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Research of Increase of the Wear Resistance of Machine Parts and Tools by Surface Alloying

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Abstract

The work scientifically substantiates the application of an effective technology for increasing the wear resistance of machine parts and tools due to complex diffusion saturation of the surface layer of parts made of iron-carbon alloys in the process of casting on gasified models based on the optimization of the composition of saturating mixtures and the establishment of patterns of structure formation.

The possibility of strengthening the surface of castings from cast iron SCH20 and steels of various composition (25L, 30L, 35L, 45L, 25HL, 110H13L), obtained by methods of casting in an open mold and on gasified models, has been established. It is shown that the diffusion boride layer on 35L steel, obtained during casting, has an order of magnitude greater thickness (up to 5 mm) compared to the diffusion layers obtained by chemical-thermal treatment methods (up to 0.25 mm). Analytical dependencies have been established that connect the components of the composition of the mixture (chromium boride (CrB_2), boron carbide (B_4C), graphite, bentonite, sodium fluoride (NaF)), which saturates, with wear resistance and the thickness of the diffusion layer after hardening in the process of obtaining a casting by the method of casting on gasified models.

A new composition of the saturating medium has been developed for surface strengthening in the production of cast parts from gray iron, carbon and alloy steels by simultaneous saturation with boron and chromium, containing chromium boride, boron carbide, graphite, bentonite, sodium fluoride (50-60 wt. % B_4C + 20-25 wt. % CrB_2 + 2-3 wt. % + 5-15 wt. % finely dispersed graphite + 5-7 wt. % bentonite). The application of the developed strengthening technology allows to improve operational properties, in particular, the wear resistance of machine parts and tools up to 25 times (compared to previously used methods), as well as to reduce the labor intensity of the strengthening process by up to 3.5 times.

Tests of dies for pressing wood waste into briquettes made of 45L steel, strengthened with the help of the developed technology, showed that their stability increases more than 4.5 times compared to the previously used ones made of HVH steel strengthened by carbonitriding, and the use of the developed strengthening technology allows reduce the cost of manufacturing this part by 1.5 times.

Key words: wear resistance, diffusion saturation, durability, surface hardening, diffusion coating, alloying.

Introduction

In the process of operation of parts of machines and tools, their surface layers are subjected to the most intensive external actions, therefore, often the structure and properties of the surface layers have a decisive influence on the performance of the products as a whole.

There are many ways to strengthen the surface: laser strengthening, surfacing, rolling, application of various coating technologies. However, the use of these technologies requires the use of complex, often unique, expensive and energy-intensive equipment, expensive reinforcing alloys, and highly qualified personnel [1].

Therefore, the development of new highly effective methods of strengthening machine and tool parts due to the diffusion saturation of the surface of metals and alloys with various chemical elements, the method of chemical-thermal treatment (CTT) is of particular interest. In some cases, when it is not necessary to strengthen the entire surface, but only certain parts of the parts, the method of strengthening with saturating coatings is practically the only possible one. At the same time, the widely used traditional chemical-thermal treatment, although it increases the wear resistance of the tool, but in addition to the advantages listed above, requires a large amount of electricity due to the duration of high-temperature diffusion processes. All this leads to an increase in the cost of the tool.

Studies of the effect of saturating media in the form of smears during CRT have shown that the use of boron-chromium compounds as an additive to boron carbide significantly increases the service life of the tool. Boration, chromium plating, titanation and combined processes (borochromization and borotitanization) are more effective than traditionally used cementation, nitriding, etc. in almost all parameters of the properties of the surface layers of the material. Boride layers on steels are characterized by high wear resistance, chrome plating provides heat resistance, and combined coatings combine the original properties of single-component coatings. The performance of borochromized layers is almost twice as high as that of borated ones. However, the known methods of obtaining such strengthening coatings are imperfect and quite time-consuming.

The method of surface strengthening, when the surface strengthening and the process of manufacturing the product are combined into a single process, is devoid of these disadvantages. Such a combination is possible only in the production of machine parts and tools by casting methods. In this case, the formation of a strengthened layer occurs as a result of the interaction of the hot casting material with the alloying facing layer applied to the surface of the mold [2].

