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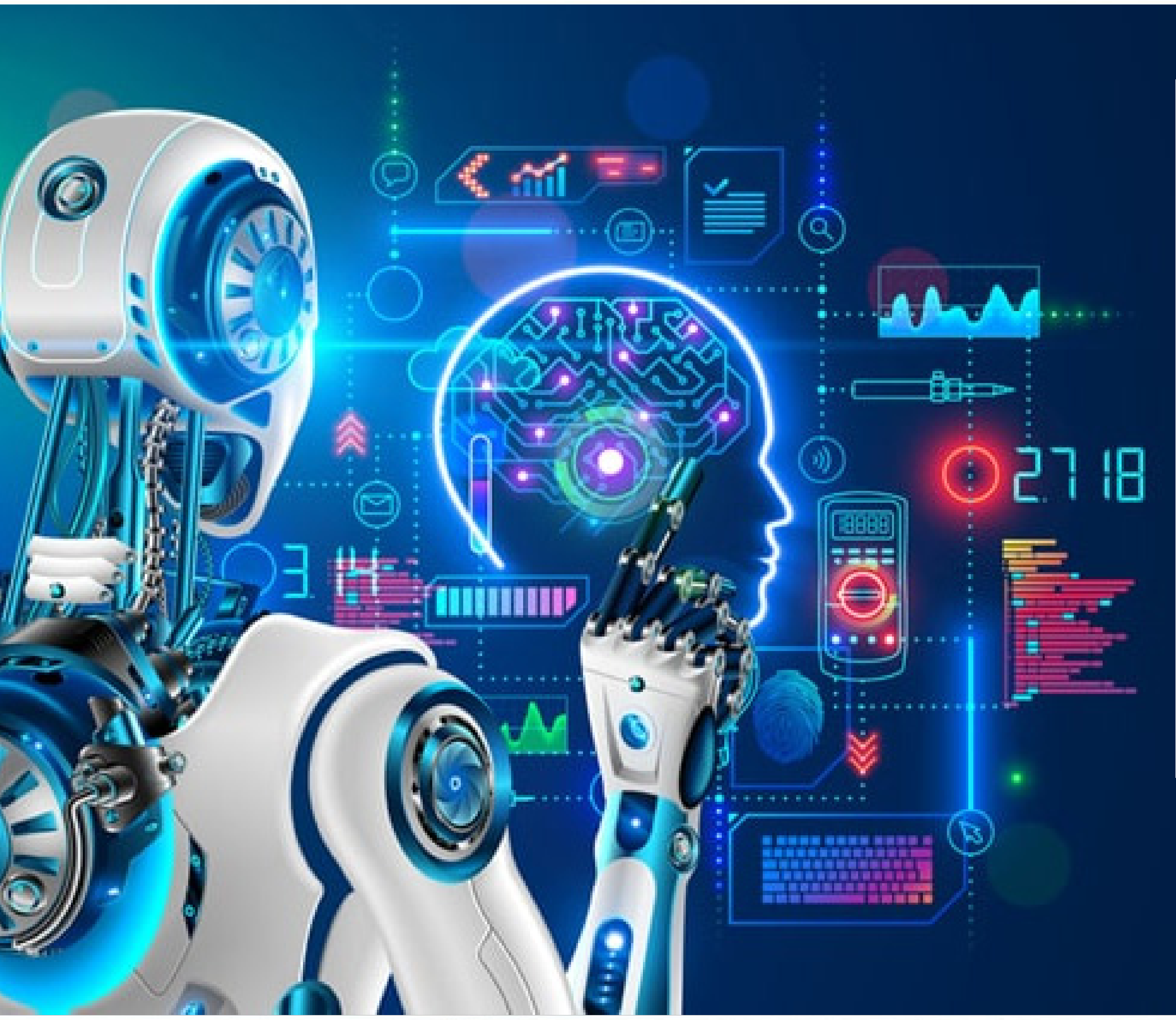

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CONTENTS

ON THE ISSUE OF RESEARCH AND DEVELOPMENT OF A SLAG-FORMING BASE FOR ELECTRODE COATINGS FOR WEAR-RESISTANT SURFACING

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Abstract: This article describes the development of a slag-forming base for electrode coatings for wear-resistant surfacing in the $CaO–SiO_2–Al_2O_3$ system, as well as the study of the influence of Na_2O and K_2O contents in this slag system on slag density, viscosity, hiding power, and the separability of the slag crust.

