Проведено аналіз програмних модулів та технологій, використаних для розробки програмного додатку, таких як: Apache Maven, Lombook, JavaFx, JavaRx, Apache Poi. З'ясовано функціональні можливості даних модулів. Розроблено програмний додаток на базі мови програмування Java та сумісних з нею технологій.

Експериментально доведено, що використання програмного додатку зменшує час обробки готового протоколу до 15 с, що збільшує швидкість обробки обчислень в 120 разів. Використання програми надає можливість проводити вимірювання в реальному часі та контролювати технічний процес стану водяних розчинів при відхиленні в 5% при наявності яких вмикається звуковий сигнал, що попереджує про відхилення продукції від заданих параметрів.

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THE INFLUENCE OF METAL HEATING AND STIRRING ON THE CONDITIONS OF STEEL INGOT SOLIDIFICATION

Barabash V. V., Biktahirov F. K., Shapovalov V. O., Hnatushenko O. V.
E. O. Paton Electric Welding Institute

Despite the increasing prevalence of continuous casting of steel, a certain part of metal production of liquid metal is poured into molds to produce large ingots weighing tens and hundreds of tons. They are intended for the production of products that are impossible or impractical to produce by continuous casting. Basically, these are so-called forging ingots, subjected to forging (pressing) to give them a shape close to the geometric parameters of specific products, such as rolling rolls, rotors, disks, etc.

During the crystallization of large masses of metal, complex thermophysical and physicochemical processes occur, which lead to the formation of various types of defects and inhomogeneities in steel ingots.

Traditional methods of improving ingot quality, such as optimizing the chemical composition of the metal, improving casting methods and technologies, changing the geometric parameters of molds, and improving working conditions for profit, have practically exhausted themselves. With these methods, it is impossible to influence the crystallization conditions of an ingot liquid core significantly. Therefore, further improvement of steel ingot quality is possible through the use of certain technological techniques that make it possible to influence the conditions for the formation of their internal structure.

It is known that one of the methods for improving the quality of cast ingots is stirring their liquid core during the process of metal solidification. This technique is widely used in continuous casting by installing external magnetic field sources, under the influence of which the liquid metal moves [1, 2]. In the production of large ingots, it is necessary to create devices of high power and large dimensions for electromagnetic stirring. Therefore, stirring the metal during the solidification of steel ingots is only possible by introducing stirring devices into their liquid core that set the melt in motion.

To use any devices inserted inside the ingot, it is necessary for the upper surface of the metal to remain in a liquid state for an extended period and avoid forming crusts. This can be achieved by heating the metal in the hot top. Therefore, an effective method to influence the conditions for the formation of steel ingots could involve the combined use of heating and stirring of liquid metal, achieved by introducing a stirring device inside the solidifying ingot.

To verify the above, physical modeling was initially carried out on transparent models. This modeling vividly illustrates the characteristics of the transition of metal from a liquid to a solid state. A 205-ton ingot was selected as the modeling object. A flat model, with dimensions similar to the axial section of the ingot in a ratio of 1:10, was created. The modeling medium was sodium hyposulfite, which is widely used for physical modeling of the crystallization of steel ingots [3, 4].

According to the results of physical modeling depicted in Fig. 1, in the absence of heating of the lucrative part of the ingot, a buried shrinkage cavity forms along the axis of the ingot. When the upper part of the modeling liquid is heated, smaller shrinkage defects occur in approximately the same area. The combination of stirring the liquid part of the model melt with heating significantly alters the solidification conditions, completely eliminating shrinkage-related defects.

