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ELECTROSLAG SURFACING OF LAYERS OF DIFFERENT THICKNESS IN STATIONARY CURRENT-SUPPLYING MOULD

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Studied was a nature of change of electrotechnical parameters of process of discrete filler melting in its portion feed and variation of thickness of deposited metal in a stationary current-supplying mould. It is determined that the process of melting in a slag pool is effected by initial values of depth and specific electric conductivity of the slag pool. A concept of averaged heat level of the slag pool was introduced. It characterizes change of physical properties and thermal state of the pool as a result of feed in it of a portion of discrete filler and allows optimizing initial position of deposited surface relatively to current-supplying section of the mould. 5 Ref., 1 Table, 5 Figures.

Keywords: *electroslag surfacing, stationary current-supplying mould, deposited metal thickness, slag pool depth*

One of the main advantages of the electroslag surfacing (ESS) is the possibility of surfacing of large thickness metal without deterioration of quality of deposited metal as well as bimetal joint in whole.

Developed at the E.O. Paton Electric Welding Institute sectional current-supplying mould (CSM) [1–3] allows depositing layers of metal of virtually unlimited thickness. For this relative movement of the product and CSM shall be provided.

In series of cases it is no need to deposit too large thicknesses of metal that allows using CSM in a stationary position. At that maximum thickness of the deposited metal is determined not only by length of mould forming section, but composition of used flux [4].

Application of the stationary CSM considerably simplifies surfacing technology. Thus, mechanical jam of the mould during its movement relatively to deposited billet and spilling of liquid metal (metallic pool) in variations of surfacing mode parameters are eliminated, and it is possible to provide better formation of the deposited layer.

CSM from electrotechnical point of view is a device inside which electroslag process takes place with specific distribution of currents in a melting chamber. The mould walls and bottom plate with located on it deposited product limit the melting chamber itself. It is naturally to suppose that growth of thickness of the deposited layer shall provoke some redistribution of currents relatively to current-supplying section of CSM (Figure 1). This situation can be considered from other point of view, i.e. at what distance from the current-supplying section is it necessary to locate surface being deposited in order to provide optimum heating of the fusion zone and good formation of deposited metal that is also determined by optimum current distribution in slag. In other words, it is necessary to regulate distribution of working current passing vertically down to the product as well as in horizontal direction (horizontal constituent). At that heating of the upper layers of slag pool is provided.

Aim of this work is investigation of current distribution in a slag pool at changing in process of surfacing thickness of deposited layer, qualitatively charac-

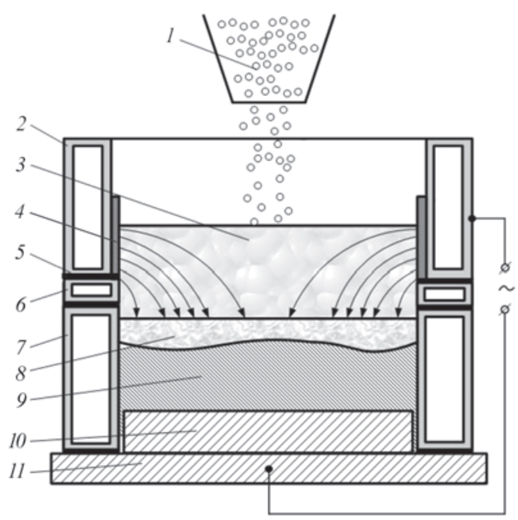

Figure 1. Scheme of distribution of lines of electric current in CSM at ESS of discrete filler: *1* — discrete filler; *2, 6, 7*, — current-supplying, intermediate and forming sections of the mould, respectively; *3* — slag pool; *4* — protective lining; *5* — insulating insert; *8* — metallic pool; *9* — deposited metal; *10* — product; *11* — bottom plate

