ГЕОТЕХНОЛОГИЯ. ГОРНЫЕ МАШИНЫ

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Methods of mining machine components reconditioning and hardening by means of concentrated energy fluxes

Liudmila I. Andreeva[1, 2]*, Sergei V. Abramov[2]
[1] Institute of Mining UB RAS (branch), Chelyabinsk, Russia
[2] Scientific Research Institute of Efficiency and Safety of Mining Production, Chelyabinsk, Russia
e-mail: tehnorem74@list.ru

Abstract

Introduction. *The value of resources is becoming increasingly important to mining proprietors, since the maintenance of mining equipment is quite expensive. Increased scope and cost of repairs are largely determined by the quality of mining machines and equipment operation in production environment, as well as by their reliability and maintainability. The costs of preventive maintenance are over the limit by 40–50%, in most instances, due to equipment shutdowns caused by subsystem failures. Components with hidden defects as well as the methods of components reconditioning that do not ensure long-term operation cause a significant overrun of costs for breakdown maintenance. The quality of mining equipment maintenance is in direct relationship with the effective methods of components reconditioning, including the methods of components hardening both during their manufacture at machine-building plants and during their repairs at repair works that carry out complex, mainly major repairs of mining equipment. Adherence to the flow process of reconditioning/hardening of the component surface in contact with another component is of great importance. Therefore, to preserve fixed assets, in particular, mining and transport equipment, it is essential to find that reconditioning methods which allow to preserve consumer properties and operability of equipment for a sufficiently long time.*

Subject matter. *The article provides an overview of methods of mining machine components reconditioning/hardening involving concentrated energy fluxes. In the authors' opinion, these are the most effective methods to increase the resource and reliability of mining machine components by 2–3 times. The choice of components reconditioning/hardening method depends entirely on the service centre capacities, necessary technological equipment availability, personnel qualifications and, most importantly, economic feasibility of using a particular method of reconditioning/hardening.*

Research objective *is to consider the most effective methods of mining machine components reconditioning/hardening.*

Methods of research *include the interpretation of a number of experiments conducted at mining enterprises to obtain comparative characteristics of the most effective methods of mining machine components reconditioning/hardening.*

Research results. *The most effective methods of components reconditioning/hardening are identified and recommended practices are provided.*

Conclusions. *It has been established that the application of a particular components reconditioning/hardening method should be based on the data from tribological maps, as well as necessary equipment availability and economic feasibility.*

Keywords: *hardening; useful life; reconditioning; wear resistance; tribotechnical coatings; detonation spray coating; explosive hardening; plasma spraying; laser irradiation.*

Introduction. Open-pit mining development is characterized by a growing concentration of operations and, as a rule, by the acquisition of domestic or foreign heavy-duty equipment. Significantly, within this trend, as far as the domestic excavators fleet is concerned, the equipment with a bucket capacity of 18–35 m3 is mainly replaced.

Since 2000, mining proprietors have embarked on a partial replacement of Russian excavators with imported hydraulic ones. In the first years of operation, imported equipment showed advantages, but in the 4–5th year of operation, the situation changed. The equipment maintenance required significant operating expenditures involving strict requirements for preventive maintenance, which predetermined a complete revision of the maintenance, repair and overhaul system, in particular, methods for components reconditioning [1–3].

A certain resource of all elements, i.e. units, components, assemblies, is included in the excavator design by the manufacturer. The resource is provided (supported) by the necessary organization and strategy level of the mining equipment repair service system [4]. As a result, it becomes possible to improve machines efficiency, significantly cut operating costs, and reduce accident and injury rates.

The factors listed above determine the growing importance of works on improving excavator's durability and maintainability, and components reconditioning and hardening. In addition to reducing the components and materials costs, which often make up a large part of the repair cost, it is possible to reduce repairs and maintenance down time, therefore increasing the capacity of both excavators and support equipment.

The choice of a method for extending component life is a rather complicated engineering and economic problem. The components wear resistance effect on their service life should be taken into account when solving the problem. The generally accepted indicator in such cases is the relative prime cost of component reconditioning in relation to its service life after repair [5, 6].

Methods and results. In recent years, the methods of electric arc surfacing, thermochemical treatment, and surface-plastic deformation have been widely used at repair plants that serve mining enterprises. Thermomechanical and electrophysical methods of applying high-strength coatings are less common.

