15].

Wear resistance tests. The results of wear resistance tests under dry sliding friction showed that the relative wear resistance of the Inconel 718 deposited material is higher than that of 38ChMA (Figure 4, *a*). The wear coefficient from the sliding distance changes the same as wear intensity (Figure 4, *b*).

The rate of the 38ChMA deposited alloy wear is about 1.7 times higher than that of the Inconel 718 deposited layer. On the surface of the 38ChMA deposited material, traces of wear, with deep grooves can be seen. The worn-out surface of the Inconel 718 deposited material is smoother, with minor scratches. So, the Inconel 718 deposited coating is more wear-resistant under dry sliding wear test conditions.

Conclusions. The present research shows the possibility of using Inconel 718 alloy to repair mining machine parts made of 38ChMA and 42ChPhA steel by laser surfacing. The following conclusions can be made:

– Inconel 718 alloy has better mechanical and tribological properties compared to other materials;

– the adhesive force of the 38ChMA–Inconel 718 or 42ChPhA–Inconel 718 formula is higher than that of the 38ChMA–38ChMA or 42ChPhA–42ChPhA formula, which may be explained by the presence of incompletely melted particles and significant porosity;

– the microhardness of the Inconel 718 and 38ChMA deposited layers has similar values;

– the wear resistance of 38ChMA (42ChPhA) alloy after surfacing is 1.7 times lower than that of the Inconel 718 material.

This technology can therefore be considered as promising for mining machine parts repair.

REFERENCES

1. Tiurin S. I. Improvement in operating efficiency of mining equipment by introduction of new repair techniques. *Gornyi informatsionno-analiticheskii biulleten (nauchno-tekhnicheskii zhurnal) = Mining Informational and Analytical Bulletin (scientific and technical journal)*. 2016; 5: 136–148. (In Russ.)

2. Lialiakin V. P. Restoration of details of cars are important direction import substitution in the agro-industrial complex. In: *Innovative technologies of restoration in mechanical engineering: Proceedings of the Internat. sci. pract. conf., 4–5 February, 2019, Moscow, Russia.* (In Russ.) Available from: doi: 10.31044/1684-2561-2019-0-9-3-5

3. Gorin A., Kuznetsov I., Prokoshina T., Byrlakova E., Kolpakova S. Study of the composition of innovative materials for the restoration and strengthening of machine parts. In: *MATEC Web of Conferences*. 2020; 329: 02030. Available from: doi: 10.1051/matecconf/202032902030

4. Chetverikov S. V. Restoration of working surfaces of machine parts by surfacing. *Transportnaia infrastruktura Sibirskogo regiona = Transport Infrastructure of the Siberian region*. 2019; 2: 280–288. (In Russ.)

5. Ivanov V. I., Kostiukov A. Iu. Use practice of electrical discharge coatings for renewal of machine parts. *Remont. Vosstanovleniye. Modernizatsiya = Remont. Recovery. Modernization*. 2017; 6: 10–17. (In Russ.)

6. Timokhova O. M., Kadyrmetov A. M., Sniatkov E. V., Romanov V. V. Recovery of valves of internal combustion engines by plasma float and direct to modulation of parameters. *Voronezhskiy nauchno-tekhnicheskiy vestnik = Voronezh Scientific and Technical Bulletin*. 2018; 1(23): 53–67. (In Russ.)

7. John M., Kuruveri U. B., Menezes P. L. Laser cladding-based surface modification of carbon steel and high-alloy steel for extreme condition applications. *Coatings*. 2022; 12: 1444. Available from: doi: 10.3390/coatings12101444

8. Khyzov A. A., Ivanov A. S., Kolmakova T. G. Prospects of application of laser surfacing at restoration of details of agricultural machinery. *Politematicheskii setevoi elektronnyi nauchnyi zhurnal Kubanskogo gosudarstvennogo agrarnogo universiteta = Polythematic Online Scientific Journal of Kuban State Agrarian University*. 2019; 154: 45–54. (In Russ.) Available from: doi: 10.21515/1990-4665-154-006.

