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# **Research and Development of a Slag-Forming Base for Acidic Type Electrode Coatings**

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**ABSTRACT:** In this article is represented the development of a slag-forming basis for the CaO-SiO<sub>2</sub>-TiO<sub>2</sub> system of acid-type electrode coatings, as well as a study of the effect of the content of NaO and K<sub>2</sub>O in the CaO-SiO<sub>2</sub>-TiO<sub>2</sub> system on the slag density, viscosity and covering slag, and the slag crust separability.

**KEYWORDS:** Triple state diagram, slag, viscosity, density, slag crust separability, manual arc welding, electrode, acidic coating

## **I. INTRODUCTION**

The simplest way to develop electrodes is the experimental selection of the coating composition and the corresponding composition of the electrode rod. Depending on the technical requirements for the electrode, such an experimental selection requires a larger number of verifiable options. However, as a rule, the number of options reaches several dozen, and in some cases more than a hundred different compositions are tested. Naturally, this is a long and often very expensive experiment.

Using the experience gained in the development of welding electrodes, as well as using some calculations that make it possible to single out the most probable composition variants, when creating new coatings, the number of required experiments to solve this problem will be reduced.

In such calculations, the necessary compositions of slag-forming components of coatings, the number of deoxidizers, alloying additives, materials providing the required stability of the welding arc, etc. can be evaluated.

Some of the initial data used for such calculations of the value of such calculations (the number of binders, forming additives, their concentration in the weld metal, etc.) can be taken on the basis of comparison with existing materials.

## **II. LITERATURE SURVEY**

The slag phase formed during the melting of the electrode coating plays an important role in the welding process. It represents a mineral melt and consists mainly of oxides and salts of various acids, both free and forming complex compounds [1]. The choice or development of the slag base is made taking into account the influence on the physic-chemical properties of the slag of the individual oxides present in it and the ratio of various compounds. In the process of melting the coating (flux) in the liquid slag phase, complex chemical compounds are formed, which can also significantly affect the properties of the weld metal. Slags are not soluble in the metal, with the exception of individual components, and form with the metal two non-miscible liquids, which allows to protect the weld metal from the harmful effects of air. In addition to insulation of the weld pool, slag performs a number of other important functions: stabilization of arc burning, alloying and refining of the weld metal.

Modern electrode coatings contain a large number of simple oxides (more than six) and other components; several double and triple diagrams are used to calculate the welding properties of slags. However, when welding conditions are non-equilibrium, and the calculation of the estimated properties of the slag can not be limited to the use of state diagrams alone. When developing new compositions of electrode coatings, the main approach is still a direct experiment [2].



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In the twentieth century, there was a steady understanding of the process of electric arc welding, which consists in the fact that the arc functions in the environment of a slag bubble. In actual welding conditions, the arc is rolled onto the flux and melts it under the influence of its own gas-flame flows in a more energy-efficient mode. Welding slag is distributed unevenly along the weld zone. A large proportion of it is located in the tail section of the weld pool, and at the head part there is a decrease in the mass of liquid slag towards the edge of the melting metal. The difference in the cooling rate of the slag layer adjacent to the seam and above the layer located leads to significant differences in their structure. So the first layer cools faster and forms a glassy structure, and the second layer, due to its thermal insulation, is fully or partially crystallized [3]. These differences make it possible to separate the slag crust from the weld.

Slag removal from the surface of the formed weld is an important task. The poor separability of slag crust reduces the productivity of welding and increases the likelihood of the formation of exogenous nonmetallic inclusions in the weld metal. Slag can be tightly held on the surface of the seam if it contains compounds that form stable bonds with oxides located on the surface of the weld pool. The poor separability of the slag crust is usually associated with the formation of a chemical bond between the slag and the weld metal through an intermediate layer of oxides on its surface [4]. However, the presence of an intermediate layer does not always cause strong adhesion of the metal to the slag. The intermediate layer can become a weak link in the metal-slag system and the bond is broken precisely because of this. Another process that causes the adhesion of the slag crust to the weld metal during welding is often considered epitaxial crystallization on the oxide film as on the substrate of the slag phases, which meet the principle of structural, orientational and dimensional conformity with respect to the oxide film [5]. In cases of unsatisfactory separation of the slag crust, the phase components in it do not correspond to the principle of structural, orientational and dimensional conformity with respect to the most typical oxides formed on the surface of the weld metal. Conversely, with good separation, it is almost always possible to determine which phases in the slag crust correspond to the principle of structural, orientational and dimensional conformity [6].