Thermomechanical coating methods include plasma and detonation spraying. In ***detonation spraying***, explosion energy is the source of energy for heating and accelerating the sprayed particles (Figure 1).

The flow process of detonation spraying does not have a noticeable effect on the microstructure of the base material due to the local property of the thermal effect. The advantage of detonation coatings is explained not only by the higher particle velocity (up to 800–1000 m/s), but also by the quality of the layer formation, the pulsed nature of the processes, higher concentration of sprayed particles, and the effects of abrasive separation and impact molding. The physical-mechanical and performance characteristics of detonation coatings greatly exceed the corresponding characteristics for coatings obtained by plasma spraying in terms of density, strength, adhesion to the base material (120–200 MPa), and wear resistance. The possibility to use fine powders is the advantage of the detonation method, which is due to the high rates of spraying. Significant noise up to 140 dB and the high cost of equipment are the disadvantages of detonation spraying [7].

A domestic installation used for detonation spraying is a model with electronic summing computer numerical control called IDUS-1. The advantages of the installation include fast adjustment of coating spraying modes and the possibility to increase or reduce the dose of an explosive mixture ingredient, the time of air blowing, the beginning and end of the spraying cycle, and the mixture ignition delay time. Theoretical studies and recommendations on the practical implementation of methods for component surfaces reconditioning/hardening with explosion energy are reflected in the works of IM UB RAS.

The introduction of newer generation installations, such as detonation-gas installations, will increase the range of machined components of the mining equipment that operates in conditions of high abrasivity of rocks and dust pollution (excavator bucket teeth, drive wheels, gear rims, etc.), as well as increase the component life and reliability by 2–3 times.

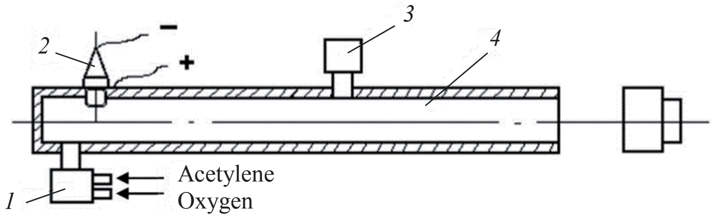

Figure 1. Diagram of the working head for detonation spraying: *1* – mixer; *2* – ignition device; *3* – powder dispenser; *4* – working pipe

Рисунок 1. Схема рабочей головки для детонационного напыления: *1* – смеситель; *2* – запальное устройство; *3* – дозатор порошка; *4* – рабочая труба

In addition to detonation spraying, positive results were obtained with ***explosive hardening*** of some excavator components (Figure 2).

The main point of the method is that the explosive applied to the component explodes and creates a pressure of hundreds of thousands of atmospheres. Passing through the metal, the shock wave hardens the component. This method is especially effective for components made of steel with a pronounced ability to form surface strain hardening, for example, of 11OG1ZL (GOST 977-88) class austenitic cast steel. It is commonly used to produce high impact excavator components such as bucket teeth, track links, etc.

The technology of hardening by explosion energy has been tested in Kuzbass for bucket teeth of EKG-5A and EKG-8I excavators and lining of KMD-2200 crushers. The depth of 11OG1ZL steel hardening by explosion energy reached 50 mm, which is unattainable by other methods of surface hardening. Detonation hardening made it possible to improve the surface hardness of EKG-5A and EKG-8I excavators bucket teeth and the linen of the KMD-2200 crushers from 180–200 to 380–400 HB and increase the wear resistance by 20–25%.

Explosive hardening has the following advantages: relatively large depth of hardening; the possibility of hardening surfaces of complex configuration, as well as individual sections of surfaces, including hard-to-reach sections; relatively simple technology and equipment; the possibility of increasing the durability of parts by 1.5–1.8 times.

The disadvantages include difficulties in ensuring occupational safety (preparation of specially equipped premises or providing grounds), significant noise load [8, 9].

The ***plasma spraying method*** of components reconditioning and hardening has recently become widespread.

In plasma spraying, the initial material is heated to a liquid or plastic state and sprayed over the substrate by a high-temperature jet. In most cases, powders are used as materials for spraying (Figure 3).