The production of the tool by various methods of casting leads to a reduction in the consumption of expensive tool steel, a decrease in the cost of manufacturing the tool and an increase in its stability. When using foundry technologies, it becomes possible to use additional alloying, microalloying and modification of steel to increase the performance of the tool based on the specific conditions of its operation. The most promising in this direction is the method of casting on gasified models (LGM), which allows you to obtain high-precision castings with good surface cleanliness.

Of great practical interest is the production of diffusion layers based on iron boride, which, as is known, has high hardness and wear resistance during the casting process. Increasing the performance of parts of machines and mechanisms, tools and technical equipment, their reliability and durability is ensured to a certain extent by optimizing the technology of applying boron-containing coatings and the chemical composition of the saturating mixture.

Literature review

Surface hardening of steel pursues the following main goals: increasing the hardness of metal products, increasing wear resistance and increasing the endurance limit of parts. After surface hardening, gear teeth, shaft necks, machine bed guides become harder, wear-resistant and durable. The core of the part with such hardening remains viscous and withstands impact and other loads well.

The industry uses various methods of surface hardening of steel:

- surface hardening of steel with induction heating by high-frequency currents (microwave);
- surface hardening of steel with electric contact heating;
- surface gas flame hardening of steel;
- surface hardening of steel in electrolyte.

All of the above methods of surface hardening of steel have one thing in common. A common feature for all methods of surface hardening of steel is that the surface layer of the part is heated to a temperature above the critical point As_3, and then quickly cooled and a martensite (hardened steel) structure is obtained. Surface hardening of steel and mechanical processing with induction heating by high-frequency currents (microwave) have become the most widely used. Somewhat less often, mainly for large parts, the method of surface tempering with gas flame heating is used [3].

The essence of the process of surface hardening of steel when heated by high-frequency currents is that the part is heated on a special installation using a copper inductor made according to the shape of the part being hardened. A high-frequency alternating current is passed through it. The surface of the part is heated to the required depth in a few seconds. After that, the current is turned off and the part is quickly cooled. During the hardening process, cooled water circulates inside the inductor, and therefore it does not heat up.

The method of surface hardening of steel by electric contact heating is as follows. The part is heated when heat is released at the point of contact between the part and the electrode made in the form of a copper roller attached to a special device [4]. The surface of the hardened part is cooled with the help of a shower that moves after the electrode.

The surface hardening of steel by the method of heating with a gas flame burner consists in the fact that the surface of the part is heated in the flame of an acetylene-oxygen burner to the required tempering temperature, and then quickly cooled with a stream of cold water. This happens as follows: the gas burner moves at a certain speed over the surface of the part, and behind the burner, at the same speed, the quenching tube, through which water is supplied, moves. The flame of an acetylene-oxygen burner has a temperature of 2500-3200°C, and therefore it heats the surface of the steel product to the temperature required for hardening in a very short period of time. During that time, the layers of steel lying under the surface do not have time to warm up to a critical point and do not receive hardening. The thickness of the hardened layer is 2-4 mm, and the hardness reaches HRC 50-56. Surface hardening of steel by the gas-flame method deforms the steel part less than volume hardening, and the surface does not pollute. This method of surface hardening of steel is more cost-effective for large parts than hardening with microwave induction heating.

Chemical-thermal treatment is the process of changing the chemical composition, structure and properties of surface layers and metal [5].

This treatment is applicable to parts that require a hard and wear-resistant surface while maintaining a viscous and sufficiently strong core, high corrosion resistance, and high fatigue resistance.

Chemical-thermal treatment of steel is based on the diffusion (penetration) of atoms of various chemical elements into the atomic crystal lattice of iron during heating of steel parts in an environment rich in these elements.

The most common types of chemical and thermal treatment of steel are: cementation - saturation of the surface of steel parts with carbon; nitriding - saturation of the surface of steel parts with nitrogen; cyanation - simultaneous saturation of the surface of steel parts with carbon and nitrogen.

In addition to these main types of chemical and thermal treatment, industry also uses surface saturation of steel with metals: aluminum, chromium, silicon, etc. This process is called diffusion metallization of steel.

