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IMPROVING THE EFFICIENCY OF REPAIR AND STRENGTHENING OF THE DIESEL EXHAUST SYSTEM BY USING A HIGHLY COMMON HIGH-TEMPERATURE SYNTHESIS OF ALLOYS

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Abstract: *In accordance with the requirements of the Ukraine strategy of economic development and coverage of processes economic approaches to the transformation of the national economy in various industries, we present a separate methodology in the field of restoration and repair of marine vehicles.*

The main direction of improving shipbuilding production is to reduce the duration, improve the quality and reduce the cost of ship repair.

Such factors influencing production and repair as material supply and energy consumption can be reduced by 10-20 percent if we apply the latest technological implementations that are already developed and improved in the research of both Ukrainian and foreign scientists.

Keywords. *Repair, protective coatings, gas distribution valve, gas corrosion, restoration, plasma surfacing, exothermic mixture, fluxes.*

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ПІДВИЩЕННЯ ЕФЕКТИВНОСТІ РЕМОНТУ ТА ПОСИЛЕННЯ ВИХЛОПНОЇ СИСТЕМИ ДИЗЕЛЯ ШЛЯХОМ ВИКОРИСТАННЯ ДУЖЕ ПОШИРЕНОГО ВИСОКОТЕМПЕРАТУРНОГО СИНТЕЗА СПЛАВІВ

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Анотація: *Відповідно до вимог Стратегії економічного розвитку України та охоплення процесів економічних підходів до трансформації національної економіки в різних галузях, надаємо окрему методику у сфері відновлення та ремонту морської техніки.*

Основним напрямком удосконалення суднобудівного виробництва є скорочення тривалості, підвищення якості та здешевлення судноремонту.

Такі фактори впливу на виробництво і ремонт, як матеріалозабезпеченість і енергоємність, можна знизити на 10-20 відсотків, якщо застосувати новітні технологічні розробки, які вже розроблені та вдосконалені в дослідженнях як українських, так і зарубіжних учених.

Ключові слова. *Ремонт, захисні покриття, газорозподільний клапан, газова корозія, відновлення, плазмове наплавлення, екзотермічна суміш, флюси.*

Introduction. It is known that meeting the needs of ship engines and mechanisms during operation and maintenance is accomplished through the procurement of new parts or the restoration of defective ones.

In the context of repair and restoration work, significant attention should be paid to the economical use of material resources, labor costs, the development of technological processes, and the production of equipment for the restoration of parts. The cost of restoration is generally 30-50 % lower than the cost of producing new similar products.

Therefore, promising technological processes, equipment, and materials for the restoration and strengthening of ship parts are proposed, along with the results of tests on restored parts.

During the operation of ship diesel engines, the components of the exhaust gas system, specifically the exhaust valves, are the most stressed and responsible for the engine's operational lifespan. Valves and seats, being the most stressed elements of the diesel engine, operate under conditions of significant temperature gradients and abrupt changes, as well as chemical and mechanical influences. They are subjected to cyclic impact loads at the contact point with the valve seat sealing surface. Additionally, exhaust gases heat the valve, leading to significant temperature-induced deformations.

The characteristics of fuel, such as coking tendency, ash content, acidity, elevated sulfur content, water, and mechanical impurities, have a significant impact on the condition of exhaust valves. Ash, along with coke deposits formed during fuel combustion, contributes to abrasive wear on the valve seat surfaces. The most harmful ash elements causing corrosion are vanadium pentoxide, iron oxide, and sulfur oxide. In the high-temperature zone, oxides directly act on the metal, leading to gas corrosion. The mechanical impact of sulfur manifests as abrasive wear, which is intensified as the condensation products of sulfur compounds concentrate in deposits, leading to abrasive wear of the working surfaces.

Typical malfunctions can be seen in Fig. 1 such as:

1. Development of fatigue cracks caused by mechanical impact and temperature stresses.
2. Warping, corrosion damage, burning of valve seats.
3. Wear, buildup of burrs.
4. Corrosion and mechanical damage to the seats.

Currently, research is being conducted on the development of methods for strengthening worn valve seats, both those worn during operation and those manufactured in production.

