in comparison with applied today powders of spherical shape are described. The results of metallographic investigation of samples derived from the experimental powders are presented, which showed a good level of layer adhesion without visible discontinuities.

Keywords: additive technologies; titanium; powder; particles; shape; fractions; surface; layer; compaction; fusion; structure; properties.

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PROCESS OF ARGON-ARC SURFACING OF BLAST FURNACE CHARGING APPARATUS AT LOW POWER CONSUMPTION

The feeding apparatus, which ensures the loading of charge materials into the blast furnace, operates under high specific dynamic loads caused by ore, coke, sinter, abrasive and gas-abrasive wear, high temperatures and aggressive environments. Increasing the wear resistance of charging machines reduces production costs, improves the quality of pig iron and increases the efficiency of metallurgical production. Therefore, increasing the crack resistance and wear resistance of backfill machines is an important scientific and technical problem.

Keywords: *filling apparatus, argon arc surfacing, influence of arc concentration, microstructure grinding.*

Problem statement. The cone of the backfill machine is made of steel 30L. However, the operating conditions, under the influence of abrasive and gas-abrasive wear, require that the hardness of the deposited metal should be at least 55 HRC, which is ensured by a high carbon content of 5.5%, chromium 20.2% and the formation of chromium carbides. Cracks are allowed when surfacing the protective surface of a cone with a width of no more than 1.5 mm and a contact surface of no more than 0.3 mm. Therefore, the study of the crack formation mechanism and the development of a high-speed surfacing process at low power consumption, which ensures an increase in crack resistance and wear resistance of blast furnace charging apparatus, is an important scientific and technical problem.

It is well known that the susceptibility to cracking increases with increasing carbon content. An effective way to increase crack resistance is high-speed surfacing at low power consumption, which reduces welding stresses, grinds the microstructure and increases interatomic bonds, the nature of which is electromagnetic.

Analysis of recent research and publications. The influence of arc concentration, energy, speed and surfacing energy on the crack resistance and wear resistance of the deposited metal under conditions of abrasive and gas-abrasive wear has been insufficiently studied [1-11].

The object of the study. To develop a process of argon-arc high-speed surfacing at low power consumption of blast furnace charging apparatus with high-carbon chromium cored wire.

The main material of the study. The automatic welding process is a nanoprocess, as the current flowing through the electrode creates a strong magnetic field and a pinch effect, i.e. compression under the influence of its own magnetic field. The pinch effect causes a chain reaction - the compression of the cathode spot under the influence of its own magnetic field reduces the spot diameter, which strengthens the magnetic field, which leads to a reduction in the spot diameter. The process continues until the arc breaks. The arc is re-excited at the point where the distance between the electrodes is smallest, according to the law of least resistance.

The magnetic field when current flows through a conductor was studied by R.M. White [6]. The presence of a strong magnetic field during welding in the area of the active spot is confirmed by the fact that the arc acts as a pump that sucks in air from the environment, which is diamagnetic and draws it into a heterogeneous magnetic field, heats it up and throws it towards the products in the form of powerful plasma streams, at a speed of up to 103 m/s [7]. Powerful plasma streams create welding arc pressure, which depends on the movement of the active spot by the electrode end. However, the magnetic field of the welding current has not been studied sufficiently.

At high-speed surfacing at low power output, due to cooling, the temperature of the outer layers of the column decreases and the current begins to flow in a narrow channel, the arc concentrates, and the arc diameter decreases.

To study the effect of arc concentration, deposition rate and power consumption on crack resistance, a methodology was developed to study the effect of wire diameter on the magnetic field of the welding current, which is as follows. A direct current of 300 A flows along a welding wire of different diameters (1.6, 2.8, and 3.6)·10^{-3} m and measurements of magnetic field induction on the wire surface are made. The measurements are made with a teslameter EM4305.