The separability of slag crust can be improved by changing the oxidative potential of the slag so as to eliminate the formation of an intermediate layer of oxides or eliminate the epitaxial accretion of this layer with the surface of the seam. The separability of the crust may also depend on the temperature of solidification of the slag and the difference in temperature coefficients of the linear expansion of the slag and the weld metal. Changing the strength of the slag crust and improving its separability is possible due to the targeted influence on the features of its micro- and macrostructures, in particular, due to the presence of phases prone to polymorphic transformations, which leads to slag self-diffusion [7].

### III. METHODOLOGY

Consider as an example the development of acidic-type electrodes that meet the following technical requirements: the electrode is designed for welding carbon and low-alloyed steels on alternating current at any spatial arrangement of the seams and should provide the properties of the weld metal with a tensile strength of at least 460 MPa.

Since the electrode being developed is of a general purpose, it is advisable to use low carbon steel wire with a content of 0.08%C with a reduced sulfur and phosphorus content of up to 0,025% each as rods. From the experience of existing electrodes with a tensile strength of 460 MPa of the deposited metal, it is known that the mechanical properties of the deposited metal can be ensured with the following chemical composition: C  $\approx$  0,1%; Mn  $\approx$  0,4-1,0%; Si  $\approx$  0,07-0,15%; S  $\leq$  0,04%; P  $\leq$  0,04%, and with restrictions on nitrogen, oxygen and hydrogen. With the selected composition of the electrode rod, alloying of the deposited metal with silicon and manganese should be carried out through the coating.

The slag system for electrodes with an acidic coating, containing the following components, wt.%: Feldspar – 21-24; dolomite – 13-15; kaolinite – 2-4; rutile – 32-35; ferrosilicamanganese – 20-23; cellulose – 5-6 are oxides of calcium, silicon and titanium.

Consider the ternary system: CaO-SiO<sub>2</sub>-TiO<sub>2</sub> (Fig. 1). As follows from the presented state diagram, the melting point of slags in this ternary system is 1300° C, i.e. this temperature can satisfy the requirements imposed on welding slags when welding steels.