To enhance the durability of the valve, the surfacing method is used to reinforce the sealing band of the valve disc with heat-resistant cobalt or nickel-based alloys (stellites). Cobalt-based stellite alloys, containing chromium, tungsten, and carbon, are traditional alloys for surfacing the valve disc's sealing band. Nickel-based materials with added chromium also exhibit high corrosion resistance in various environments and have wide applications for reinforcing valve discs. Previously, manual argon arc surfacing with stellite grades B2K, B3K, and Sormait was used to ensure optimal properties of the surfacing metal. Ship repair companies abroad use stellite-1, stellite-6, and stellite-12 materials to strengthen valve disc bands, which differ in their carbon, chromium, and tungsten content. Analysis of typical valve damages in engine operating conditions (see Fig. 1) and comparison with research results from leading diesel manufacturers indicates that the primary cause of premature failure of restored valves is insufficient corrosion resistance of stellite surfacing on valve discs when using heavy fuel grades with high vanadium and sodium content. It should be noted that the weight ratio of sodium to vanadium in fuel, exceeding 1:3, contributes to lowering the melting point of vanadium ash, which in its molten state exhibits high corrosive aggressiveness.

In light of this, the French company «Pielstick» does not recommend the use of stellite-12 when using heavy fuel. Instead, they propose surfacing with stellite-20 and manufacturing exhaust valves from Nimonic-80A alloy.

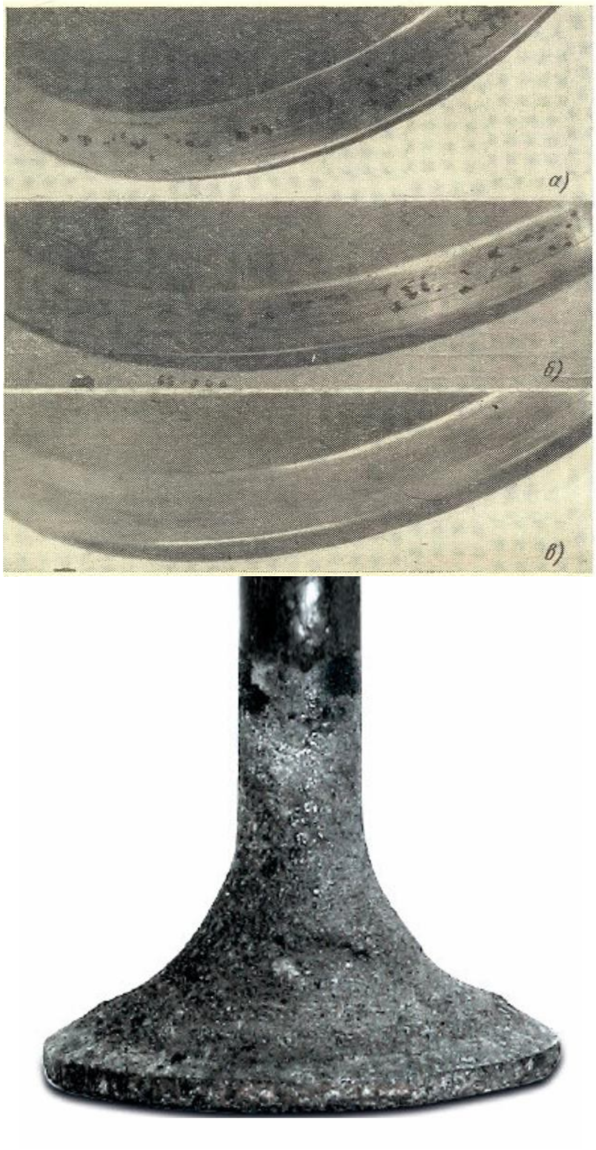

Fig. 1. Typical damages on the surface of the valve disc

One of the most effective modern methods for restoring worn and damaged parts is arc and powder surfacing under the protection of inert gases. A reliable process of automatic plasma surfacing with self-fluxing powder PR – N77H15CZR2 [2] has been developed and implemented to strengthen the surface of valve discs, with slag – forming compounds. However, to meet the requirements of resource conservation and scientifically justify the indicators that ensure increased productivity and savings of material, labor, and financial resources in the field of repair production, it is necessary to apply advanced technological processes.

Plasma surfacing is carried out on the EPS – 303 (Equipment for plasma surfacing) installation under the following regime parameters: direct polarity arc current of 120-150A, arc voltage of 26-37 V, powder consumption of 2-3 kg/h, surfacing speed of 7-8 m/h, plasma gas flow rate of 4.5-5.0 l/min. Powder is injected into the plasma. Surfacing is performed with transverse oscillations of the plasma torch. Argon is used as the plasma – forming, shielding, and transporting gas. Before surfacing, the valve disc is preheated with acetylene – oxygen flame or another heat source to a temperature of 200 – 250 ºC. This is done to remove thermal fatigue, where the accumulation of plastic deformations and residual stresses occurs.