As a result, it was found (Fig. 1.a, b, c) that, with a decrease in the diameter of the wire, the magnetic field induction increases, in accordance with the Bio-Savar law, according to which the induction B is directly proportional to the magnetic permeability of the medium μ = 4π·10-7 Gn/m, current value I i inversely proportional to the distance from the conductor with current R [7]:

$$B = \mu \frac{I}{2\pi R}, \text{ T} \tag{1}$$

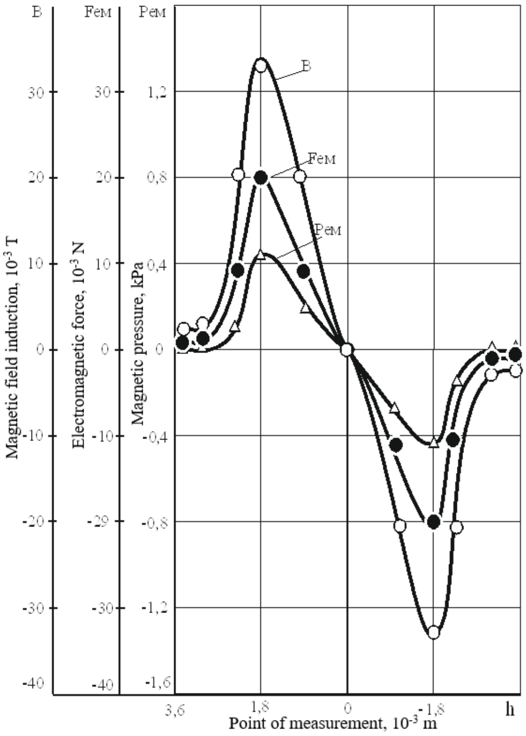

Figure 1 (a) – Magnetic field of a welding arc on a wire with a diameter of 3,6 -10^{-3} m, current value 300 A

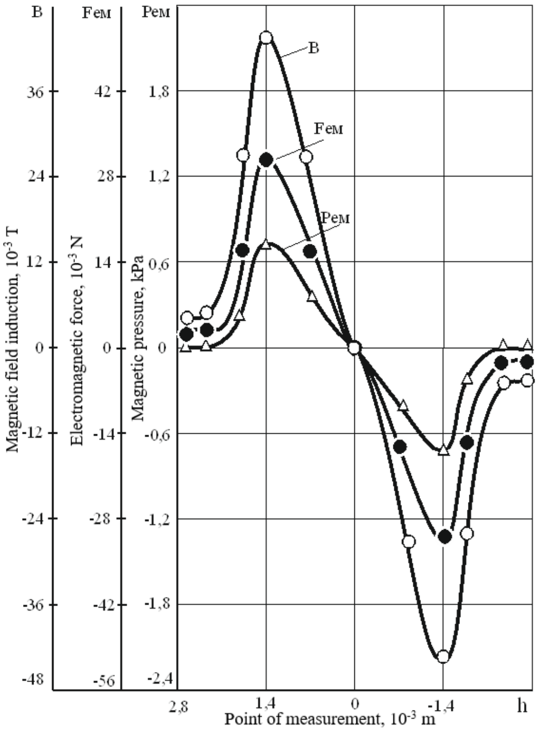

Figure 1 (b) – Magnetic field of a welding arc on a wire with a diameter of 2,8-10^{-3} m, current value 300 A

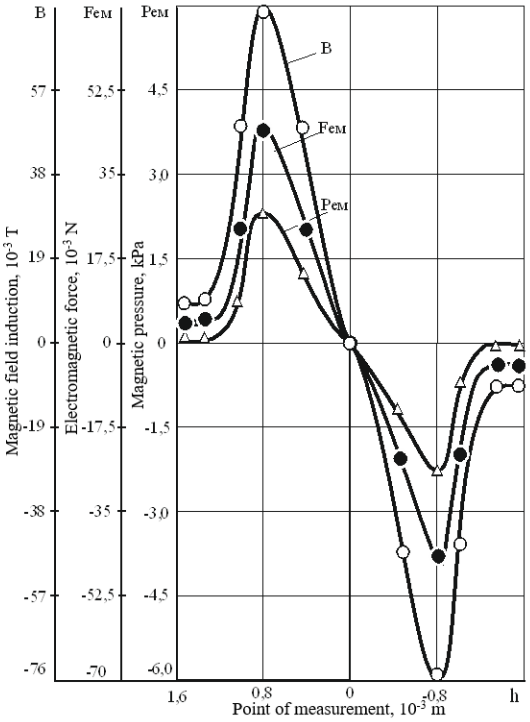

Figure 1 (c) – Magnetic field of a welding arc on a wire with a diameter of 1,6 -10^{-3} m, current value 300A

On the wire axis, the induction is zero, increases as it approaches the surface and reaches its maximum value on the wire surface. When the wire diameter decreased from $3{,}6\cdot10^{-3}$ m to $1{,}6\cdot10^{-3}$ m, the maximum value of the magnetic field induction of the welding current increased from 0,033

T to 0,075 T. When moving away from the wire surface, the magnetic field induction initially decreases sharply and then less significantly. When moving from one arc surface to another, the induction changes direction to the opposite, in accordance with the direction of the magnetic field lines. The experimental data are in good agreement with the calculated values, which confirms the possibility of using the calculated values to determine the magnetic field induction of the welding arc.