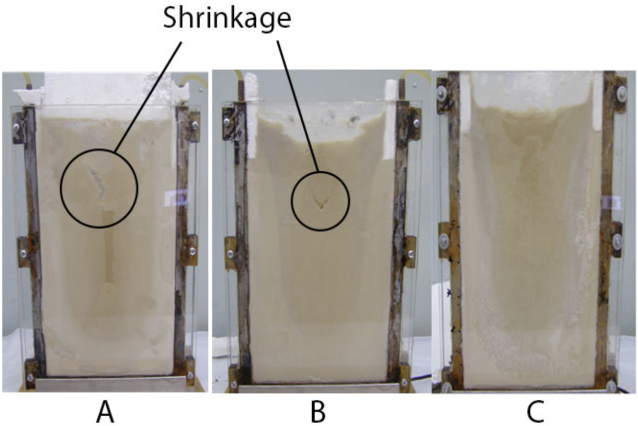

Fig. 1. Effect of heating and stirring on ingot formation:
A – without external influences, B – with heating,
C – with heating and stirring

A change in the conditions of ingot formation is indicated by the position of the crystallization front, which has the largest angle relative to the axis during the heating and stirring of the model melt.

After physical modeling, experiments were carried out in laboratory conditions with the casting of steel ingots. The ingots had an average diameter of 200 mm and a height of approximately 400 mm. In order to increase the residence time of the metal in the liquid state, the ingots were cast into a sand-clay mold.

Electroslag heating of the top of the ingot was used in way, similar to what happens in the TREST process [5, 6]. Stirring was carried out by periodically inserting a stirring device into the liquid part of ingot during crystallization.

The experiments were conducted in two ways:

A – without additional heating of hot top;

B – with heating of hot top and the stirring of the liquid metal.

Examinations of the internal structure of the produced ingots revealed that, in the first variant, a volumetric shrinkage cavity forms in roughly the same area as observed in the physical modeling. In the ingot obtained using the second variant, shrinkage defects are entirely absent. Clear signs of stirring are evident on the macrostructure revealed through etching, corresponding to the position of the solidification front during these stirring events.

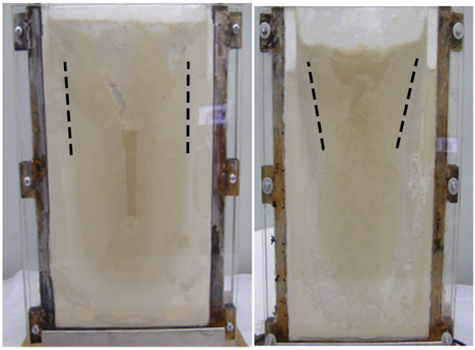

Fig. 2. Effect of heating and stirring on the angle of the crystallization front: A – without heating and stirring, B – with heating and stirring

The absence of shrinkage defects in the upper half of the ingot, obtained according to the second option, is evident from the metal density measurements in Figure 4.

Fig. 3. Macrostructure of experimental ingots: A – without heating and stirring, B – with heating and stirring

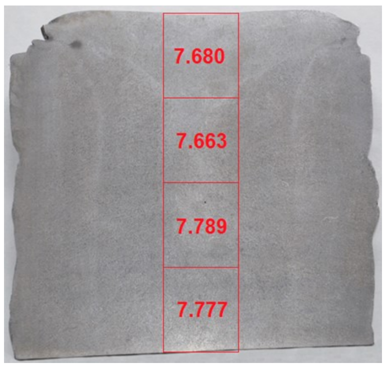

Fig. 4. Average values of density along the axis of the upper half template

The axial part of the ingot was segmented into four zones, with density measurements conducted on five samples in each zone. The figure displays the average metal density values across these zones. As evident, the metal density along the axis of the ingot remains nearly uniform, with a minimal difference between the maximum and minimum values of only 0.126 g/cm^3 or 1.6 %. The lack of a decrease in metal density in the upper half of the ingot results from a change in crystallization conditions when stirring its liquid core.

The results from both physical modeling and full-scale experiments with liquid steel demonstrate that active control of crystallization processes during ingot manufacturing is achievable through the combination of steel heating and stirring the liquid core of steel ingots. This discovery unveils new possibilities for producing large, high-quality ingots.

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