Key words: Manual arc surfacing, electrode, ferroalloys, marble, pegmatite, ternary phase diagram, slag, viscosity, density, separability of the slag crust.

Annotatsiya: Mazkur maqolada $CaO–SiO_2–Al_2O_3$ tizimida yeyilishga chidamli qoplama payvandlash uchun elektrod qoplamalari tarkibida shlak hosil qiluvchi asosni ishlab chiqish, shuningdek, ushbu shlak tizimida Na_2O va K_2O miqdorining shlakning zichligi, qovushoqligi, yopish qobiliyati hamda shlak qobig'ining ajraluvchanligiga ta'siri tadqiq etilgan.

Kalit so'zlar: Qo'lda yoyli qoplama payvandlash, elektrod, ferroqotishmalar, marmar, pegmatit, uch komponentli faza diagrammasi, shlak, qovushoqlik, zichlik, shlak qobig'ining ajraluvchanligi.s

Аннотация: В статье описана разработка шлакообразующей основы для покрытий электродов, предназначенных для износостойкой наплавки в системе $CaO–SiO_2–Al_2O_3$, а также исследовано влияние содержания Na_2O и K_2O в данной шлаковой системе на плотность, вязкость, укрывистость шлака и отделяемость шлаковой корки.

Ключевые слова: Ручная дуговая наплавка, электрод, ферросплавы, мрамор, пегматит, тройная фазовая диаграмма, шлак, вязкость, плотность, отделяемость шлаковой корки.

INTRODUCTION

Metal surfacing on the surface of a part makes it possible to impart the required mechanical and physicochemical properties, thereby increasing operational reliability and service life while reducing overall costs.

Surfacing operations are used to form surface layers on parts with specified properties, as well as to restore the original dimensions of worn components. For example, surfacing enables the manufacture of parts from structural, relatively low-cost steels, on the working surfaces of which wear-resistant, heat-resistant, or other special alloys are deposited.

During surfacing, it is generally necessary to ensure minimal penetration of the base metal and limited mixing between the base and deposited metals in order to preserve the mechanical properties of the deposited layer.

At the same time, the deposited metal must be firmly bonded to the base metal and should be free from pores, slag inclusions, crack shells, and other defects.

LITERATURE REVIEW

The wear of parts is the result of the wear process, which involves the destruction and separation of material from the surface of a solid and/or the accumulation of residual deformation during friction. This process occurs in a friction pair, that is, a combination of two movably сопряжённых surfaces under real operating conditions, and is manifested in a gradual change in the size and/or shape of the body. The mechanisms of surface destruction during friction are diverse, which is associated with the combined action of mechanical, physicochemical, electrochemical, and other processes, as well as environmental conditions such as temperature and humidity [1–2].

The main factors determining surface damage and wear include plastic deformation; destruction of microroughness and oxide films due to the penetration of surface asperities of one part into the mating surface of another and their relative displacement; adhesive bonding and transfer of metal from one surface to another; hydrogenation and oxidation processes; and the rupture of seizure bridges, among others [3].

Production surfacing is applied to obtain new bimetallic (multilayer) products. Such products consist of a base metal that provides the required structural strength and a deposited working layer with special properties, including wear resistance, heat resistance, and corrosion resistance [4].

Recovery surfacing is used to restore the original dimensions of worn or damaged parts. In this case, the deposited metal may be similar in composition and properties to the base metal (dimensional restoration) or may differ from it in order to enhance performance characteristics, such as wear resistance (restorative wear-resistant surfacing) [5, 6].

RESEARCH METHODOLOGY

In the vast majority of cases, electrodes for surfacing are provided with basic coatings. Owing to the low hydrogen content in the deposited metal, such coatings ensure improved resistance to cracking during surfacing of parts made of high-carbon steels and hard alloys.