The electromagnetic force changes in proportion to the induction, current I and arc length L [7]:

$$F = IBL, \text{H} \qquad (2)$$

Proportional to the induction, as the wire diameter decreased, the electromagnetic force increased from 0,02 H up to 0,045 H (Fig.1)

The magnetic pressure changes quadratically with induction [8], which is directly proportional to the square of the magnetic field induction B and inversely proportional to the magnetic permeability of the medium μ:

$$P_{EM} = \frac{B^2}{2\mu}, \text{Pa} \qquad (3)$$

Magnetic pressure determines the pinch effect, which depends on the diameter of the welding wire and the area over which the arc moves, arc concentration and heat input. With a decrease in wire diameter, the magnetic pressure increased from 0,43 kPa to 2,24 kPa (Fig. 1).

As the pinch effect increases, the magnetic pressure increases and the droplet detachment from the electrode end increases, and the droplet transfer becomes fine-droplet and jet-like. Droplet transfer determines the layer thickness and the rate of crystallization of the weld pool liquid metal. The process of crystallization of liquid metal is periodic, the frequency of which is determined by the transfer of drops. As the pinch effect increases and the droplet size decreases, the thickness of the crystallization layer decreases and the crack resistance of the weld metal increases.

As established (Fig. 1, Fig. 2), the pinch effect increases with increasing welding current.

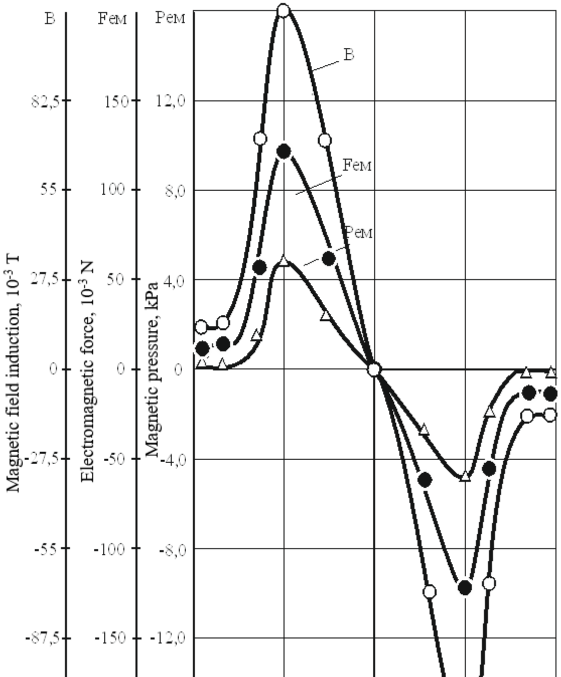

Figure 2 – Magnetic field of the welding arc on a wire with a diameter of 2,8-10^{-3} m, current value 750 A

When the welding current was increased from 300 A to 750 A, the maximum magnetic field induction increased from 0.043 T to 0.107 T, the electromagnetic force increased from 0,03 N to 0,16 N and the magnetic pressure increased from 0,736 kPa to 4,543 kPa. As a result, the fine-droplet transfer turns into jet and vapor transfer, which ensures the minimum thickness of crystallization layers, fine-scale formation and increased crack resistance.

As a result of heat input, during the surfacing process, the metal is exposed to a thermal deformation cycle that determines the microdistortion of the crystal lattice, microstresses, and dislocation density [1]. Under the influence of the thermal deformation cycle, the equilibrium of the liquid metal in the bath is disturbed and welding stresses occur [9] q_u/v , due to reduced heat input, deformation of the base metal and welding stresses are reduced [9]:

$$\sigma \geq \mu E \frac{q_И}{VF}, \text{Па} \qquad (4)$$

To prevent the formation of cracks, the linear energy with increasing carbon content decreases (Fig. 3) to 0,5 MJ/m, which reduces heat input, welding stresses, microstructure refinement, reduction of the interatomic distance, increase of interatomic bonds and crack resistance of the deposited metal.

