INTRODUCTION

For the production of semicontinuous steel consumable electrodes with a large cross section for vacuum arc remelting (VAR), metallurgists use slag-forming exothermic or thermal-insulating mixtures. The experience of the Zlatoust metallurgical plant shows that the efficiency of application of exothermic mixtures decreases substantially because of their high costs, fire and explosion risk, hygroscopicity, the formation of dust and harmful gases and oxides, and the introduction of slag increases in a metal (especially during the addition of an exothermic mixture). The content of nonmetallic and gas inclusions increases in steel, and the integrity of a steel microstructure is violated. VAR of electrodes is accompanied by a break in a current regime up to spontaneous termination of remelting because of intense slag formation and strong ionization \[1, 2\]. For example, the defect “titanium rim” is revealed on polished macrosections in the under shrinkage region in an electrode and in the surface zone across the entire height to a depth of 40—45 mm during casting of corrosion-resistant 03Kh11N10M2T (EP678U) steel in a mold 520 mm in diameter under an exothermic mixture consisting of 26% silicocalcium, 38% fluor spar, 10% soda nitrate, 20% manganese ore, and 6% boric anhydrite. When polished macrosections are analyzed, coarse aggregates of titanium nitrides and oxides are visible at the defect. The electrode metal is contaminated by titanium nitrides, which mainly form groups. Low contents of sulfides and carbosulfides, which are located along grain boundaries, and titanium carbonitrides are detected. VAR of such electrodes is accompanied by intense slag formation, strong ionization, and the formation of a skull (reaching 50—55 mm in some cases). Sometimes, remelting was spontaneously terminated because of intense slag formation and continuous ionization. A rim and exothermic mixture slag, which entered into a metal in casting, are observed during visual inspection of the face surface of the electrode (Fig. 1).

During semicontinuous casting, heat-insulating slag-forming mixtures are partly melted under the heat of the liquid metal filling the mold and a mixture melt forms. The upper powderlike layer has heat-insulating properties and protects the metal surface from cooling, which prevents the formation of a rough rim and excludes its turning. The mixture melt in contact with the liquid metal surface in the mold assimilates floating nonmetallic inclusions and favors a decrease in the steel contamination.

The purpose of this work is to study the effect of heat-insulating slag-forming mixtures on the quality of semicontinuous consumable VAR electrodes as compared to
those cast under exothermic mixtures and on the process of remelting and the quality of VAR ingots.

EXPERIMENTAL

The investigation was performed on the Zlatoust metallurgical plant on electrodes 520 mm in diameter and 7.3–7.6 t in mass made of 03Kh11N10M2T (EP678U), 08–12Kh18N10T, and 30KhGSN2A steels. From a metallurgical standpoint, these steels are interesting in the degree of alloying (the sum of the alloying element concentrations is 5–28%), the content of high-activity oxide- and nitride-forming elements (chromium, titanium, aluminum), a carbon content of 0.03%, the physicochemical properties, and the specific features of electrode casting and solidification under conditions of low heat inflow and low casting rates.

The heats were carried out by remelting of alloyed wastes upon mixing of steels from two furnaces in one ladle, namely, electric arc DSP-5 furnaces or an electric arc furnace and an induction IST-1 furnace. The metal in the ladle was argon blown. The compositions of the initial charge materials and the technological heat parameters remained unchanged. Steel was cast in copper smooth-wall molds 1200 mm long with a back taper of 4 mm. A mold reciprocated according to sinusoidal cycle at an oscillation step of 20 mm and a frequency of 25 oscillations per minute. Casting was performed under the level through a funnel with an elongated graphite–chamotte cup with one central and two horizontal channels 30 mm in diameter. The metal temperature before casting was 1590–1610°C, the mold filling time was 4–5 min, and the electrode pulling speed was 0.15–0.20 m/min (it increases gradually in a length of 150–200 mm). The component composition of the heat-insulating mixture was as follows: 48–53% slag from the production of carbon-free ferrochromium, 7–12% fluorspar, 11–16% soda ash, 22–27% chamotte powder, and 3–4% amorphous graphite. The mixture was prepared by mechanical mixing of fused slag powders, namely, ferrochromium slag with the fused slag of the other components (fluorspar, soda ash, chamotte) [3–6].

We estimated the electrode surface quality, macrostructure, the chemical homogeneity, the density, the content and distribution of nonmetallic and gas inclusions using transverse templates after cutting a 600-mm head. Moreover, we estimated the VAR stability and the quality of VAR ingots and the billets rolled from these ingots [1, 7].

RESULTS AND DISCUSSION

Figure 2 and Tables 1–3 present the results of investigating the quality of the electrodes cast under a heat-insulating mixture (HIM) and an exothermic mixture (exomixture).

It is seen that the geometry of the electrodes cast at the level of HIM is correct: the profile distortion of these electrodes decreased twofold as compared to those cast under the exomixture and does not exceed 2.8% for the electrodes made of 03Kh11N10M2T and 08–12Kh18N10T steels and 2.4% for the electrodes made of 30KhGSN2A steel (Table 1). The macrostructure of the electrodes cast under HIM is dense, without visible defects. We did not detect a substantial difference in the lengths of the edge, intermediate zone of transcrysals and the axial zone of small disoriented crystals as compared to the electrodes cast under the exomixture. The defects detected on the surfaces of the electrodes made of 03Kh11N10M2T and 08–12Kh18N10T steels and cast under HIM have a single and local character and are weakly pronounced. The defect penetration depth in the electrodes is insignificant (up to 6 mm). The metal losses upon roughing in the course of preparation for VAR decreased twofold.

The results of metallographic analysis of the metal contamination and the distribution of nonmetallic inclusions demonstrate that the main type of inclusions in casting of the 03Kh11N10M2T and 08–12Kh18N10T steels is represented by titanium nitrides 10–20 μm in size (Table 2). Oxygen inclusions are represented by coarse exogenous slag particles (≥40 Mm) in the form of complex silicate inclusions with a high content of iron, titanium, and calcium. Such inclusions are present mainly in the axial zone of the electrode. The estimation of the content of coarse (more than 40 μm) oxygen inclusions over the cross section of the electrodes shows that casting of the steels under the level of the exothermic mixture is accompanied by high contamination in the edge and, especially, axial.

Fig. 2. Macrostructures of electrodes 520 mm in diameter cast under a heat-insulating mixture: (a) 03Kh11N10M2T, (b) 08–12Kh18N10T, and (c) 30KhGSN2A steels ((a), (c) cross section; (b) longitudinal section).