9. Dmitriuk A. I., Farmakovskii B. V., Bobkova T. I., Gerashchenkov D. A. Restoration and repair of equipment by supersonic cold gas-dynamic and micro-plasma spraying. *Voprosy materialovedeniia = Inorganic Materials: Applied Research*. 2019; 2(98): 64–70. (In Russ.) Available from: doi: 10.22349/1994-6716-2019-98-2-64-7

10. Andreeva L. I., Abramov S. V. Methods of mining machine components reconditioning and hardening by means of concentrated energy fluxes. *Minerals and Mining Engineering*. 2023; 1: 7–15. Available from: doi: 10.21440/0536-1028-2023-1-7-15

11. Ivanov V. P. (ed.) *Machine parts restoration.* Moscow: Mashinostroenie Publishing; 2003. (In Russ.)

12. Jovanović M. T. Nickel, cobalt and titanium-based alloys – from aircraft vehicles to medical applications – REVIEW. *Metallurgical and Materials Engineering*. 2016; 22(3): 205–220.

13. Karimihaghighi R., Naghizadeh M. Effect of alloying elements on aqueous corrosion of nickel-based alloys at high temperatures: A review. *Materials and Corrosion*. 2023; 74(8). Available from: doi: 10.1002/maco.202213705

14. Varenberg M. Adjusting for running-in: Extension of the Archard wear equation. *Tribology Letters*. 2022; 70: 59. Available from: doi: 10.1007/s11249-022-01602-6

15. Akca E., Gursel A. A Review on superalloys and IN718 nickel-based INCONEL superalloy. *Periodicals of engineering and natural sciences*. 2015; 1(1): 15–27. Available from: doi: 10.21533/pen.v3i1.43

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Восстановление деталей горных машин лазерной наплавкой

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Реферат

Введение. *Основной причиной выхода из строя горного оборудования является износ деталей. Для их эффективного ремонта следует применять современные технологические процессы. В авиапромышленности, например, благодаря хорошим механическим характеристикам широко используются сплавы на основе никеля. Их можно рассмотреть и для ремонта деталей горных машин.*

Методика проведения исследования. *Для формирования покрытий, получаемых лазерной наплавкой на установке Optomec LENS 450, использовали сплав на основе никеля ХН45МВТЮБР и порошки сталей 38ХМА, 42ХФА. Определяли прочность сцепления наплавленного слоя с поверхностью детали, твердость по Виккерсу (HV) и трибологические свойства образцов при трении скольжения всухую. Изучение структуры проводили металлографическим анализом на электронном сканирующем микроскопе.*

Результат исследования. *Сила сцепления слоя сплава из ХН45МВТЮБР, наплавленного на стали 38ХМА и 42ХФА, выше, чем у слоя из 38ХМА, наплавленного на сталь 38ХМА,* *и слоя из 42ХФА, наплавленного на сталь 42ХФА. Микротвердость наплавленных слоев ХН45МВТЮБР и поверхности детали 38ХМА или 42ХФА имеют аналогичные значения (около 520 HV). Разрушение образцов с наплавленным слоем ХН45МВТЮБР имеет вязкий характер, а разрушение образцов с наплавленным слоем 38ХМА или 42ХФА – хрупкий характер. Морфология изношенной поверхности для наплавленных материалов 38ХМА и 42ХФА аналогична.*

Выводы. *Показана возможность ремонта деталей горного оборудования из сталей 38ХМА, 42ХФА методом лазерной наплавки. Наплавленные слои из сплава ХН45МВТЮБР обладают хорошими механическими и трибологическими свойствами. Износостойкость деталей с наплавленным материалом ХН45МВТЮБР в среднем в 1,7 раза выше, чем после наплавки сталями 38ХМА и 42ХФА.*

Ключевые слова: *восстановление деталей; износостойкость; механические свойства; наплавка; сталь; твердость.*

БИБЛИОГРАФИЧЕСКИЙ СПИСОК

1. Тюрин С. И. Повышение эффективности эксплуатации горного оборудования за счет внедрения новых технологий ремонта // ГИАБ. 2016. № 5. С. 136–148.