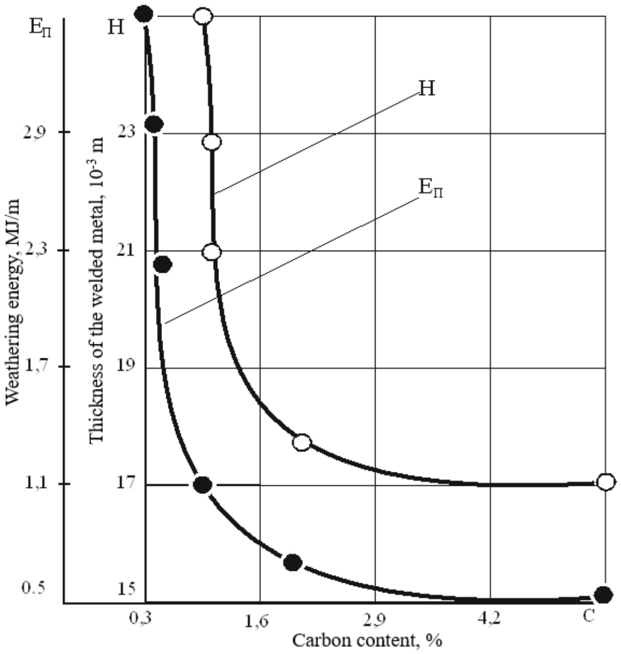

Figure 3 – Dependence of the running energy EП and the thickness of the deposited metal H as a function of carbon content

According to the superposition principle, as the amount of weld metal increases, the welding stresses increase. When welding stresses increase above the tensile strength, cracks form. Therefore, as the carbon content increases, the thickness of the deposited metal decreases (Fig. 3). When surfacing backfill machines with a high carbon content, the thickness of the deposited metal is limited to $17 \cdot 10^{-3}$ m compared to the support rolls of $25 \cdot 10^{-3}$ m.

To prevent the liquid metal from flowing out of the weld pool and impairing weld formation, it is necessary to reduce the weight and length of the weld pool.

The formation of welds is determined by the forces acting on the arc and the liquid metal of the weld pool, the size and weight of which is set by the liquid metal spilling out of the pool. In this case, a portion of the liquid metal is lost and it is difficult to estimate the mass of the weld pool.

To determine the size and weight of the weld pool liquid metal, a method has been developed that consists of the following. The flux cushion is pressed against the welding plates. At the end of the weld, the flux is loosely adjacent to the welding plates. One-sided submerged arc welding of plates on a flux cushion is performed. After the established welding process in real conditions, when the arc approaches the place of loose flux fitting, where there is no upward pressure force of the flux cushion, the balance of forces is disturbed and under the influence of downward arc pressure, magnetic and hydrodynamic pressure, liquid metal (Fig. 4) flows out of the bath. The developed methodology makes it possible to estimate the shape, size, and weight of the weld pool. Due to the fact that one-sided welding with a composite electrode is carried out at high currents, the dimensions and weight of the weld pool are significant, so the error does not exceed 10%.

It was found that during one-sided welding with a composite electrode on a flux cushion from a current-carrying wire in the following mode: current 2000 - 2100 A, arc voltage 27 -29 V, welding speed 0,021 m/s, weld pool length 0.18 m, pool width 0.022 m, pool liquid metal mass 0,101 kg (Fig. 4). The calculated value of 0,099 kg is in good agreement with the experimental data.

а

б

Figure 4 – Weld pool crater (a) and metal (b)

The advantage of the developed technique, in comparison with the existing splash method, is as follows: in addition to measuring the size and weight of the weld pool, it allows to determine the area over which the active spot moves, the position of the arc during welding, the location of the electrode relative to the leading edge of the crater, and the size of the weld pool crater by the hole left (Fig. 4). However, an increase in welding current leads to an increase in the weld pool weight, liquid metal leakage, and impaired weld formation.

To calculate the mass of the liquid metal of the weld pool, we used the dependence of the time of metal residence in the liquid state on the power consumption [10], mass and welding speed [11]:

$$t_B = \frac{q_И}{2\pi\lambda V T_{ПЛ}} = \frac{0{,}24 I U \eta_И}{2\pi\lambda V T_{ПЛ}} \tag{5}$$

$$t_B = \frac{G_B}{\rho V F} \tag{6}$$

where G_B – weight of liquid metal, kg; ρ – density of metal, 7850 kg/m^3;
F – cross-sectional area of the weld metal, m^2;
V – welding speed, m/s.