The purpose of the work. Ensuring the preservation of a minimal portion of the base metal and adherence to necessary thermal conditions are crucial features of the surfacing process for cobalt alloys.

During the surfacing of heat – resistant alloys, minimizing the transition of iron from the base metal to the surfacing material is essential; otherwise, the properties of the latter deteriorate significantly. Surfaced metal is prone to the formation of cold and crystallization cracks; therefore, surfacing is carried out with prior and often simultaneous preheating of the valve to a temperature of 600-700 ºC. Such heating preserves a significant portion of the base metal (up to 30 %), hence to achieve a minimal iron content, surfacing needs to be done in three layers. This increases the consumption of the expensive surfacing material, electricity consumption, and labor intensity of the work.

Fig. 2. Plasma surfacing with self – fluxing powder containing exothermic flux

Therefore, plasma surfacing with self – fluxing powder will restore the damaged surface of the valve disc and increase engine efficiency but will not reduce the aforementioned costs. To modernize the surfacing process in order to increase the mass fraction of metal and reduce expenses on expensive flux and electricity consumption, research on scientific works and industrial technologies based on widely distributed high – temperature synthesis of alloys has been considered.

Research on the application of exothermic components in the composition of electrode coatings and fluxes in electroslag processes, significantly increasing the productivity of manual arc welding and resource conservation, has been conducted. Such research was carried out at the Donetsk State Machine – Building Academy on the basis of utilizing the effect of exothermic reactions, focusing on the theme: «Investigation and development of exothermic fluxes for electroslag remelting of steels 9XF, 9X2MФ, and 60X2CMФ with the aim of increasing the yield of usable metal and saving electrical energy» (No. GR 185.0007457). Their work inspired us to improve their practical experiments aimed at conducting surfacing work using the plasma – powder surfacing method with the addition of exothermic mixture to self – fluxing powders.

Using an operational automatic plasma surfacing with self – fluxing powder SP – N77H15CZR2, after adding exothermic flux components to the mixture, additional alloying and increasing the yield of usable metal by 2-10 % can be achieved due to the restored metal in the high – temperature synthesis process. The obtained surfacing metal corresponds to the physical, chemical, and mechanical properties of the grade composition. Among the general characteristics of Ni – Cr – B – Si – C alloys, to which the alloy forming a hard wear – resistant coating on the valve disc surface belongs, is the ability to maintain hardness and resistance to abrasive wear after tempering at 600 °C. The hardness of alloys at elevated temperatures («hot» hardness), for example, at 650 °C, can be 70-80 % of the hardness measured at room temperature. Therefore, increasing the productivity of plasma spraying by introducing alloying additives into the flux composition, in addition to thermitic components, is necessary. Rare – earth metals and up to 2-5 % sodium oxide (Na_2O) and silicon dioxide (SiO_2) have a positive effect on the properties of the sprayed alloy produced by sintering a thermitic and nickel mixture. The latter forms an acidic slag cover above the mixture, dissolving free iron oxide (FeO) and forming it into a silicate $FeO \cdot SiO_2$, which does not decompose at high temperatures. Since sodium significantly lowers the slag's solidification temperature, its protective effect is maintained during cooling.

Therefore, phase transformations that occur in the iron – carbon system with volume changes pose a risk of cracking the coating on steel substrates during cooling. Consequently, it is recommended to cool products with self – fluxing alloy coatings at a slowed pace. The recommended cooling rate range is, for example, for steels used in exhaust valves, such as 40X9C2 and 40X10C2M, less than 5 °C/s. The slag cover formed on the surface of the sprayed alloy during the exothermic reaction contributes to such cooling.

The properties of the thermite mixture largely depend on its granulometric composition. Better results are achieved with a mixture porosity of 50 %, and the smaller the difference in grain size, the more uniformly the exothermic reaction occurs over time and volume. The use of a self – fluxing powder mixture, produced by gas atomization, is subjected to sieving into narrow particle size fractions for various coating application and spraying technologies: gas powder spraying, gas flame and plasma spraying, laser and electric spark deposition, plasma and induction deposition. Powder fractions for plasma and induction coating technologies range from 63-125, 80-160, 94-280, 140-280 micrometers. Therefore, the exothermic mixture should have a fraction no more than 5 % different from the total flux powder.

