STUDY OF THE STRUCTURE AND PROPERTIES OF A HOLLOW INGOT OBTAINED BY THE ELECTRO SLAG REMELTING METHOD

CHUMANOV Ilya[1], ANIKEEV Andrey[1]

[1]*South Ural State University (national research university), Faculty of Engineering and Technology, Zlatoust, Russian Federation*

Abstract

Electro-slag remelting is one of the ways to produce high-strength metal. For this reason, the machining of electro-slag metal is difficult. It is especially difficult to obtain a cylindrical billet from such a metal. The article proposes a new, high-tech method for producing a hollow ingot with electro-slag remelting. The production of a hollow ingot is obtained by introducing the melting point during melting. Due to the difference in the melting point between the base metal and the phase introduced, the low-melting material is forced into the center of the ingot that is being formed. The course of the experiment, the investigation of the macro- and microstructure, and the mechanical properties of the resulting hollow ingot are described.

Keywords: Electro-slag remelting, low-melting material, hollow ingot, macro and micro structures, mechanical properties

1. INTRODUCTION

For producing hollow billets by electro-slag firmware are known methods [1-3], as well as the means of obtaining a hollow ingot electro-slag remelting with rotation of the electrode relative to its axis [4]. These methods have several disadvantages. The complexity and high cost of manufactured construction is one of the main disadvantages, since the implementation of this method is through the use of additional copper elements, the special pan and sewed mandrel. The second drawback of the proposed method is then, that the use of the lifting mechanism linking mandrel and the mechanism of rotation of the electrode without increasing the frame which moves the carriage with the electrode holder, will have to reduce the length of the electrode being melted, which later will affect the size of the final ingot. The increase in frame is not always possible in consequence of the limited height of the room. In addition to structural disadvantages, the disadvantages include the complexity of calculation of the dependencies of the speeds of rotation of engines, responsible for the upgrade of sewed mandrel, the lowering of the remelted electrode and the rotation speed of the electrode when switching to a different size of electrode being melted. As the transition to another size will necessitate changes in the design sewed mandrel. In this article we propose and implement a method of obtaining a hollow work piece by feeding fusible phase with higher density than the metal being melted in the molten slag bath with the subsequent removal of this element from the pierced billet heating furnace.

2. TECHNOLOGY OF OBTAINING A HOLLOW INGOT

Was developed a technology for producing a hollow ingot at the Department "Machinery and Technology of Production of Materials", branch of South Ural State University in Zlatoust, the essence of which is that, during the process of electro-slag remelting at the same time with the remelted electrode into a bath of molten slag is fed fusible phase which will be melted along with the electrode. Supply low-melting phase is carried out in the course of the melting process, fusible phase should have a higher density relative to the metal being melted. Low-melting phase will be deposited in the center of the ingot under the action of gravitational forces, a high rate of crystallization of the ingot during electro-slag remelting will not allow it to spread throughout the body of the ingot. As fusible phase you can use such elements as lead, bismuth. Developed two technologies supply low-melting phase. In the first case, the remelted electrode is wound heating wire containing powder with a fusible element (**Figure 1a**). In the second case, the fusible phase is supplied directly into a bath of molten slag through a portioning device (**Figure 1b**).