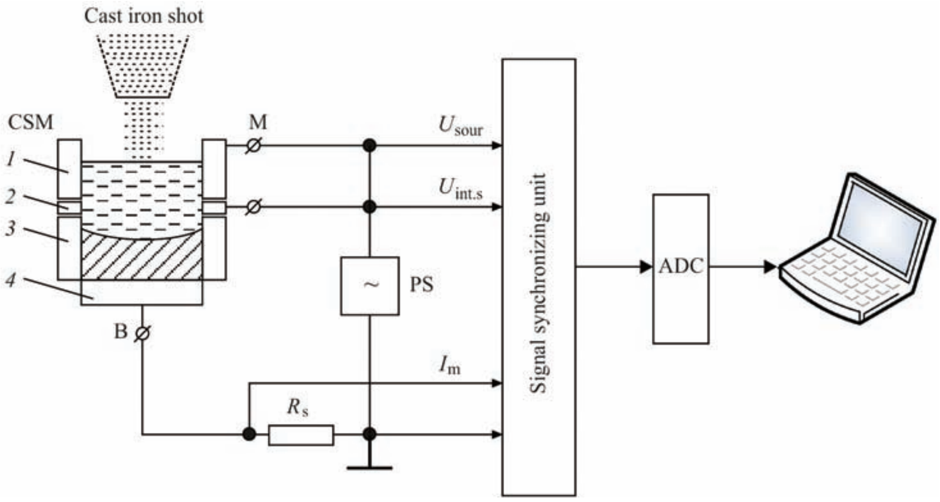

Figure 2. Structural scheme of electric connections in performance of experiments on surfacing: M, B — connection terminals to current-supplying section of mould and bottom plate with product, respectively; PS — power source; R_s — measurement current shunt; U_{sour}, $U_{int.s}$, I_m — signals proportional to power source voltage, potential difference between intermediate section and bottom plate as well as mould current (bottom plate), respectively; ADC — analog-to-digital converter; *1, 2, 3* — current-supplying, intermediate and forming sections of the mould, respectively; *4* — bottom plate with product

terized by variation of specific electric conductivity of the slag pool on its depth.

The most perspective surfacing material, namely discrete filler in form of chipped shot of non-alloy cast iron of approximately 2 mm diameter was selected as a feed material.

The experiments were carried out on the following procedure. CSM of 180 mm diameter was filled with molten in graphite crucible slag (flux ANF-29) of volume allowing providing CSM working capacity, i.e. slag pool should wash graphite lining of current-supplying section at approximately 20 mm height. After stabilizing thermal state of the pool and start of its rotation in a horizontal plane a surfacing shot was fed in CSM of special design by portions (four times by 2 kg) with progressive feed of each portion. In melting, a portion of shot transformed in a liquid metal (metallic pool), which later on solidified in form of the deposited layer of approximately 12 mm thickness. Initially a distance between the lower edge of current-supplying section and bottom plate with product h_{mp} made 85 mm, then, after filling of each portion of cast iron shot, h_{mp} reduced by 12 mm. In course of the whole process (including the periods of slag pool stabilizing after pouring the molten slag into the mould, change of its state in shot feed and due to growth of thickness of deposited layer) the measurements of such its electric parameters as mould current I_m and power source voltage U_{sour} were carried out.

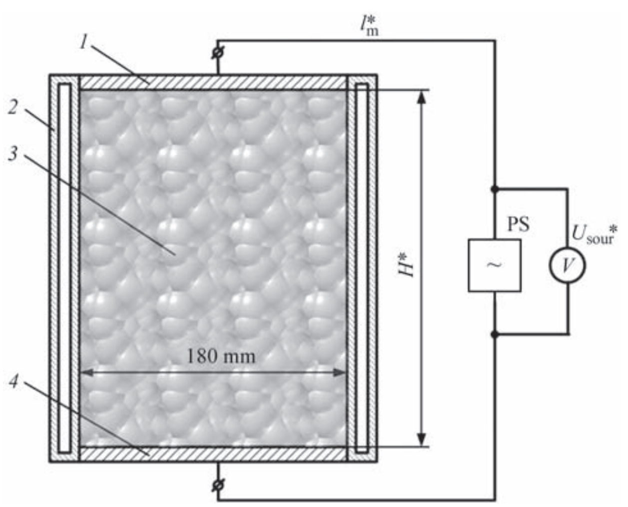

Figure 3. Model of CSM substitution structure: U^*_{sour} — voltage of «model» power source; I^*_m — current of mould «model»; H^* — height of slag pool of «model»; *1* — upper cylinder current-supplying plate; *2* — water-cooled isolated section; *3* — slag pool; *4* — lower cylinder current-supplying plate