Foundry technologies for obtaining composite materials and blanks are the least studied and rarely used in production. This is explained by the complexity and diversity of foundry technologies, a large number of used foundry alloys. At the same time, composite, bimetallic castings are a significant reserve of foundry production, a lever for a sharp increase in the competitiveness of castings in comparison with other billets for machine building. The use of composite materials makes it possible to successfully solve many complex technological and structural problems, the solution of which is difficult, and sometimes impossible, with conventional methods of casting [6].

Castings made of carbon, high-manganese, complex-alloyed steels and cast iron are subjected to strengthening surface alloying. The most common castings are strengthened in a casting mold: tracks tracks, teeth of excavator buckets, cultivator feet, plow blades.

Cast structural steel 45L was chosen as the main metal of composite castings. The choice of this particular steel as a research material is due to its wide application in mechanical engineering for critical parts operating under conditions of high contact and alternating loads, as well as abrasive wear.

Steel 45L has satisfactory casting and mechanical properties. However, its abrasive wear resistance in the hardened state is relatively low.

In accordance with the concepts of the processes of deposition of wear-resistant layers on the surface of the casting, the mechanisms of fusion of alloying powders of different fractions and different chemical compositions were studied. Mixtures of crushed ferroalloys, surfacing powders for welding processes, alloy chips, fluxes, and other materials were used as materials for surface alloying [7].

The process of surfacing castings using a composite material consisting of ferromanganese and sludge, borax should be considered the most rational.

The above composition of the powder makes it possible to obtain on steel castings the largest thickness of the deposited layer, defect-freeness of this layer, maximum hardness up to 55 HRC and high wear resistance. The labor intensity of the production of the powder composition and the cost of materials are minimal.

One of the modern methods of changing the structure and properties of the surface layers of the material is the doping of coatings from a foundry mold. The use of mold coatings in foundry production has been known for a long time, but the main goals of their use are to improve the surface quality of castings, preserve the casting mold and prevent its interaction with the poured molten metal, and eliminate the burning of castings. However, the introduction of special compositions into the composition of the coating makes it possible to produce alloying of the surface layers of the casting in the places of its application. This approach allows in some cases to significantly change the properties of the surface of castings without changing the properties of the inner layer of the casting.

When using this technology, the metal to create a layer on the surface of the formed casting comes from a special coating that is applied to the surface of the mold before pouring. The working mixture is applied, as well as standard coatings and coatings used in metal and sand-clay forms [8].

Grain base. It is a dispersed component of the coating, which gives the surface of the casting the required purity or specified properties. The average particle size of this coating component is usually 30-80 μm. The main substances for the grain base are: graphite, carbon black, ferrochrome slag, zircon, borax, etc.

Purpose

The purpose of the research is to increase the wear resistance of machine parts and tools due to the complex diffusion saturation of the surface layer of parts made of iron-carbon alloys in the process of casting on gasified models based on the optimization of the composition of the saturating mixtures and establishing the patterns of structure formation.

Research methodology

Steels of various purposes (25L, 30L, 35L, 45L, 25HL, 110H13L), as well as cast iron SCH15 and SCH20 were chosen as the materials under study.

The chemical composition of the components of the saturated mixture used for diffusion saturation (boron carbide, chromium and titanium boride, etc.) is given. Chemical and thermal treatment was carried out from saturated smears (pastes) applied to the surface of parts and samples to be strengthened.

Cast samples of steel and cast iron for studying the structure and properties of the hardened layer were obtained in two ways:

1 - casting according to gasified models (size of samples for steel 040 mm, length 830 mm, for cast iron - 90x45x20 mm);

2 - in a mold made of a core mixture (a cold-hardening mixture (HTS), consisting of quartz sand of the 4K20202 brand, orthophosphoric acid and BS-40 resin). Sample size: 0.25 mm, length 40 mm.

Cast iron and steel were melted in an induction electric furnace of the LHGW - 0.5/ISM crucible with a power of W=500 kW, and pouring was carried out with a kettle-type ladle with a capacity of V=250 kg. The melt temperature was measured using a Kelvin 1800P infrared thermometer. The chemical analysis of the studied alloys was determined on the Argon-5 and MSA I spectrometers [9].