Relatively expensive powders such as PG-SR2, PG-KhN80SR4, PG-KhN80SR2, SNGS, VSNGN have become most common. Coatings made of these materials are wear-resistant, and corrosion- and erosion-resistant under higher temperatures.

Nickel and chromium based powders with additives of boron and silicon, as well as intermetallic compounds in Ni-Al system (STS) hold a special place. STS materials are 5–30 times more wear resistant than structural steel. Polishability is an important property of these alloys, it determines their high wear resistance under metal-to-metal contact without lubrication.

According to rough estimate, 1 ton of powder material for spraying results in saving 24–150 tons of ferrous metals.

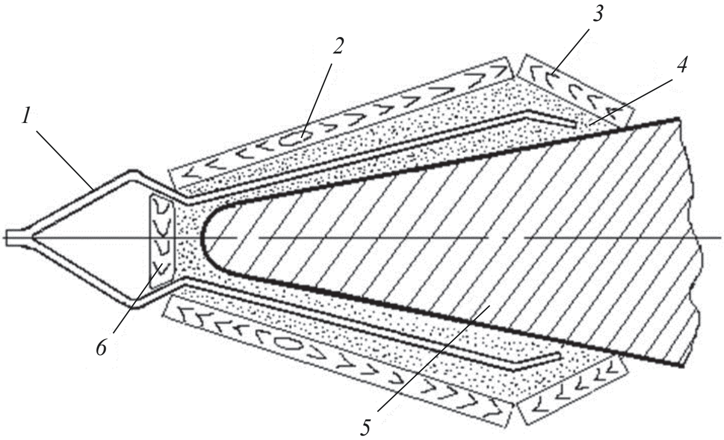

Figure 2. Scheme of detonation hardening of excavator bucket teeth: *1* – detonating cord; *2*, *3* – timber; *4* – explosive; *5* – tooth; *6* – bar

Рисунок 2. Схема детонационного упрочнения взрывом зубьев ковшей экскаваторов: *1* – детонирующий шнур; *2*, *3* – брус; *4* – взрывчатое вещество; *5* – зуб; *6* – брус

The coating wear resistance largely depends on high-quality preparation of the surface under spraying aimed at ensuring its maximum roughness and chemical activity. The preparation is based on gas erosion treatment using quartz sand, corundum or a steel end plate. Plasma spraying modes are chosen first and foremost depending on the type of the sprayed material and its particles dispersion degree. The strength of adhesion to the base is about 20–25 MPa and is mainly due to mechanical interlocking, adhesion, partially with welding, and stresses caused by shrinkage during material cooling [10, 11].

It should be noted that the processes of components plasma hardening require proper protection of the personnel.

In addition to dust and light radiation, operating open plasma torch produces strong sound vibrations with a sound intensity of up to 125 dB and an oscillation frequency of up to 50–4000 Hz.

The recent ***physical methods of components surface treatment*** make it possible to obtain mono- and multilayer antifriction and wear-resistant coatings with a thickness from molecules to hundreds of microns.

Physical vacuum coating methods are based on ionizing the atoms of molecules of applied materials or gases sprayed onto hardened parts.

Ion beam metal surface treatment is used for surface hardening modification and significantly increases anti-friction and wear-resistant properties.

Chemical methods of vacuum deposition are based on the phenomenon of gaseous compounds condensation on the hardened components surface, followed by the formation of solid precipitates. It makes it possible to obtain high-strength layers from carbides, nitrides, carbonitrides, borides, silicides, and oxides. Here, to speed up chemical reactions, the hardened material is heated up to 1000 °C, which weakens the base material and can lead to shape distortion [12]. This method could therefore be recommended for highly alloyed materials characterized by high heat treatment process temperatures. The coating quality depends on the process temperature, gaseous medium composition, gas flow pressure and velocity, and the rate of cooling after saturation.

In recent years, it has become possible to actively introduce and master the processes of creating tribological coatings using ***laser energy*** [6, 13, 14].

