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EXPERIMENTAL STUDY OF SLAG AND METAL POOL ROTATION DURING THE ELECTROSLAG PROCESS IN CURRENT-SUPPLYING MOULD

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Experiments on studying the rotation of slag and metal pools during the electroslag process in current-supplying mould were conducted. It was found that metal pool rotation can occur both due to the forces of friction from the rotating slag pool, and due to electromagnetic forces applied to the molten metal. Operating current, passing through the mould current-conducting section, has a decisive influence on generation of the rotating effect. 13 Ref., 1 Table, 3 Figures.

Keywords: *rotation, slag and metal pools, electroslag process, current-supplying mould*

The electromagnetic effect on electroslag process showed that under certain conditions it makes possible not only to increase the coefficient of melting of the consumable electrode, but also to change the structure of the solidifying metal [1–3]. At the same time, the basic aim of the most investigations is solving namely the second problem without evaluating the physical phenomena which occur during interaction of the operating current and the magnetic field current.

Actually, the first work, where the process of rotation appearance in a metal pool was studied, was the work [4]. On the basis of the investigations performed on a physical model and evaluation of the results obtained in it, the following conclusion was made: «a metal pool can be brought to rotation only due to the friction forces arising at the contact boundary with a rotating slag pool».

On the other hand, it was shown in works [1, 5, 6] that with the help of external magnetic fields in a metal pool, it is possible to create electro-eddy flows and vibration of the melt as well as its rotation independently of slag movement over its surface due to the action of volumetric electromagnetic forces.

The current-supplying mould (CSM), designed at the E.O. Paton Electric Welding Institute, represents a sectional device, consisting of a nonconsumable circular type electrode, manufactured as a single-turn inductor, and a forming section which is, in fact, a conventional mould [7, 8]. Between these sections an additional intermediate section can be installed, which prevents the liquid metal from getting into the current-carrying section from the forming one.

The electroslag process in the CSM should be accompanied by the same electromagnetic phenomena which occur in the conventional mould using any technology of melting metal, i.e. welding, surfacing, remelting and the action of additional external magnetic field. Nevertheless, the application of CSM, in which its current-carrying section is not an external source of magnetic fields and represents an element of electrical circuit providing the running of the electroslag process with the melting of a remelting metal of any type, supplied into a slag pool, can affect the nature of interaction of the operating current and the magnetic field of the CSM.

This article is devoted to the study of this influence, in particular, on peculiarities of the slag and metal pools rotation.

In a general form, in case of the electroslag process in the CSM, the interaction of the axial component of the magnetic field B_z (formed by the current-conducting section) with the radial component of the electric current in the slag pool I_r should lead to the formation of an azimuthally directed electromagnetic force F_φ rotating the slag around the pool axis.

Moreover, this effect can be pronounced not only in the form of angular displacement of slag layers, but also in the formation of a funnel in the slag at the mould centre. Thus, for example, in edge electroslag surfacing (ESS) in the CSM of 180 mm diameter using a consumable electrode of 40 mm diameter and at a mould current of about 2.4–2.6 kA, the depth of the funnel was more than 50 mm (at a depth of the slag pool of about 110 mm) with its maximum diameter of about 50–70 mm under the electrode end. In connection with such dimensions of the funnel, the electrode

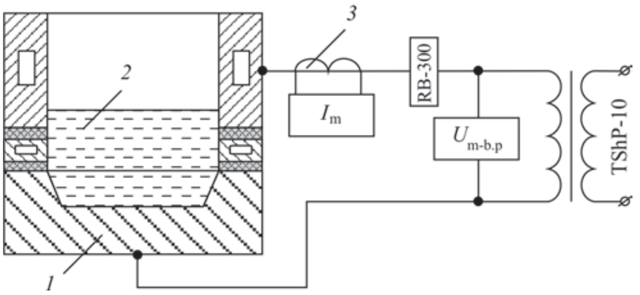

Figure 1. Scheme of the physical model for evaluation of slag and metal pool behavior in the CSM: *1* — plug-bottom plate; *2* — mercury; *3* — measuring transformer of current

Influence of the circular ESS mode on the slag pool rotation speed (flux AN-75)

Surfacing mode		Speed of rotation, rpm
U, V	I_{CSM}, kA	
28	2.0–2.6	30
40	3.4–3.7	35–40
42	3.6–3.9	36–45
38	3.5–4.0	40–50
32	4.6–4.9	60

had to be introduced inside the funnel until its surface came into contact with the slag pool.

A similar situation occurs also in a metal pool. However, the rotational effect is revealed to a much lesser extent, as the components B_z and I_r are much lower in the metal pool than those in the slag pool.