Strengthening was carried out with a coating applied to the surface of the gasified model and to the surface of the cavity of the mold with HTS.

After diffusion saturation processes, the structure, phase and chemical composition of the boride layers were studied. Metallographic research was carried out on optical microscopes: MIM-7, MIM-10, Neophot - 21 and by scanning electron microscopy (SEM) methods on a JSM - 6510 LV JEOL scanning electron microscope with a microanalysis system INCA Energy 350, Oxford Instruments, transmission electron microscopy (TEM) on the EM-125K electron microscope and atomic force microscopy (AFM) on the "FEMTOSKAN" microscope in the surface relief scanning mode. For viewing in an optical microscope, sections were prepared by chemical and electrochemical poisoning methods. X-ray structural phase analysis was performed using a DRON-1.5 diffractometer.

Mechanical properties were determined by standard methods. Wear resistance was determined in laboratory conditions on an Amsler machine according to ISO 47421. Durometric tests were performed on a Rockwell TP 5005 hardness tester on a scale according to ISO 9013 and on a PMT-3M device according to ISO 9450.

Research results

At the first stage of selecting the composition of the saturating mixture, four types of saturated coatings based on the boriding mixture (70 wt.% B_4C, 15 wt.% graphite, 5 wt.% NaF, 10 wt.% bentonite) were used: No. 1 - with by adding 20 wt. % chromium diboride; No. 2 - with the addition of 20 wt. % nickel; No. 3 - with the addition of 10 wt. % tungsten carbide; No. 4 - with the addition of 20 wt. % of titanium diboride. The coating was brought to a cream-like state with the help of water and liquid glass, applied to the surface of the gasified model and the surface of the mold cavity with XTS thickness from 0.2 to 2.0 mm, then the coating was dried for 3-4 hours in the air at a temperature not lower than 20°C. Form was prepared. Immediately before pouring, the mold was connected to a vacuum pump and a discharge of 0.05 MPa was created, pouring was performed with melt at a temperature of 1500-1600°C from a teapot-type ladle preheated in the furnace to t=950°C. After crystallization of the casting and its aging, the mold was sent for punching [10].

Strengthening diffusion layers were obtained on steels of different chemical composition (Fig. 1), the distribution of microhardness values in the layers after hardening with boron together with other elements (Cr, Ni, Ti, and W) during casting.

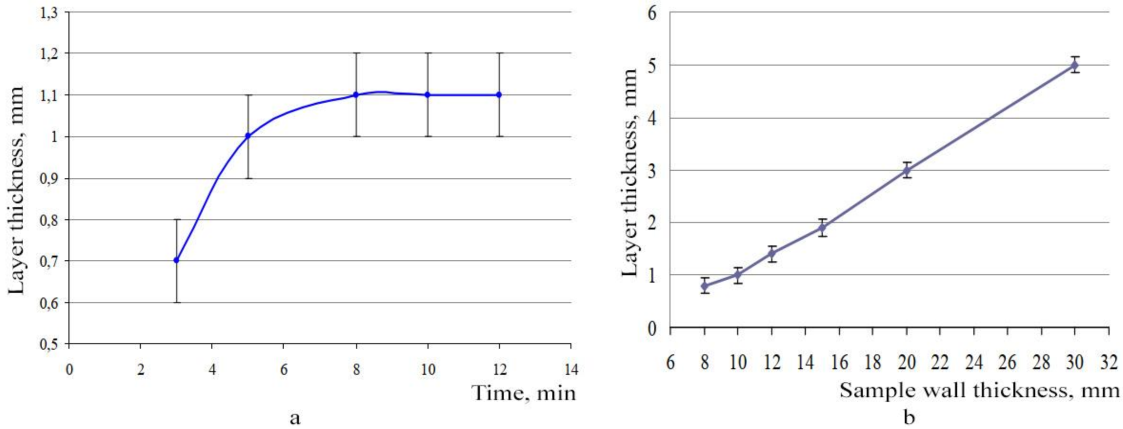


Fig. 1. Effect on the thickness of the borochrome layer on 45L steel:
a - exposure time in the mold (sample thickness 10 mm);
b - wall thickness of the sample (holding time in the form 5 min)

On all steels, layers with a thickness of 0.9 to 1.2 mm were obtained with a casting wall thickness of 10 mm and a holding time in the mold of 5 minutes. The main influence on the formation of the diffusion layer is the duration of the crystallization and cooling process in the austenitic state, which is determined by the thickness of the casting wall (Fig. 1, b) and the time of holding the casting at a temperature above 800°C (Fig. 1, a). The microhardness of the layer varies significantly from 7,500 MPa during borochroming to 14,000 MPa during borotitanization. The data in Fig. 2 are given for samples with a thickness of 10 mm and exposure time in the form of 5 minutes.