In this work, the exothermic flux comprises a mechanical mixture of iron scale, aluminum powder, ferrotitanium, and alloying elements in the form of ferroalloys (Table 1). The mass of the layer containing alloying elements (Mo, Cr, V, Si, Mn, etc.) in the exothermic metal flux mixture is determined to achieve the desired volume of quality deposited metal in one pass.

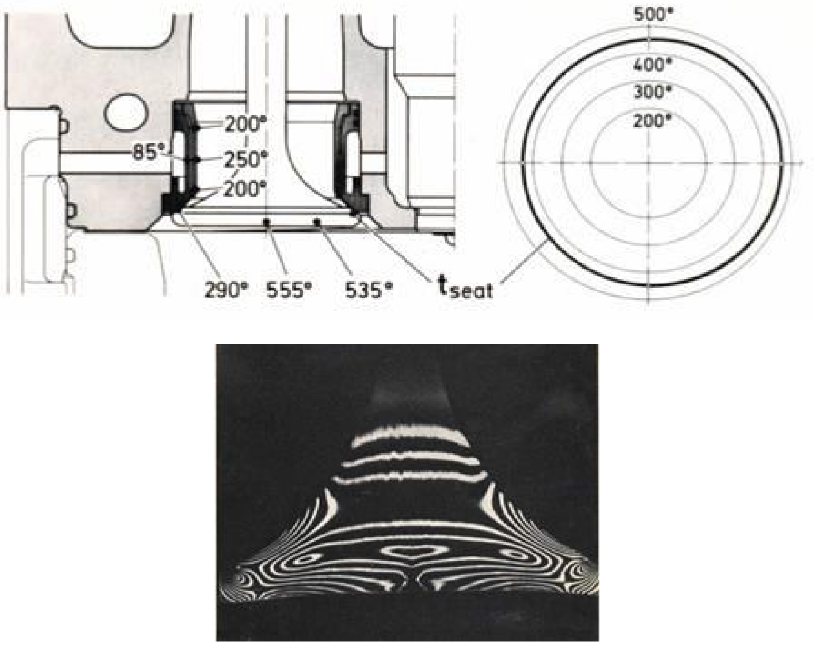

Fig. 3. Temperature fields affecting phase transformations during operation

Table 1

Composition of the used exothermic flux for enhancing the productivity of deposited coatings

Components of the composite mixture	***Dispersion, µm***	***Content of deposited steel, mass %***	
		12X13H2	14X17H2
Iron slag (Fe_3O_4)	260-500	56-58	54-56
Aluminum	260-500	23-25	23-25
Chromium oxide (Cr_2O_3)	5-100	11-13	14-17
Nickel oxide (NiO)	5-100	0,9-2,1	1,0-1,2
Calcium fluoride (CaF_2)	5-50	4,5-8,5	4-6
Lanthanum chloride ($LaCl_3$)	5-50	0,05-0,1	0,05-0,1
Calcium	260-250	0,01-0,2	0,01-0,02

The proposed method allows obtaining a corrosion – resistant and heat – resistant protective layer of metal, which consists of complex alloyed steels, as well as has been tested in the research of the Donetsk State Academy of Mechanical Engineering on refractory metals and alloys. In particular, to obtain a protective layer on ordinary quality carbon – alloyed steel (40X9C2), the surfacing of high – alloyed steels of grades 12X13H2 and I4XI7H2 was carried out as a result of the joint restoration of chromium and nickel oxides and lanthanum chloride during the surfacing process. Chromium and nickel oxides are restored by aluminum, and lanthanum chloride is restored by calcium. To reduce losses of alloying elements and eliminate technological defects according to the proposed method, the convergence of the mass burning rates of the main (3FeO+8Al) and alloying mixtures is further achieved by changing the dispersion of oxides and reducing agent.

To increase the mass burning rate of the alloying mixture $Cr_2O_3 + 2Al$, chromium oxide with maximum dispersion (5-50 μm) is used, which provides an increase in the rate from 0,11 to 0,65 $g/cm^2 \times s$. Aluminum grade ASD – 1 as an activating mixture along with a mixture of potassium perchlorate ($KClO_4$) should have a dispersion of (50-100 μm), and the density of the mixture should be 0,8 g/cm^3. The composition of the activating mixture is calculated under the condition of complete melting of aluminum oxide and restored chromium. To fulfill this condition, the mixture should contain 1,2-2,2 % amorphous boron, which, together with silicon, forms low – melting eutectics with nickel with a melting temperature of 950-1080 °C, and also restores oxide films (AlO_3) on the surface of the base with the formation of borosilicate slag (self – fluxing) in the presence of a liquid phase and improves the wettability of the base «parent» metal by the liquid metal. Additionally, as a result of the exothermic reaction during the melting of the nickel coating with the exothermic mixture, the restored iron formed enters the alloy, increasing the productivity of the surfacing process, and the heat released contributes to accelerating the melting of the coating surface.