The developed composition of the electrode coating for wear-resistant surfacing includes the following components, wt.%: marble — 26–28; pegmatite — 14–16; graphite — 9–11; ferrosilicomanganese — 10–12; ferrochrome — 25–27; and ferrotitanium — 10–12.

ANALYSIS AND RESULTS

The slag system of electrodes for wear-resistant surfacing is formed by oxides of calcium (from marble), silicon, and aluminum (from pegmatite), which together ensure the formation of a stable slag with the required physicochemical properties (Figure 1).

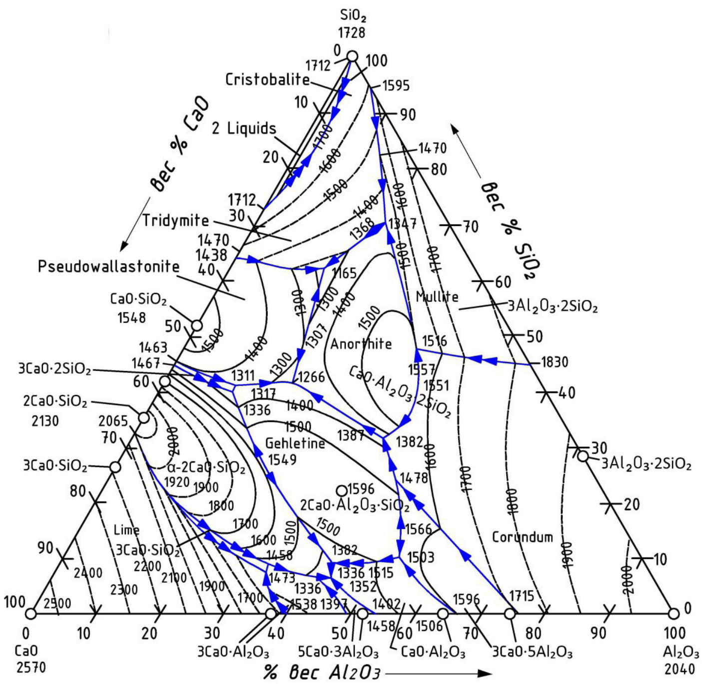

Figure 1. Ternary diagram of the $CaO–SiO_2–Al_2O_3$ system

In the $CaO–SiO_2–Al_2O_3$ system, a minimum melting temperature of about 1300 °C is observed at compositions of approximately 50 % SiO_2, 30 % CaO, and 20 % Al_2O_3. Several chemical compounds are formed in this system, including two ternary compounds: $CaO·Al_2O_3·SiO_2$, containing 20 % CaO, 37 % Al_2O_3, and 43 % SiO_2 and melting at 1550 °C, and $2CaO·Al_2O_3·SiO_2$, containing 41 % CaO, 37 % Al_2O_3, and 22 % SiO_2 and melting at 1590 °C.

The system under consideration is characterized by a wide region of melts with melting temperatures not exceeding 1600 °C, which ensures the broad applicability of slags based on the $CaO–SiO_2–Al_2O_3$ system. Slags of this system containing 48–54 % CaO tend to disintegrate into powder upon cooling.

The mineralogical composition of the slag and its structure significantly influence its physical and technological properties.

In this study, the effect of Na_2O and K_2O oxide additives (with contents of 7.08 % and 4.15 % in pegmatite, respectively) on the properties of slags belonging to the $CaO–SiO_2–Al_2O_3$ system was investigated. The influence of these additives on slag density, viscosity, and surface tension was analyzed. In parallel, the effect of the slag's physical state on welding and technological characteristics, such as slag covering power and its separability, was also examined (Figure 2).

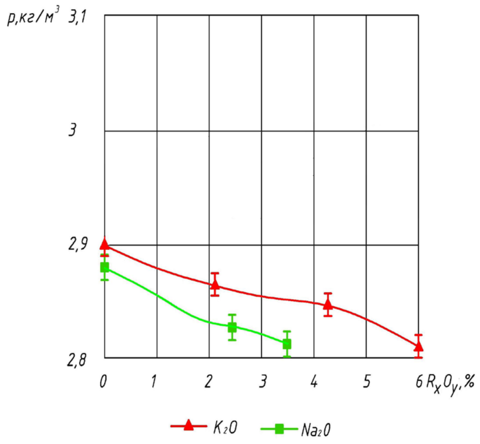

Figure 2. Dependence of the density of surfacing slag of the $CaO–SiO_2–Al_2O_3$ system on the Na_2O and K_2O content

As shown in Figure 2, the addition of sodium and potassium oxides leads to a noticeable decrease in slag density, indicating their effective role in modifying the physical properties of the slag.