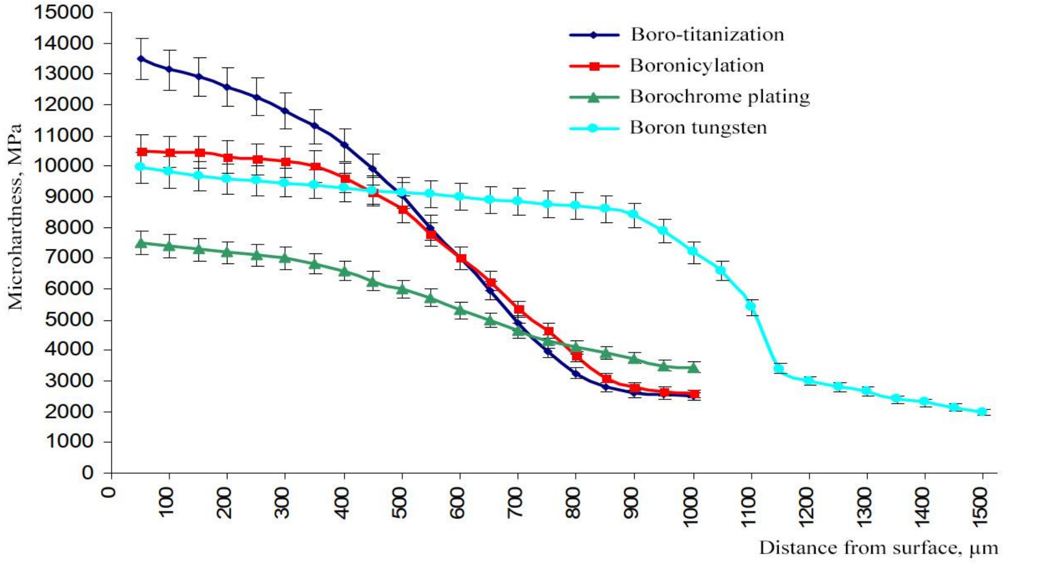
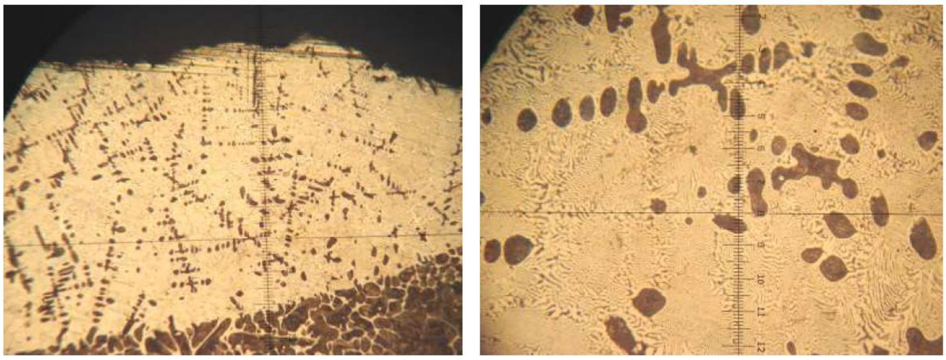


Fig. 2. Distribution of microhardness values in the hardened layer of 45L steel after hardening with boron together with other elements (Cg, Ni, Ti, and W)

The microstructure of the resulting diffusion borochromized layer is shown in Fig. 3. Instead of needle-like layers (Fig. 4), diffusion layers thicker than 1 mm have a boride eutectic structure with large inclusions of pearlite (up to 30 μm), where the eutectic is a finely dispersed mechanical mixture of borides and pearlite.