The productivity of melting flux metal during surfacing together with an exothermic flux can be calculated using the formula

$$G_{M(m-\partial)} = g_{m.N_i} \times (1 + K_f \times \rho_{m.a} + K_f \times \rho_{e.m.} \times K_{r.m.}),$$

where $g_{m.N_i}$ – melting productivity of the total nickel iron powder, kg/s;

K_f – elative mass of melted flux, kg;

$\rho_{m.a}$ – proportion of metallic additives in the flux composition;

$\rho_{e.m.}$ – proportion of the exothermic mixture;

$K_{r.m.}$ – coefficient of recovery of the reduced metal from the thermite mixture included in the flux composition.

Increasing the relative mass of the molten flux K_f with increasing plasma arc voltage leads to an increase in the productivity of flux – cored welding, which is most significant when welding under flux, where the flux contains both a thermite mixture and metal powder.

With an increase in the concentration of the thermite mixture in the flux composition, the relative masses of the molten flux K_f and K_s slag formed, as well as the productivity of welding, increase. The productivity of the thermite – arc welding process under an exothermic flux compared to the conventional process under flux – powder PR – N77X15SZR2 increases by 1,5-2,5 times.

The thermal effect of exothermic reactions can be regulated by the content of the exothermic component in the filler, and by establishing the optimal composition and content of this component in the filler, regulate the melting rate of the nickel and iron self – fluxing alloy and the filler, ensuring their uniform melting.

Conclusion: The use of exothermic mixtures (fluxes) of appropriate composition and the proposed new methods of melting the working flux allow for increasing the yield of usable metal by up to 5 %, reducing electricity consumption by 10 %, and decreasing the consumption of working nickel and iron fluxes by 20 %. The prospects for the development of technologies involving self – propagating high – temperature synthesis (SHS) are rapidly expanding worldwide, enabling savings in valuable materials, labor resources, technological costs, and reducing energy dependence.

REFERENCES

1. *Rykalin N.N. Calculations of thermal processes in welding / N.N. Rykalin. – Moscow: Mashgiz, 1951. – 197 c.*
2. *Glushchenko A.S. Determination of productivity of the thermite-arc welding process under the exothermic flux / A.S. Glushchenko // Welding production. – 1980. № 9. – P. 25-27.*
3. *Brykov N.N. Increasing the service life of parts under abrasive wear / N.N. Brykov Y.M. Tkachenko // In Vn. Wear resistance of alloys, restoration and hardening of machine parts. – Zaporozhye: Motor Sich. – 2006. – P. 109-124.*
4. *Chigarev V.V. Investigation of combustion parameters of exothermic mixtures / V.V. Chigarev D.A. Zarechenskiy // Visnik Pryazovskogo Priazovskogo sobranik nauk. pracie. – 2006. – № 16. – P. 1-4.*
5. *Lapshin O.B. Influence of the heating stage on the ignition conditions of a powder mixture of nickel with aluminum / O.V. Lapshin, V.E. Ovcharenko // Physics of Combustion and Explosion. – 2000. – T. 36, № 5. – P. 22-26.*
6. *Kuvshinova N.N. Energy-saving technology of steel parts cladding (in Russian) / N.N. Kuvshinova // Welding production. – 2010. – № 1. – P. 24-28.*
7. *Vlasov A.F. Development of the scientific and technological bases for increasing the efficiency of exothermic mixtures application at the electric arc welding and electroslag processes / Dissertation. – 2016. – P. 172-214.*
8. *Doria J.G. Welding consumables: Market trends / J.G. Doria. – Istanbul: European Welding Association, 2001. – 20 p.*

9. *Lebedev B.V., Bogomolov E.P. Analytical determination of the amount of heat required for welding of steel structures in air by exothermic rods / Problems of Engineering. – 2017. – P. 21-29.*
10. *Kuvshinova N.N. Technology of steel casting defects elimination by exothermic cladding // Abstract of thesis on the rights of manuscript. – 2004. – P. 8-15.*

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