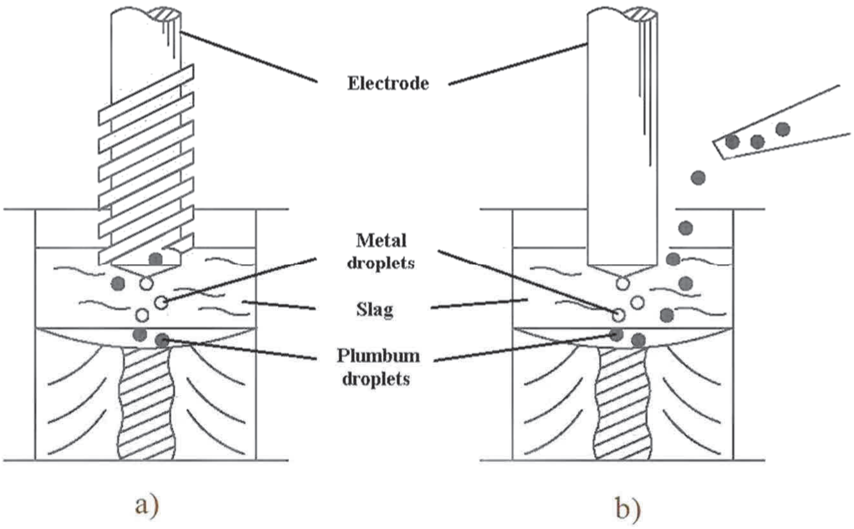

Figure 1 Proposed ways to introduce a low-melting phase: a - remelted electrode of wrapped wire containing low-melting phase; b - submission of low-melting phase by means of a metering device directly into a bath of molten slag

It is necessary that the speed drops of the metal being melted and a drop of low-melting phases were the same, to ensure the deposition of low-melting phase in the center of the ingot. The calculation of the radius of the metal droplets passing through the liquid slag was produced in the work [5]. On the basis of this calculation was the calculated radius of the metal droplets and droplets of the fusible element:

$$V_M \rho_M \frac{d\omega}{d\tau} = V_M g(\rho_M - \rho_S) - C_0 F_M \frac{\rho_M \omega^2}{2}, \tag{1}$$

where V_M - the amount of metal droplets' (cm^3);
ρ_M - the density of the metal (g/cm^3);
ρ_S - the density of the slag (g/cm^3);
C_0 - the hydrodynamic drag coefficient;
F_M - the area of the frontal section of the drop (cm^2);
ω - the speed drops (cm/sec).

Express the volume of the metal droplets and its area of drag using the formula (1):

$$V_M = \frac{4}{3}\pi r_M^3; \tag{2}$$

$$F_M = \pi r_M^2. \tag{3}$$

Thus substituting equations (2) and (3) to (1) get:

$$\frac{4}{3}\rho_M r_M \frac{d\omega}{d\tau} = \frac{4}{3} r_M g(\rho_M - \rho_S) - C_0 F_M \frac{\rho_M \omega^2}{2}. \tag{4}$$

The drag coefficient is equal to:

$$C_0 = 1.25\,\mathrm{Re}^{-0.5}. \tag{5}$$

Where the Reynolds number for a spherical droplet is:

$$\mathrm{Re} = \frac{2r_M \omega \rho_S}{\eta}. \tag{6}$$

Differential equation (6), will receive:

$$\frac{d\,\mathrm{Re}}{d\tau} = \frac{2r_M \omega \rho_S}{\eta} \cdot \frac{d\omega}{d\tau}; \tag{7}$$

$$\frac{d\omega}{d\tau} = \frac{\frac{d\,\mathrm{Re}}{d\tau}\eta}{2r_M \rho_S}; \tag{8}$$

$$\omega = \frac{2\,\mathrm{Re}\,\eta}{2r_M \rho_S}. \tag{9}$$

Thus substituting equations (5), (6) and (9) into equation (4), we get:

$$\frac{\frac{4}{3}\rho_M r_M \eta \frac{d\,\mathrm{Re}}{d\tau}}{2r_M \rho_S} = \frac{4}{3} r_M g(\rho_M - \rho_S) - \frac{1.25\,\mathrm{Re}^{-0.5} \rho_M \eta^2 \mathrm{Re}^2}{4r_M^2 \rho_S^2}, \tag{10}$$

where η - the coefficient of dynamic viscosity of slag (g/cm·sec).

Substituting the known values of the densities and coefficients in the formula (10) we calculated the radius of the droplet of liquid metal, as well as the radius of the fusible phase. Based on this calculated weight of the feed granules of low-melting phase to ensure he was 4 gr. The ingot is placed in a heating furnace and subjected to heat treatment after completion of the melting process. Previously on the furnace hearth heating furnace installed capacity with stops at which the ingot is positioned vertically. Places where low-melting phase melts and are derived from the ingot into the container during the heat treatment, thus forming large porosity inside the body of the ingot.