a b

Fig. 3. Microstructure of the diffusion borochrome layer on steel 45L obtained during casting:
a - the price of a scale division of 10 μm, b - the price of a scale division of 2.5 μm

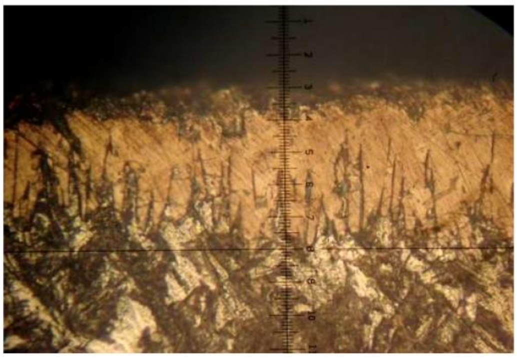


Fig. 4. The microstructure of the diffusion borochromized layer on steel 30: temperature 1000°C, saturation time - 6 h (the price of the scale division is 5 μm)

From Fig. 5, it can be seen that the diffusion boride layer on 30L steel obtained by surface alloying has an order of magnitude greater thickness (2.5 mm) and lower microhardness (up to 16,000 MPa) compared to diffusion layers obtained by chemical-thermal treatment methods (0,25 mm with microhardness up to 30000 MPa, see Fig. 4). Abrasive wear resistance of diffusion layers obtained on cast steel increases by 28.0 times, while the wear resistance of borated ones in the process combined with heating for hardening increases by 7.7 times compared to the standard (U8 steel with a hardness of 51-52 HRC). The diffusion layer on steel 30 has a small thickness and high fragility, therefore, under high loads (above 0.40 MPa), it breaks down faster, and during long-term tests, it wears out much earlier than the layer on steel 30L [11]. In Fig. 6 arrows show the destruction of the brittle phase (cross-section) of boride.

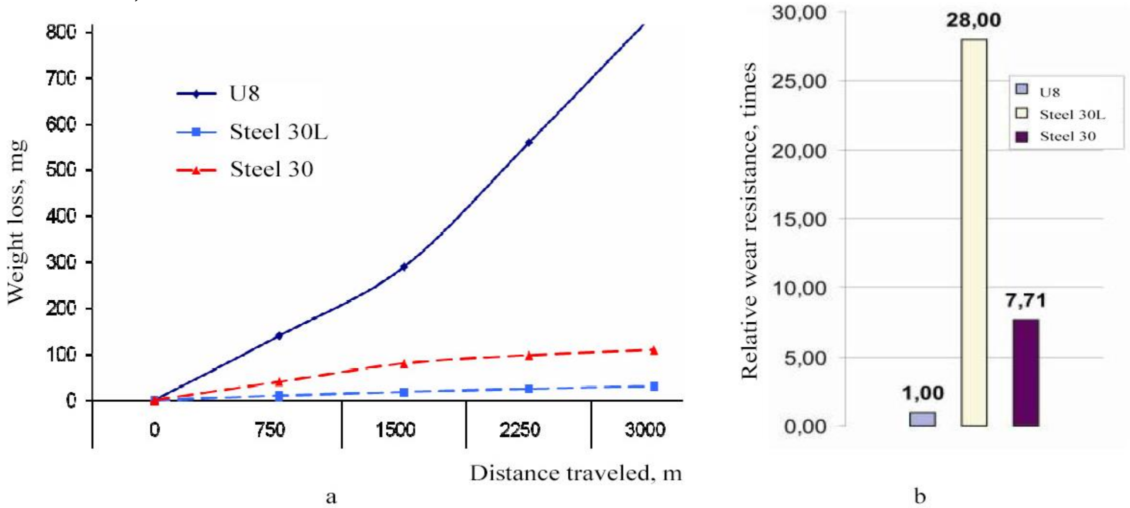


Fig. 5. Wear resistance during abrasive wear of carbon steel (0.3% carbon):
steel 30 - solid-phase boronization from coating, steel 30L - saturation of the surface with boron during LGM (a - mass loss, b - relative wear resistance)