Equating the time spent in the bath in the liquid state, using formulas (5) and (6), we obtain an expression for the mass of the liquid metal:

$$t_B = \frac{G_B}{\rho V F} = \frac{0{,}24 I U \eta_И}{2\pi\lambda V T_{ПЛ}}$$

$$G_B = \frac{0{,}24 I U \eta_И}{2\pi\lambda V T_{ПЛ}} \cdot \rho V F \quad , \quad G_B = \frac{0{,}24 I U \eta_И}{2\pi\lambda T_{ПЛ}} \cdot \rho F \tag{7}$$

The calculation and experimental method established that with an increase in the current value, the mass of the liquid metal of the weld pool increases (Fig. 5), which leads to metal leakage and disruption of the formation of welds on the end surface, so it is necessary to reduce the current value and the cross-section of the weld metal.

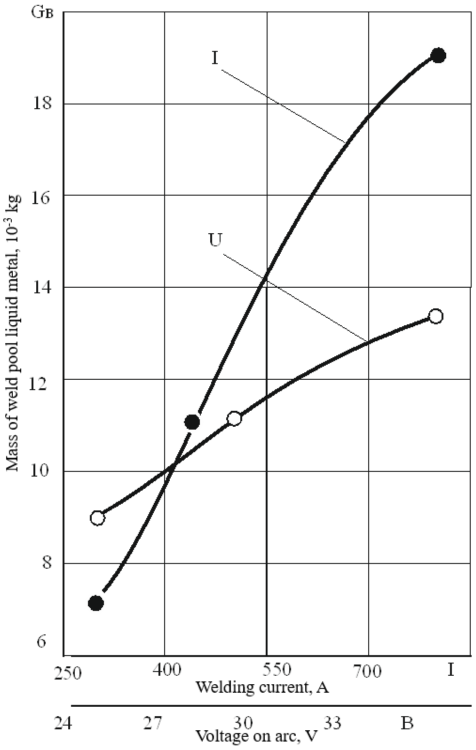

Figure 5 – Dependence of the mass of the liquid metal of the weld pool on the current I and arc voltage U

The length of the weld pool, when surfacing a roller to a massive body, is determined for a powerful fast-moving heat source using the equation for the melting isotherm [10]

$$L = Vt_B = \frac{q_И}{2\pi\lambda T_{ПЛ}} = \frac{0{,}24IU\eta_И}{2\pi\lambda T_{ПЛ}} \qquad (8)$$

o reduce the time spent by the bath in the liquid state and improve the formation of the deposited metal, it is necessary to perform high-speed surfacing at low power consumption, which increases the bath crystallization rate $V_{кр} = V_{св}Cos\alpha$ and the structure refinement, increases the resistance to the formation of crystallization and sub-solidus cracks and corrosion resistance of the deposited metal.

With an increase in current, the length of the weld pool (Fig. 6), which is directly proportional to the effective arc power $q_И$, current I and voltage U and inversely proportional to the thermal conductivity coefficient λ, and melting point T_{PL}, increases [10], which leads to the flow of liquid metal from the pool and disruption of weld formation.

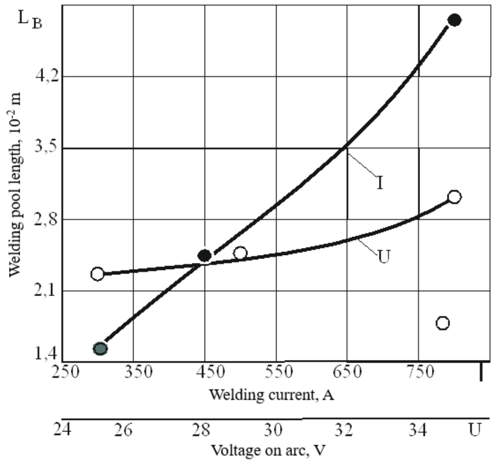

Figure 6 – Dependence of weld pool length on current I and arc voltage U

An effective way to reduce the length of the weld pool is to reduce the welding current provided by argon arc welding by reducing the diameter of the electrode.

The most effective way to prevent liquid metal leakage from the weld pool and weld formation disruption is high-speed surfacing at low power consumption, which reduces the time the pool remains in the liquid state by increasing the welding speed and reducing the power consumption (Fig. 7).