The viscosity of the slag was determined using viscometry methods. This method is based on the law of fluid flow in the gap between two coaxial bodies, one of which rotates while the other remains stationary. The viscosity is calculated from the measured torque at a given angular velocity. Slag viscosity measurements were carried out using a rotational viscometer with a rotating working element immersed in the molten slag.

The dependence of slag viscosity on the Na_2O and K_2O contents in the initial slag at T = 1700 K is presented in Figure 3.

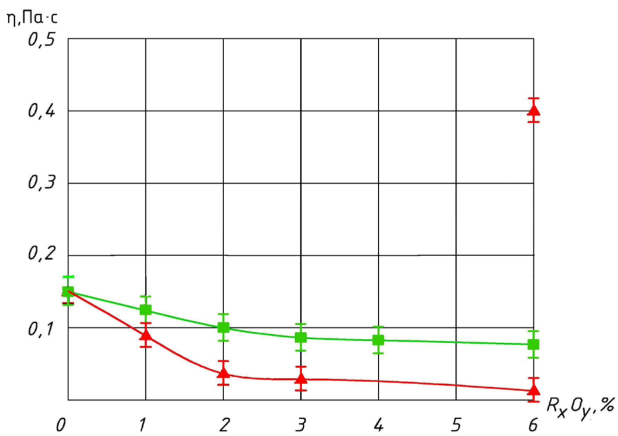

Figure 3. Dependence of the slag viscosity of the $CaO–SiO_2–Al_2O_3$ system on the Na_2O and K_2O content

Potassium and sodium oxides contribute to a reduction in the viscosity of the molten slag. Moreover, with an increase in the K_2O content, the slag viscosity decreases more markedly than with an equivalent amount of Na_2O. This behavior can be explained by the characteristics of the anions and cations formed during the dissociation of these oxides in the slag melt.

The covering power of the slag during surfacing with coated electrodes was determined as the product of two ratios: the ratio of the slag crust thickness at the top of the deposited bead to that at the base of the bead, and the ratio of the surface area of the bead covered with slag, S1S_1S1, to the total surface area of the bead, S2S_2S2, i.e.:

$$K_{C.P.} = \frac{\Delta_1}{\Delta_2} \cdot \frac{S_1}{S_2}$$

The influence of the Na_2O and K_2O contents in the slag on its covering power is illustrated in Figure 4.

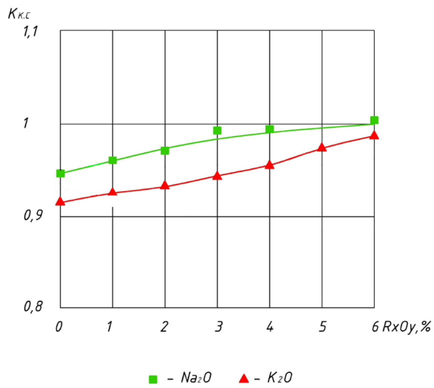

Figure 4. Dependence of the covering power of the $CaO–SiO_2–Al_2O_3$ system on the Na_2O and K_2O content

As shown in Figure 4, an increase in the Na_2O and K_2O contents leads to a corresponding increase in the covering power of the slag, indicating an improvement in its ability to uniformly protect the molten metal during surfacing.

The determination of slag crust separability is based on measuring the impact force applied to the specimen. The essence of this method lies in the following procedure: first, a bead is deposited on the surface of a plate. After surfacing, the bead is cleaned of slag, and a second bead is then deposited so that it overlaps the first one by half of its width.

The surfaced plate is subsequently placed in the quick-acting clamps of a pendulum testing device. When the temperature of the deposited metal is above 450 °C, an impact is applied to the reverse side of the deposited layer. The angle of rise of the pendulum is kept constant at 60° in all experiments. The magnitude of the impact load is selected so that plastic deformation of the specimen does not occur. The separability of the slag crust is evaluated based on the area of the slag layer detached from the surface.