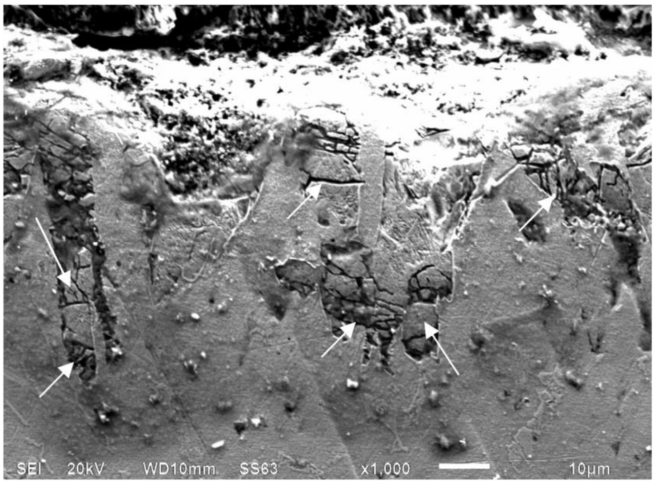


Fig. 6. Destruction of borides in a hardened layer (SEM)

Thus, the possibility and expediency of strengthening the surface layer of parts by complex saturation with boron and chromium during the production of cast products is shown.

Based on previous research, boron carbide was adopted as a boron supplier in the basis of the composition of the saturated mixture for surface hardening of steel parts and tools. The next component included in the coating is chromium diboride, which is a supplier of chromium [12]. Sodium fluoride is used to activate the impregnation process. Finely dispersed graphite provides sufficient thickness of the diffusion layers and easy separation of the coating after the saturation process. Bentonite provides the necessary stiffness of the coating during the saturation process and prevents the coating from falling off during the drying process. In separate experiments, different combinations of these coating components were chosen in percentage ratio of the total mass.

In order to change the number of experiments that were carried out, a more mathematical design of the experiment was carried out when searching for the optimal composition of the chemical coating. To change the area, to determine the optimal value of replacing the skin component of the infused mixture, for surface treatment, the cutaneous component B_4C - 40-80%, CrB_2 - 10-30%, graphite was experimentally established - 5-20%, NaF - 5-15%, bentonite - 2-5%.

For an analytical description of the “warehouse-power” distribution in richly component systems, the simplex method is a useful method, which allows one to derive a mathematical model of the traced distribution and does not require a large volume of experiments [13]. This method is used for stagnation during the injection of a chemical warehouse with a five-component pumped medium for the durability and wear resistance of boron chromium-plated steel coatings.

Among the tested parts, there were high quality rollers made of 35L steel, used to feed the drill to the bench for drilling [14]. The wear resistance of the rollers was determined by the resource by the number of darts supplied (in tons). Robot feed roller mode: feeding a 0.4 mm shot to the workbench for sanding.

The fragments of the historical creation of insatiable sums of this kind are rich in factors, and the song system is the basis for it. Previous studies have shown that in this case, the accumulation of power of boron-chromed balls in a warehouse of compressed coating must be carried out not in the entire area of change in the concentration of components, but rather in a local area.

Conclusions

1. The structures and phase composition of the diffusion layers obtained during the casting process by simultaneous saturation of steels 25L, 30L, 35L, 45L, 25HL and 110G13L with boron together with chromium and boron together with titanium were studied and described. The conditions for the surface alloying process are established, in which there is a possibility of the formation of eutectics of boride, boride, carbides, carboborides, solid solutions based on α-iron.

2. The possibility of obtaining a strengthened surface on structural ferrite-pearlite and pearlite cast iron, medium carbon steels and wear-resistant high-manganese austenitic steel by the method of casting in an open mold from a core mixture and casting on gasified models from expanded polystyrene has been established. It is shown that the boride diffusion layer on 30L steel, obtained during casting, has an order of magnitude greater thickness (up to 5 mm) and a slightly lower microhardness (11,000-16,000 MPa) compared to diffusion layers obtained by chemical-thermal treatment methods (up to 0.25 mm with a microhardness of 16500-25000 MPa).

3. The optimal combination of saturated medium components for surface hardening of steels during the production of machine and tool parts by casting (chromium boride, boron carbide, graphite, bentonite, sodium fluoride) was determined. The study of the ability of the presented saturated media showed that boron-chromium compounds (chromium diboride, ferrochromium), used as components of a saturated coating, are effective both as suppliers of boron and as suppliers of chromium.