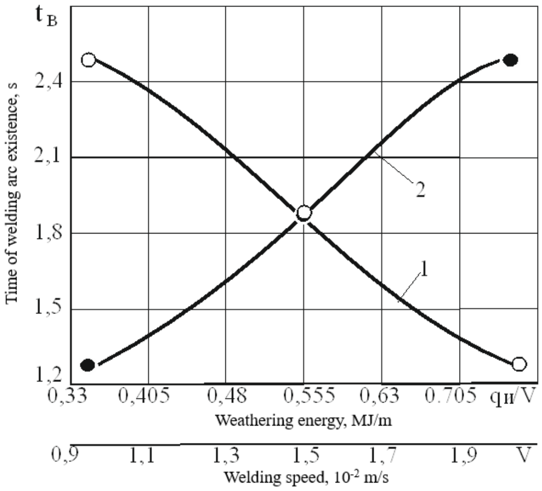

Figure 7 – Dependence of weld pool lifetime on deposition rate (1) and power consumption (2)

Based on the research and established patterns, a high-speed surfacing process was developed for low power consumption of backfill machines.

Surfacing is performed on a horizontally positioned plate, which makes it difficult to keep the liquid metal from flowing out of the weld pool on a conical surface. The metal is held by the pressure of the welding arc, due to the location of the electrode at an angle of 90^0 to the forming conical surface and $95...100^0$ to the tangential conical surface. To prevent liquid metal from leaking out of the weld pool and to ensure high-quality weld formation, it is necessary to reduce the length of the weld pool and its residence time.

During argon arc high-speed surfacing of blast furnace charging apparatus, preliminary and accompanying heating is performed with gas burners up to 100-150°C. First, the protective surface is automatically surfaced with high-carbon chromium flux-cored wire with a diameter of 2,8 mm in the following mode: welding current 550-600 A, arc voltage 29 V, surfacing speed 75 m/h, and line energy 0,7 MJ/m. Surfacing is performed using direct current of reverse polarity. The angle of inclination of the torch to the forming conical surface is 90^0, to the tangential conical surface is $95...100^0$. After surfacing, slow cooling to a temperature of 50°C is performed.

Then the hardfacing of the contact surface is performed. Prior to surfacing, preliminary and accompanying heating is performed to 100 - 150°C. The buffer layer is surfaced with chromium-nickel solid uranium wire Zv06Kh19N9T, 1.6 mm in diameter in argon in the following mode: welding current 350 - 400 A, arc voltage 28 - 29 V, deposition rate 75 m/h in two passes, linear energy 0,5 MJ/m.

Preliminary and concomitant heating to 150-200°C for hardfacing of the contact surface is performed. Surfacing is performed with high-carbon chromium flux-cored wire with a diameter of 2,8 mm in the following mode: welding current 550 - 600 A, arc voltage 29 - 30 V, surfacing speed 75 m/h, running energy 0,7 MJ/m. After surfacing, the process is followed by slow cooling to a temperature of 50°C. The hardness of the deposited metal on the protective and contact surfaces should be at least 55 HRC.

Chromium-nickel wire, the concentration of arc and energy, when surfacing the buffer layer, provides strong adhesion of the deposited metal to the base metal and no delamination.

CONCLUSIONS

1. An effective way to increase crack resistance is to concentrate the arc and energy, which increases the efficiency of the surfacing process. Concentration of the arc, by reducing the diameter of the electrode, provides an increase in magnetic field induction, electromagnetic force, magnetic compression pressure, pinch effect, droplet grinding and microstructure, reduction of welding stresses, increase in the rate of crystallization of the weld pool metal, crack resistance and wear resistance of the deposited metal.

2. It was found that with an increase in carbon content, the energy per unit length decreases to 0,5 MJ/m, which reduces heat input, welding stresses, increases the rate of liquid metal crystallization, refines the microstructure, increases the interatomic compression pressure, crack resistance and wear resistance of the deposited metal.

3. According to the law of superposition, as the amount of deposited metal increases, the welding stresses increase, which leads to delamination of the deposited metal when the welding stresses become greater than the interatomic bonds. It has been found that with an increase in carbon content, the maximum thickness of the deposited metal decreases to reduce welding stresses. To prevent delamination, the thickness of the deposited metal when surfacing backfill apparatus should be 12-17 mm.