The rotational effect is observed when using consumable electrodes, current-free billets, as well as discrete filler both in edge and circular ESS. The determining factor, affecting the slag pool rotation is the current (I_{CSM}) passing through the mould current-carrying section.

The Table shows the results of a circular ESS using discrete filler of the 170 mm diameter billet in the broadened CSM of 255/215 mm diameter.

G.V. Ksyondzyk, the designer of the CSM, considered, the same as in work [4], that the rotation of metal pool is transmitted due to friction forces from the rotating slag pool [9].

The comparative melting of a large-section electrode in a conventional mould and of a discrete filler in the CSM showed that in the structure of the metal produced by remelting of the filler, the grain size has about three times smaller dimensions [10]. However, it should be noted that during melting in the CSM it is difficult to determine what proportion of the influence on these structural changes is due to the inoculating effect of the filler particles, and which one occurs due to the magnetic rotation of the metal pool.

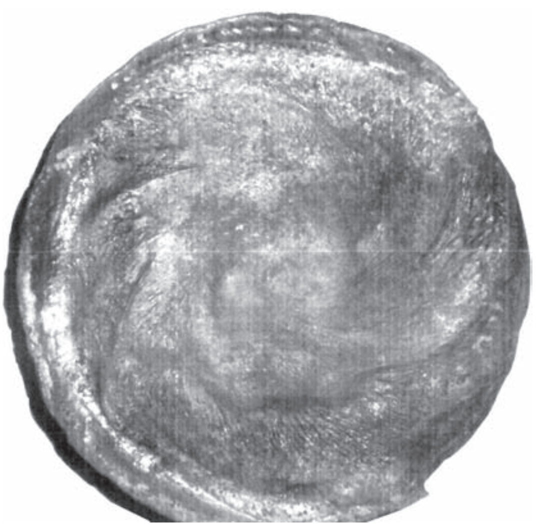

Figure 2. Molten surface of the bottom plate primer after a 10-minute electroslag process in the CSM

The use of a liquid filler metal (ESS LM) [11, 12] during surfacing allowed showing that even without melt inoculation, the structure of the produced ingots is characterized by a fine-grained structure [13]. However, the authors of the article do not consider the influence of rotation on the structural formation of a solidifying metal. Moreover, the metal produced by ESS LM is compared not with the metal of electroslag melting using consumable electrode, but with the metal melted according to the traditional casting technology. Therefore, the main advantage of the ESS LM metal is associated with a high rate of its solidification.

For a deeper understanding the behavior of slag and metal pools under melting conditions in the CSM, it was decided to carry out experiments on the physical model according to Figure 1. The CSM of 60 mm diameter with the bottom section made in the form of a plug-bottom plate with a groove at its center was filled with mercury of about 40 mm depth. As the source of power the transformer TShP-10 was used. The value of current I_m was regulated by the ballast resistance RB-300. It was found that during supply of voltage $U_{m\text{-}b.p}$ in the range of 15–30 V from the power source terminals to the current-carrying section of the CSM and the plug, the mercury pool rotation with its little pulsation is occurred.

Figure 3. Shape of metal pool in the metal surfaced, formed during electroslag remelting (surfacing) of discrete filler in the CSM

Thus, the interaction of magnetic fields, formed by the operating current passing in the mercury, and the current-carrying section of the mould, contributes to the appearance of a rotational effect in mercury (metal pool) together with the slag pool. The additional data were obtained in a real electroslag process. With this purpose, a slag pool was induced into the CSM of 180 mm diameter on a steel primer of 170 mm diameter and 20 mm thickness, providing a normal operation of the mould and its stable existence at the currents of 2.3–2.5 kA. At the same time, the angular speed of rotation of slag ANF-29 was changed from 72 to 106 rpm during 10 min. After that, the power source TShP-10 was switched off, the slag cap was removed from the mould after its cooling and the primer was inspected. The inspection showed that during the experiment the surface of the primer was fused approximately by 8–10 mm and formed into the shape of a «saucer» with the edges raised approximately by 10 mm around the periphery. From the upper view on the fused surface of the primer (Figure 2), the bands from the rotation of the fused metal are visible and the central part of the primer is little affected by the rotational movement, i.e. the circumferential rotation is observed in practice. Such character of rotation has also influence on the formation of a metal pool of the metal deposited and it can acquire a shape of the «sombrero» type (Figure 3).

Conclusions

1. The rotation of metal pool in the CSM can occur both due to the friction forces from the rotating slag pool as well as due to the electromagnetic forces directly affecting the molten metal.

2. The determining effect on the occurrence of rotational effect in the metal pool is provided by the operating current passing through the current-carrying section of the CSM.

3. The centrifugal forces, moving the molten metal to the periphery (walls) of the mould, have a minimum value at its center, which leads to unequal conditions for the formation of a metal pool and its solidification.

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