4. Analytical dependencies have been established that link the components of the composition of the saturated mixture (CrB_2, B_4C, graphite, bentonite, NaF) with the operational and physico-mechanical properties of steels (microhardness, wear resistance, thickness of the diffusion layer) after hardening in the process of obtaining a casting by the casting method on gasified models.

5. On the basis of the studied ideas about the behavior of steels with a diffuse coating, as well as taking into account the obtained analytical dependences of the properties of hardened steels on the composition of the saturated mixture, a new composition of saturated medium for surface strengthening of cast steels by simultaneous saturation with boron and chromium was developed, containing: 50-60 mass. % B_4C, 20-25 wt. % CrB_2, 2-3 wt. % 5-15 wt. % graphite, 5-7 wt. % bentonite.

A new composition of saturated medium was developed for surface strengthening of cast steels by simultaneous boron and titanium saturation, containing: B_4C - 40-80 wt.%, TiB_2 - 10-30 wt.%, graphite - 10-20 wt.%, NaF - 5- 10 wt.%, bentonite - 2-5 wt.%.

Optimum temperature and time modes of processing are recommended for the developed compositions.

6. The application of the developed technology of the method of processing with the combined technology of laser-plasma-ultrasound hardening allows to improve the operational properties, in particular, the abrasive wear resistance of the diffusion layers obtained on 35L steel increases by 15.4 times during borochroming and by 25.6 times after borotitanization.

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Марченко Д.Д., Матвєєва К.С. Дослідження підвищення зносостійкості деталей машин і інструменту поверхневим легуванням

У роботі науково обґрунтовано застосування ефективної технології підвищення зносостійкості деталей машин і інструменту за рахунок комплексного дифузійного насичення поверхневого шару деталей із залізовуглецевих сплавів в процесі литва по газифікованих моделях на основі оптимізації складу сумішей, що насичують, і встановлення закономірностей структуроутворення.

Встановлена можливість зміцнення поверхні відливок з чавуну СЧ20 і сталей різного складу (25Л, 30Л, 35Л, 45Л, 25ГЛ, 110Г13Л), отриманих методами литва у відкриту форму і по газифікованих моделях. Показано, що дифузійний боридний шар на сталі 35Л, отриманий при питті, має на порядок велику товщину (до 5 мм) в порівнянні з дифузійними шарами, отриманими методами хіміко-термічної обробки (до 0,25 мм). Встановлені аналітичні залежності, що зв'язують компоненти складу суміші (борид хрому (CrB_2), карбід бору (B_4C), графіт, бентоніт, фтористий натрій (NaF)), що насичує, зі зносостійкістю і завтовшки дифузійного шару після зміцнення в процесі отримання відливання методом лиття по газифікованих моделях.

Розроблений новий склад середовища, що насичує, для поверхневого зміцнення при отриманні литих деталей з сірого чавуну, вуглецевих і легованих сталей одночасним насиченням бором і хромом, борид хрому, що містить, карбід бору, графіт, бентоніт, фтористий натрій (50-60 мас. % B_4C + 20-25 мас. % CrB_2 + 2-3 мас. % + 5-15 мас. % дрібнодисперсного графіту + 5-7 мас. % бентоніту). Застосування розробленої технології зміцнення дозволяє поліпшити експлуатаційні властивості, зокрема, зносостійкість деталей машин і інструменту до 25 разів (порівняно з раніше використовуваними способами), а також зменшити трудомісткість процесу зміцнення до 3,5 разів.

Випробування філь’єр для пресування деревних відходів в брикети із сталі 45Л, зміцнених за допомогою розробленої технології, показали, що їх стійкість підвищується більш ніж в 4,5 рази в порівнянні з раніше вживаними із сталі ХВГ зміцнені карбоазотуванням, а використання розробленої технології зміцнення дозволяє зменшити витрати на виготовлення цієї деталі в 1,5 рази.

Ключові слова: зносостійкість, дифузійне насичення, довговічність, поверхневе зміцнення, дифузійне покриття, легування.