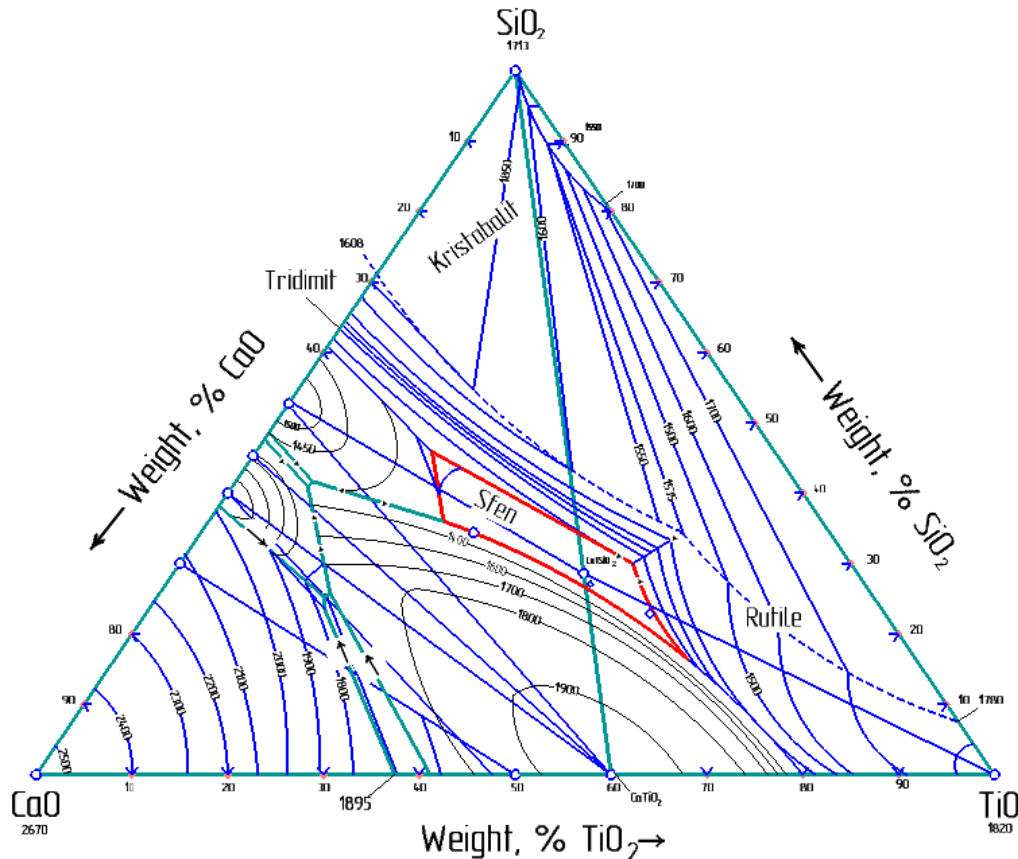


Fig. 1. Triple diagram CaO-SiO<sub>2</sub>-TiO<sub>2</sub>

In the system CaO-SiO<sub>2</sub>-TiO<sub>2</sub>, the region of such melting points is in the composition of slags close to ~ 30-40% CaO, 35-55% TiO<sub>2</sub> and 20-35% SiO<sub>2</sub>

The mineralogical composition of the slag and its structure also affect its physical and technological properties.

We studied the effect of the addition of oxides, Na<sub>2</sub>O and K<sub>2</sub>O on the properties of the slag (melting point, density, viscosity, surface tension) belonging to the CaO - SiO<sub>2</sub>- TiO<sub>2</sub> system. At the same time, was investigated the influence of the physical state of slags on the welding-technological properties, such as the slag covering ability and its separability.

Studies of the physical and technological properties of slags were carried out according to the following methods.

The determination of the separation of the slag crust is based on the determination of the impact force applied to the sample. The essence of this method lies in the fact that the surface of the plate is surfacing the first roller. After surfacing, it is freed from slag and the surfacing of the second roller is performed with the first one being covered by half of its width. The plate with the overlaying is placed in the high-speed clamps of the pendulum scraper, at the temperature of the weld metal was above 450 °C, and on the reverse side of the weld layer of the plate strikes were made. In all experiments, the angle of elevation of the pendulum is constant and equal to 60°. The magnitude of the shock load is chosen such that there is no plastic deformation of the sample. The separation of the slag coating is estimated by the area of the separated slag crust.

The slag covering capability during the deposition of coated electrodes according to the method [7] was determined by the product size from the division of the slag crust thickness at the top of the weld bead to the slag crust thickness at the base of the weld bead and the surface of the weld slab covered with slag,  $S_1$  to the total roll surface area  $S_2$ , those.:

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

To measure the viscosity of the slag, viscometric methods were used. The method is based on the law of fluid flow, located in the gap between two coaxial bodies, one of the bodies rotating, and the other motionless. Viscosity is determined by the measured torque at a given angular velocity produced on a rotational viscometer with a rotating working fluid. Slag viscosity was measured on a rotary viscometer with a rotating working fluid.

The dependence of slag separability on its content of oxides Na<sub>2</sub>O and K<sub>2</sub>O is shown in Fig. 2. Separability of slag crust is one of the most important indicators of weldability of surfacing materials. The performance of multilayer surfacing is largely determined by the nature of the slag separability.