Measurements and record of current as well as voltage were done using universal ADC module E14-140, Lenovo notebook (model Ideal Pad 4560 with 64-bit operational system) and software «Power Graph». Figure 2 provides the structural scheme of electric connections in performance of the experiments on surfacing. Voltage of the intermediate section was also registered, which allowed controlling and recording difference of potentials between the intermediate section and bottom plate $U_{int.s}$. A-622 M transformer was used as a power source in the experiments.

The next electric parameters were calculated for solution of the specified problem:

- conductivity of slag pool G on mould current-supplying section-bottom plate channel;
- specific electric conductivity σ before and after filling of the next shot portion for slag pool of a model of CSM substitution structure (Figure 3);
- specific averaged heat level of slag pool T^*.

Regarding a heat relationship the local temperature conditions (figuratively speaking «heat layer-cake») are formation after each feed of the portion of filler in the slag pool. It is virtually impossible to register these short-term changes of temperature. Therefore, we have conventionally accepted a calculated averaged (generalized) temperature of slag T^*, determined by a value of its specific electric conductivity σ before and after feed of each portion of the filler.

Figure 4 shows the diagrams of change in time of of difference of potentials between the intermediate section and bottom plate $U_{int.s}$ as well as conductivity of slag pool G. $U_{int.s}$ voltage shall give an idea on change of the level of metal pool in melting of discrete filler. It was considered that the level of pool approaches to lower edge of the intermediate section of mould at $U_{int.s}$ = 10–15 V voltage and it is necessary to finish surfacing process. However, the experiment showed that at uniform increase of the level of metal pool and its approaching to intermediate section (by 12 mm after filling of each portion of shot) in t_1–t_2 interval $U_{int.s}$ voltage rapidly decreases, then a drop of $U_{int.s}$ is delayed and after timing mark t_4 (see Figure 4) starts step-by-step growth. At that, U_{sour} voltage drops (Table) with rise of current I_m due to insufficiently rigid characteristic of power source. It is obvious that in this moment there is a redistribution of relationship of conductivities of the circuit sections between the bottom plate and intermediate section as well as between the intermediate section and current-supplying section. Conductivity between the bottom plate and intermediate section fairly shall increase due to decrease of distance between them in rise of level of the metal pool, and conductivity between the intermediate section and current-supplying section shall reduce quicker than conductivity between the bottom plate and intermediate section. Such a situation is possible only at rapid growth of temperature of the slag pool in the interval after t_4 mark. Electric conductivity of slag pool, which is calculated as $G = I_m/U_{sour}$ in its essence reflects average (mean-integral) characteristic of the slag pool. Electric conductivity G over the whole time interval from t_1 to t_5 increases with rising speed (see

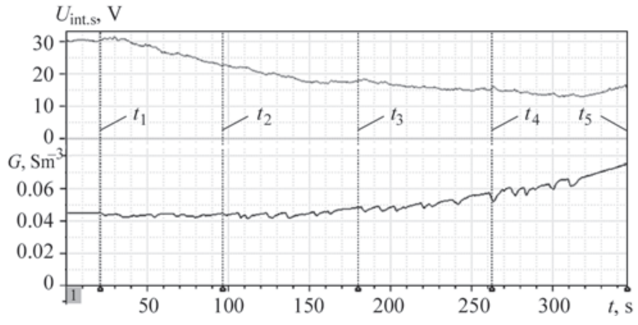

Figure 4. Change in time of difference of potentials between current-supplying section and bottom plate $U_{int.s}$ and conductivity of slag pool G; t_1–t_2 — time marks

Table). This parameter indicates that energy level of the process increases, but it is difficult to evaluate change of heat level on it.