2. Лялякин В. П. Восстановление деталей машин – важное направление импортозамещения в агропромышленном комплексе // Инновационные технологии реновации в машиностроении: сб. тр. Междунар. науч.-практ. конф. Москва, 4–5 февраля. 2019. С. 3–5. DOI: 10.31044/1684-2561-2019-0-9-3-5

3. Gorin A., Kuznetsov I., Prokoshina T., Byrlakova E., Kolpakova S. Study of the composition of innovative materials for the restoration and strengthening of machine parts // MATEC Web of Conferences. 2020. Vol. 329. Art. 02030. DOI: 10.1051/matecconf/202032902030

4. Четвериков С. В. Восстановление рабочих поверхностей деталей машин наплавкой // Транспортная инфраструктура Сибирского региона. 2019. Т. 2. С. 280–288.

5. Иванов В. И., Костюков А. Ю. Практика применения электроискровых покрытий при восстановлении деталей машин // Ремонт. Восстановление. Модернизация. 2017. № 6. С. 10–17.

6. Тимохова О. М., Кадырметов А. М., Снятков Е. В., Романов В. В. Восстановление клапанов двигателей внутреннего сгорания плазменной наплавкой и напылением с модуляцией параметров // Воронежский научно-технический вестник. 2018. № 1(23). С. 53–67.

7. John M., Kuruveri U. B., Menezes P. L. Laser cladding-based surface modification of carbon steel and high-alloy steel for extreme condition applications // Coatings. 2022. Vol. 12. Art. 1444. DOI: 10.3390/coatings12101444

8. Хызов А. А., Иванов А. С., Колмакова Т. Г. Перспективы применения лазерной наплавки при восстановлении деталей сельскохозяйственной техники // Политематический сетевой электронный научный журнал Кубанского государственного аграрного университета. 2019. № 154. С. 45–54. DOI: 10.21515/1990-4665-154-006

9. Дмитрюк А. И., Фармаковский Б. В., Бобкова Т. И., Геращенков Д. А. Восстановление и ремонт деталей узлов машин с помощью сверхзвукового холодного газодинамического и микроплазменного напыления // Вопросы материаловедения. 2019. № 2(98). С. 64–70. DOI: 10.22349/1994-6716-2019-98-2-64-70

10. Andreeva L. I., Abramov S. V. Methods of mining machine components reconditioning and hardening by means of concentrated energy fluxes // Minerals and Mining Engineering. 2023. No. 1. P. 7–15. DOI: 10.21440/0536-1028-2023-1-7-15

11. Восстановление деталей машин: справочник / под ред. В. П. Иванова. М.: Машиностроение, 2003. 672 с.

12. Jovanović M. T. Nickel, cobalt and titanium-based alloys – from aircraft vehicles to medical applications – REVIEW // Metallurgical and Materials Engineering. 2016. Vol. 22. No. 3. P. 205–220.

13. Karimihaghighi R., Naghizadeh M. Effect of alloying elements on aqueous corrosion of nickel-based alloys at high temperatures: A review // Materials and Corrosion. 2023. Vol. 74(8). DOI: 10.1002/maco.202213705

14. Varenberg M. Adjusting for running-in: Extension of the archard wear equation // Tribology Letters. 2022. Vol. 70. Art. 59. DOI: 10.1007/s11249-022-01602-6

15. Akca E., Gursel A. A Review on superalloys and IN718 nickel-based INCONEL superalloy // Periodicals of engineering and natural sciences. 2015. Vol. 1(1). P. 15–27. DOI: 10.21533/pen.v3i1.43

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