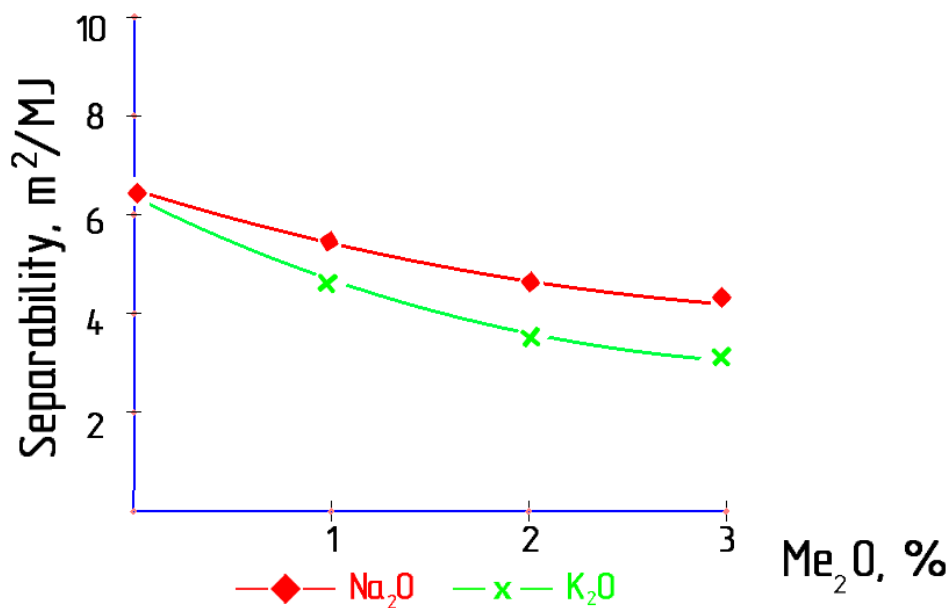


Fig. 2. The dependence of the separability of the slag crust from the amount of oxide in the slag

The effect of the type of oxide and its content in the slag on the slag covering capacity is shown in Fig. 3.

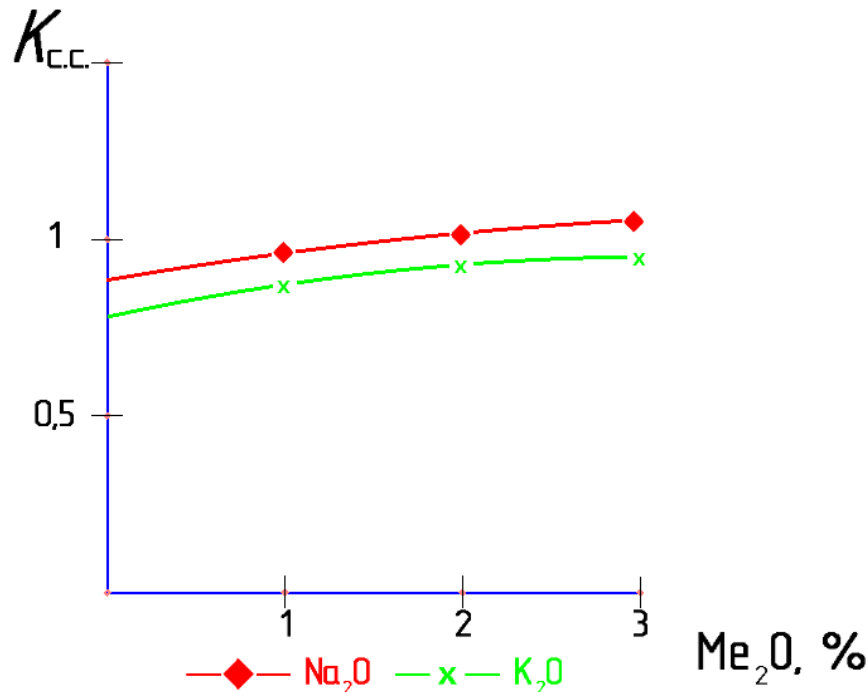


Fig. 3. The dependence of the covering ability of slag on the type and content of oxide

As can be seen from Fig. 3. with an increase in the content of Na<sub>2</sub>O and K<sub>2</sub>O, the slag covering capacity increases. Such an effect of the type and amount of oxides is related to their effect on such properties as viscosity and surface tension.

The change in slag density depending on the content of Na<sub>2</sub>O and K<sub>2</sub>O oxides in it is shown in Fig. 4. The effect of the amount of oxides on the density of the surfacing slag was studied with a fixed value of the other oxides studied.