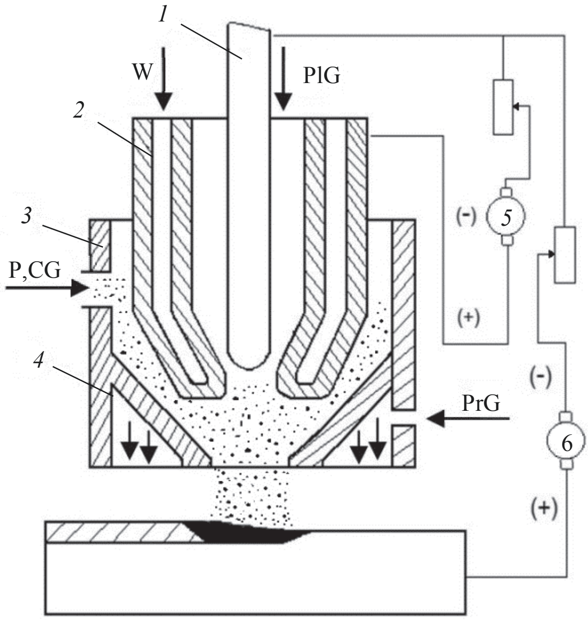

Figure 3. Diagram of plasma-powder surfacing: *1* – electrode; *2* – nozzle; *3* – protective nozzle; *4* – mouthpiece; *5* – arc ignition source; *6* – the source of arc formation; W – water; PlG – plasma gas; P – powder, CG – carrier gas; PrG – protective gas

Рисунок 3. Схема плазменно-порошковой наплавки: *1* – электрод; *2* – сопло; *3* – защитное сопло; *4* – мундштук; *5* – источник зажигания дуги; *6* – источник формирования дуги; W – вода; PlG – плазмообразующий газ; P – порошок, CG – транспортирующий газ; PrG – защитный газ

The use of laser irradiation for the surface modification of materials has some advantages over conventional surface treatment methods:

– suitability for use for thin samples or samples of small diameter;

– capability for processing internal surfaces and easy control of the area and depth of heating;

– easy to create narrow hardened zones;

– zero pollution;

– minimal oxidation of treated surfaces;

– capability of transporting a laser light in order to process hard-to-reach places and complex profiles;

– minimal deformation of workpieces;

– replacement of high-alloy steels with low-alloy ones, including simple carbon steels;

– substantial reduction in the complexity of surface finishing;

– high processing speed and easy control of process parameters, which ensures high productivity and the possibility of automation.

Laser energy is also widely used in the USA, Japan, and Great Britain [14]. About 40,000 cast-iron steering column housings are processed daily at General Motors' three plants. As a result, wear was reduced by 10 times compared to parts without hardening. Heat treatment costs were reduced by 80% and productivity was 50% higher than with conventional hardening. Fiat and Ford Motors process valve seats and harden engine valve guides made of gray cast iron.

Various studies in the field of laser material processing confirm the possibility of:

– using laser processing as a finishing operation;

– using a laser for hardening treatment of plasma-sprayed coatings;

– hardening cutting tools and mining machines components;

– surface alloying;

– a significant improvement in microgeometry, obtaining a rough layer with a high level of relative bearing area and profile fill factor;

– increasing the hardness and physical and mechanical properties of the surface coating.

Summary. Information on the technical condition of components that have undergone fault detection influences the decision-making on the application of a particular method of reconditioning/hardening mining machine components in the conditions of repair plants and workshops. It is also essential to determine the degree of their "responsibility", i.e. setting point in a motor vehicle. The operating conditions (rock strength, operations in the face or on the dump), the environmental conditions of the region, the type of wear, the nature of the load, the rate of protection against the abrasive environment, the availability and sufficiency of resources to recondition/harden the surface in accordance with the technical requirements (manufacturer's drawings) should be taken into consideration. All information is summarized in tribological maps. Based on the maps the decision is made on the possibility of using a particular method of surface hardening. The main criterion for choosing a hardening method is the economic feasibility of its application.

Conclusions. Prolonged exposure to high temperatures which negatively affects the preservation of material bulk strength is the accompanying factor of hardening treatment. It should be taken into account when choosing a method of components surface hardening. In this light, laser treatment of components surface is the most preferable.

Tribological maps contain the systematized data on the results of the study and analysis of the assemblies and parts design features, the physical and mechanical characteristics of the mating components, their operating conditions, the loads nature and magnitude, the main type of wear, lubrication, and interfaces protection against the abrasive environment, etc. Based on these maps, a decision is made on the application of a particular method of components surface hardening.