The dependence of slag separability on the Na_2O and K_2O contents is presented in Figure 5.

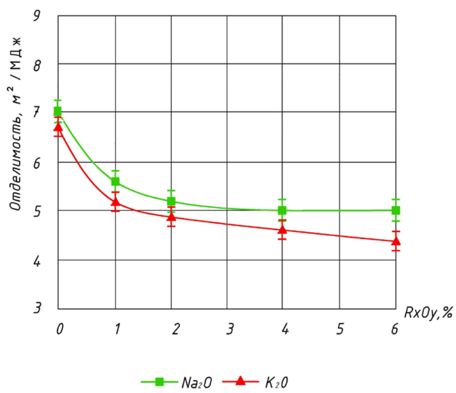

Figure 5. Dependence of slag crust separability (m^2/MJ) on the Na_2O and K_2O contents in the slag of the $CaO–SiO_2–Al_2O_3$ system

The separability of the slag crust is one of the most important indicators of the processability and technological suitability of surfacing materials.

Slag separability mainly depends on the epitaxial intergrowth between the slag and the weld metal, which may occur when both phases have similar structures at the phase boundary. As shown in Figure 5, an increase in the Na_2O and K_2O contents is associated with a decrease in slag crust separability. This trend reflects the formation of stronger interfacial bonding, which influences the interaction between the slag and the deposited metal.

Electrodes for wear-resistant surfacing were developed with the following coating composition, wt.%: marble — 26–28; pegmatite — 14–16; graphite — 9–11; ferrosilicomanganese — 10–12; ferrochrome — 25–27; and ferrotitanium — 10–12.

CONCLUSIONS AND RECOMMENDATIONS

The introduction of Na_2O and K_2O into the $CaO–SiO_2–Al_2O_3$ system leads to a decrease in slag density and viscosity, enhances its covering (hiding) power, and is accompanied by a reduction in slag crust separability, which reflects intensified interaction between the slag and the deposited metal. Studies by Sadikov et al. (Uzbekistan) confirm that slag systems based on the $CaO–SiO_2–Al_2O_3$ composition are technologically suitable for wear-resistant manual arc surfacing due to their relatively low melting temperature and stable physicochemical properties. According to Verkhoturov (Russia) and other international researchers, controlling slag viscosity and density is a key factor in ensuring defect-free deposited layers, which is consistent with the results obtained in this work. The introduction of Na_2O and K_2O oxides into the slag system significantly reduces slag density and viscosity, in agreement with conclusions reported by foreign authors studying alkali oxide modification of welding slags. Experimental results demonstrate that K_2O has a stronger effect on viscosity reduction than Na_2O, which can be explained by differences in ionic radius and slag structure modification, as noted in international welding metallurgy literature. Uzbek researchers emphasize that improved slag fluidity contributes to more uniform slag coverage of the weld pool, which is confirmed in this study by the increased covering (hiding) power of slags containing alkali oxides. At the same time, the observed decrease in slag crust separability with increasing Na_2O and K_2O content correlates with the mechanisms of epitaxial slag–metal interaction described by Moravetsky (Ukraine) and other foreign authors. The obtained results indicate a technological balance between slag covering ability and slag crust separability, which should be taken into account when designing electrode coatings for wear-resistant surfacing. The developed electrode coating composition based on local mineral raw materials of Uzbekistan demonstrates the feasibility of import substitution in welding consumables while maintaining high technological performance. Both Uzbek and international studies confirm that optimizing slag composition makes it possible to control weld metal quality while ensuring strong metallurgical bonding with minimal dilution of the base metal. Overall, the research supports the conclusion that $CaO–SiO_2–Al_2O_3$ slag systems modified with controlled amounts of Na_2O and K_2O are promising for further development of wear-resistant surfacing electrodes, provided that slag separability requirements are carefully balanced. This work was carried out within the framework of a business contract with the Tashkent Pipe Plant named after V. L. Halperin, No. 9–2020, on the topic: “Development of coating composition and production technology of surfacing electrodes.”

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