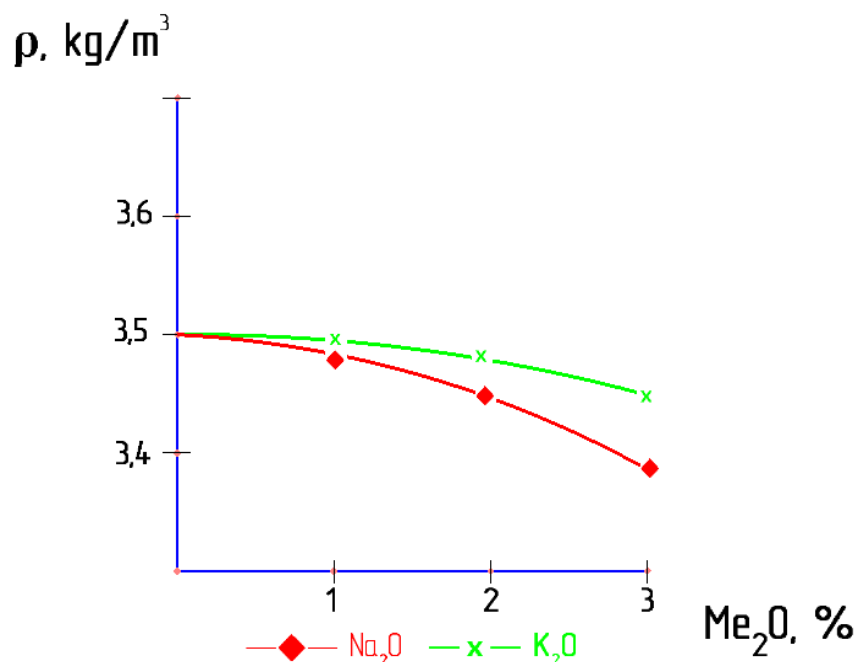


Fig. 4. The dependence of the density of the surfacing slag on the amount of oxides formed during smelting.

As can be seen from fig. 4 oxides of sodium and potassium significantly reduce the density of the slag.

The dependence of the viscosity of the slag on the content of one of the oxides in the original slag at  $T = 1700$  K is shown in Fig. 5.

The increase in viscosity is explained by the increase in interparticle bonds in the melt because of the accumulation of high concentrations of oxygen anions. Potassium and sodium oxides reduce the viscosity of the molten slag, and with an increase for  $K_2O$ , the viscosity of the slag decreases more than with the same amount of  $Na_2O$ . All this is explained by the properties of anions and cations, which are formed during the dissociation of these oxides.

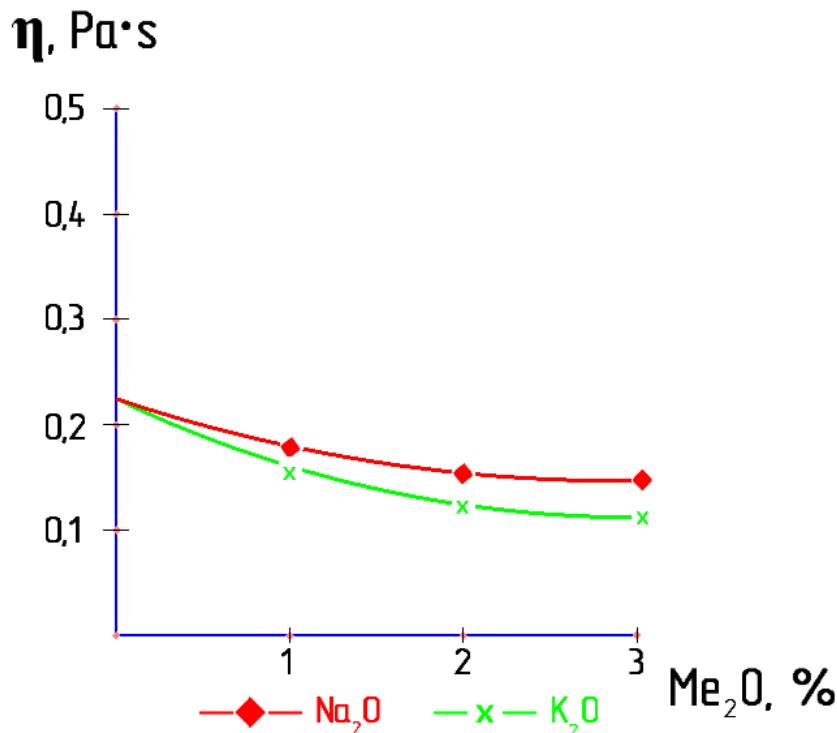


Fig. 5. The dependence of the viscosity of the slag on the content of oxides

#### IV. RESULTS

Developed electrodes with an acidic type of coating, containing the following components, wt.%: Feldspar – 21-24; dolomite – 13-15; kaolin – 2-4; rutile – 32-35; ferrosilicamanganese – 20-23; cellulose – 5-6. The introduction of  $Na_2O$  and  $K_2O$  into the  $CaO - SiO_2 - TiO_2$  system contributes to a decrease in the density, viscosity of the slag, the separability of the slag crust and the growth of the covering power.

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