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Information about the authors:

Liudmila I. Andreeva – DSc (Engineering), leading researcher, Institute of Mining UB RAS (Chelyabinsk branch), Head of the Department of Mining and Transport Equipment Operation and Maintenance, Scientific Research Institute of Efficiency and Safety of Mining Production. E-mail: tehnorem74@list.ru; https://orcid.org/0000-0001-8071-4553

Sergei V. Abramov – mechanical engineer, Department of Mining Machinery Repairs, Scientific Research Institute of Efficiency and Safety of Mining Production. E-mail: tehnorem74@list.ru

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Методы восстановления, упрочнения деталей горных машин с использованием концентрированных потоков энергии

Андреева Л. И.[1, 2], Абрамов С. В.[2]

[1] Институт горного дела УрО РАН (филиал), Челябинск, Россия.

[2] Научно-исследовательский институт эффективности и безопасности горного производства, Челябинск, Россия.

Реферат

Введение. *Ценность ресурсов для собственников горнодобывающих предприятий приобретает все большее значение, поскольку содержание горной техники обходится достаточно дорого. Увеличение объема ремонтных работ и высокие затраты на их проведение в значительной степени определяются, во-первых, качеством производственной эксплуатации горных машин и оборудования, а во-вторых, их надежностью и, что немаловажно, ремонтопригодностью. Затраты на межремонтное обслуживание – в*

большинстве случаев при остановке техники из-за отказа какой-либо подсистемы – превышают норму на 40–50 %. Значительное превышение затрат на аварийные ремонты является следствием использования запасных частей, имеющих скрытые дефекты, и применения методов восстановления ресурса деталей, не обеспечивающих их длительную эксплуатацию. Качество ремонтного обслуживания горной техники находится в прямой зависимости от использования эффективных методов восстановления деталей – методов упрочнения деталей как при их изготовлении на машиностроительных заводах, так и на ремонтных заводах, производящих сложные, в основном капитальные, ремонты горной техники. Немаловажное значение имеет точное соблюдение технологического процесса восстановления/упрочнения поверхности детали, контактирующей с другой деталью. Поэтому для сохранения основных фондов, в частности горнотранспортного оборудования, необходимо находить такие методы восстановления, которые бы позволили достаточно длительное время сохранять потребительские свойства техники и ее работоспособность.
Содержание статьи. *Приведен обзор методов восстановления/упрочнения деталей горных машин с использованием концентрированных потоков энергии. По мнению авторов, это наиболее эффективные методы, позволяющие увеличить ресурс и надежность деталей горных машин в 2–3 раза. Выбор метода восстановления/упрочнения деталей всецело зависит от мощностей ремонтной базы, наличия необходимой технологической оснастки, квалификации персонала и, что самое важное, экономической целесообразности применения того или иного метода восстановления/упрочнения.*
Целью работы *явилось рассмотрение наиболее эффективных методов восстановления/упрочнения деталей горных машин.*
Методология исследования *включает анализ результатов ряда экспериментов, проведенных на горнодобывающих предприятиях, для получения сравнительных характеристик наиболее приемлемых по эффективности методов восстановления/упрочнения деталей горных машин.*
Полученные результаты. *Выявлены наиболее эффективные методы восстановления/упрочнения деталей и даны рекомендации по их применению.*
Выводы. *Установлено, что применение того или иного метода восстановления/упрочнения деталей должно быть основано на информации, содержащейся в трибологических картах, наличии необходимой оснастки и экономической целесообразности.*

Ключевые слова: *упрочнение; долговечность; восстановление; износостойкость; триботехнические покрытия; детонационное напыление; упрочнение взрывом; плазменное напыление; лазерное излучение.*

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Сведения об авторах:

Андреева Людмила Ивановна – доктор технических наук, главный научный сотрудник Челябинского филиала Института горного дела УрО РАН, начальник отдела эксплуатации и ремонта горнотранспортного оборудования Научно-исследовательского института эффективности и безопасности горного производства. E-mail: tehnorem74@list.ru; https://orcid.org/0000-0001-8071-4553

Абрамов Сергей Васильевич – механик отдела ремонта горной техники Научно-исследовательского института эффективности и безопасности горного производства. E-mail: tehnorem74@list.ru

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