To evaluate conventional averaged heat level of the slag pool during the experiment there was calculated a specific electric conductivity σ before and after next filling of the shot portion to the slag pool of model of CSM substitution structure (Figure 3). σ values calculated at t_1–t_5 time moments were used for calculation of conventional averaged heat level of the slag pool T^* on diagram of dependence of electric conductivity of ANF-29 flux on temperature, given in work [5]. This dependence can be well described by expression $T^* = 230.6\sigma + 991.1$. Calculation of σ on the model of CSM substitution structure is based on the fact that «model» has uniform electrostatic field and at equality of the values of real measured voltage of source U_{sour} and «model» voltage U^*_{sour} as well as at equality of real current I_m and current I^*_m, specific conductivity σ of model and averaged specific conductivity of the real mould will be equal. To get indicated equalities it is necessary to determine height of the slag pool of the model of CSM substitution structure H^* at, respectively, equal values of diameters of the mould and «model» (180 mm). Specific electric conductivity σ was calculated as $\sigma = GH^*/(2\pi 90^2)$. H^* values are given in the Table.

A conventional averaged heat level of the slag pool H^* reduces during filling of the first and second portions of the shot (Figure 5) that corresponds to our understanding since each filled up portion of the shot

Measured and calculation indices of experimental surfacing in CSM

Filling of cast iron shot, time mark	Time t, s	H_{mp}, mm	$U_{int.s}$, V	G, Sm	I_m, A	U_{sour}, V	H^*, mm	σ, Sm/m	T^*, °C
Start of 1st portion filling, t_1	21	85	30.3	45.1	1926	42.7	166	295	1672
Start of 2nd portion filling, t_2	96	73	22.5	44.5	1900	42.7	142	249	1565
Start of 3rd portion filling, t_3	180	61	17.7	48.1	2020	42.0	119	224	1509
Start of 4th portion filling, t_4	262	49	15.0	56.6	2299	40.6	101	226	1512
End of filling of 4th portion, t_5	346	37	15.8	73.9	2801	37.9	91	266	1604

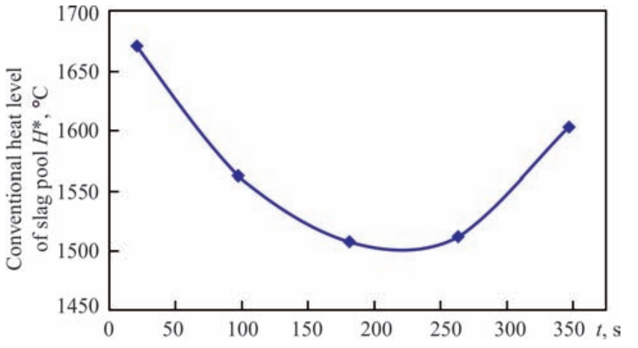

Figure 5. Change of conventional heat level of slag pool depending on time in supply of shot portion

requires heat expenses on its heating and melting, and if electric power is not enough for this then the pool cools down. After the third portion of shot the level of metal pool rises to the height, at which mould current has increased so that heat supply and consumption became equal, temperature was relatively stabilized. After the fourth portion of shot the temperature started rising up, electric conductivity of slag pool demonstrated rapid increase and there was an effect, which resulted in growth of $U_{int.s}$ (in t_4–t_5 time interval).

From given above it can be concluded that surfacing should be carried out at initial distance between the lower edge of current-supplying section and bottom plate h_{mp} = 61 mm, i.e. the distance which corresponded the start of filling of the third portion of cast iron in this experiment as well as at calculated value of specific conductivity of the «model» σ = 244 S/m. The value of specific conductivity of the «model» shall be kept during the whole process of surfacing for stabilizing quality characteristics of the deposited product by means of correction of power supply voltage. Besides, it is necessary additionally to study the possibility of evaluation of the level of metal pool on change of voltage between the intermediate section of mould and bottom plate since change of direction of voltage variation $U_{int.s}$ (increase or decrease of its value) can result in incorrect evaluation by operator of situation during surfacing.

Thus, as a result of carried investigations it was determined that production of quality deposit of a layer of determined thickness in the stationary mould requires consideration of thermophysical characteristics of the used flux and position of the product relatively current-supplying section of the mould.

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