3. EXPERIMENT

The process of obtaining a hollow ingot was performed on the electro-slag remelting of A-550. Lead was used as a low-melting phase, the melting point of which is 327 °C. The lead was in the form of wire, chopped into pieces with a thickness of 7 mm and a length of 10 mm length allows avoiding occurrence of short circuit between the electrode and the mold which would have led to a frenzy of lead, and destabilization of the current regime. With 1020 °C was used as a refiner of metal. The length of the fuse being melted part of the electrode was equal to 72 cm and its diameter is 40 mm, his weight 6.91 kg. Supply of lead was carried out after the formation of the liquid metal pool and was carried out throughout the bottoms in equal portions; the total number of submitted lead was 0.98 kg. The process of electro-slag remelting was carried out using flux ANF - 6 in the number 0.98 kg, the chemical composition of the flux are presented in **Table 1**. The flux was subjected to pre-calcinations at 400°C for removal of residual moisture within 3 hours.

Table 1 The chemical composition of the flux ANF-6 [%]

CaF_2	Al_2O_3	CaO	SiO_2	C	TiO_2	Fe_2O_3	S	P
Basis	25	No more						
	31	8	2.5	0.10	0.05	0.5	0.05	0.02

Melting was conducted on the current (1.2 kA) to reduce the waste of lead. Melt duration was 11 minutes, during melting, an increase in speed of melting of the electrode, that is probably due to increase in the hot zone inside the crystallizer. The length of the obtained ingot was 140 mm and diameter 90 mm. The mass of the obtained ingot was 7.34 kg. The ingot had a satisfactory surface quality with no visible defects. After the ingot was removed from the mold it was cut along a vertical plane. The mass of the remaining secondary flux amounted to 0.635 kg. Then, the ingot was subjected to heat treatment. The mass of melted lead was 0.424 kg. Characterized by large porosity in the center of the ingot after a thermal heat treatment, what is the consequence of the leakage of the fusible phase. Then we study the microstructure of the ingot (**Figure 2**) in three areas: on the inner surface of a hollow work piece, in the middle, outside. Research of microstructure of obtained ingot showed that the number of inclusions of lead a greater number is directly on the inner surface of a hollow work piece, while on the outer surface of the hollow billet in the number of particles is minimal.

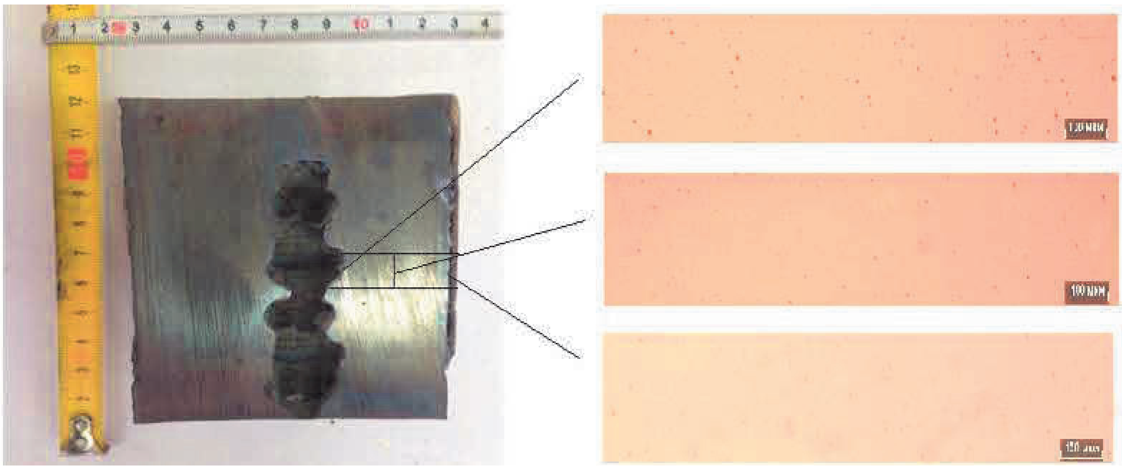

Figure 2 Sawn ingot after the heat treatment, as well as photographs of the microstructures of the inner part, of the central and external

4. CONCLUSION

This article presents a method of producing a hollow pipe blank by the method of ESR with the introduction of low-melting phase with its subsequent removal by heat treatment. Following the thermal treatment of the annealed ingot was subjected to easier machining and large porosity also facilitates machining of the inner wall of the ingot obtained without much loss of metal. The article presents the result of the analysis of the microstructure of the ingot, which showed that a greater number of particles of the fusible phase is concentrated on the inner surface of a hollow work piece.

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