4. To prevent metal leakage from the weld pool when surfacing a conical surface, a methodology for determining the pool weight and an argon arc surfacing process have been developed that ensures arc concentration, reduction of pool weight and power consumption, and increased crack resistance and wear resistance.

5. A process of argon-arc high-speed surfacing at low power consumption of blast furnace charging apparatus with high-carbon chromium cored wire has been developed, which provides concentration of arc and energy, reduction of heat input and welding stresses, increase in crystallization rate, microstructure refinement, reduction of interatomic distance, enhancement of pinch effect and interatomic compression pressures, increase in crack resistance and wear resistance of apparatus and metal quality.

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ПРОЦЕС АРГОНОДУГОВОГО НАПЛАВЛЕННЯ ЗАСИПНИХ АПАРАТІВ ДОМЕННИХ ПЕЧЕЙ НА НИЗЬКІЙ ПОГОННІЙ ЕНЕРГІЇ

Засипний апарат, який забезпечує завантаження шихтових матеріалів в доменну піч, експлуатується в умовах високих питомих динамічних навантажень під дією руди, коксу, агломерату, абразивного і газоабразівного зносу, високих температур і агресивних середовищ. Збільшення зносостійкості засипних апаратів знижує собівартість, підвищує якість чавуну і ефективність металургійного виробництва. Тому, підвищення *тріщиностійкості і зносостійкості засипних апаратів є важливою науково-технічною проблемою.*

Ключові слова: *засипний апарат, аргонодугове наплавлення, вплив концентрації дуги, подрібнення мікроструктури.*

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Зусін А.М.

ВПЛИВ РЕЖИМІВ ТЕРМІЧНОЇ ОБРОБКИ НА СТРУКТУРУ ТА ЗНОСОСТІЙКІСТЬ НАПЛАВЛЕНОГО МЕТАЛУ РОЗРОБЛЕНИМИ ПОРОШКОВИМИ ДРОТАМИ З АЗОТОМ

Переривання роботи машин через пошкодження або знос компонентів, обмежує тривалість нормальної експлуатації та призводить до простоїв. Потрібні додаткові витрати на виготовлення та ремонт запасних частин. Експлуатаційна надійність та довговічність багатьох деталей машин залежить від їх міцності, зносостійкості [1].

Багатодеталеймашинпіддаютьповерхневомузміцненнюдляпідвищеннятвердості,межі витривалостітазносостійкостіповерхневогошару.Існує три основні методи поверхневого зміцнення: поверхневе зміцнення, хіміко-термічна обробка та зміцнення пластичною деформацією [2].

У цій роботі досліджено можливість отримання залишкового аустеніту з використанням різних режимів термічної обробки, а також вплив мікроструктури та її метастабільності на зносостійкість. Фазовий склад, метастабільність аустеніту та механічні властивості цементованих карбідо-сталей можна контролювати шляхом регулювання температури відпуску.

В останні роки багато вчених продемонстрували позитивний вплив залишкового аустеніту, що утворюється в поверхневому шарі та самозміцнюється під навантаженням, на зносостійкість і втомну міцність [3].

Одним з найважливіших напрямків сучасного зварювання є створення наплавних матеріалів з метастабільними структурами, які здатні само організовуватися під впливом зовнішніх факторів.

Вони можуть адаптуватися до умов навантаження і мають значно вищі властивості. Дослідження в цій галузі розпочалися в середині минулого століття І.М. Богачовим та Р.І. Минцем. Вони висунули і реалізували надзвичайно плідну ідею використання мартенситного перетворення під навантаженням в процесі випробування механічних властивостей і працездатності спеціальних сталей.

Сплави з метастабільним аустенітом мають підвищену стійкість до гідро-абразивного зносу, абразивного, ударного, сухого тертя та втомного навантаження. Ці сплави дозволяють досягти високих рівнів механічних властивостей. Це пов'язано з тим, що на виникнення мартенситного перетворення під навантаженням витрачається більша частина зовнішньої енергії і відповідно менша частка використовується на руйнування. Розвиток мартенситного перетворення призводить не тільки до зміцнення, але і до релаксації мікронапружень, що покращує мікро об'єм і характеристики сплаву. Цьому також сприяє динамічне деформаційне старіння. [4].

Ключові слова: *порошковий дріт, аустеніт, азот, зносостійкість, легування, дугове наплавлення, карбіди, нітриди, термічна обробка, відпуск.*