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MAIN TRENDS IN THE DEVELOPMENT OF TECHNOLOGY FOR CASTING STEEL INTO INGOTS

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This article discusses promising technological measures that can be used to cast ingots. It also examines such issues as multi-ladle casting, optimization of ingot geometry and the chemical composition of the metal being cast, mastery of the production of hollow ingots, stream vacuum-degassing, aspects of the bottom-pouring of large ingots, materials for warming the hot-top part of ingots, protection from secondary oxidation, and high-speed casting. Recommendations are given to improve the technological regimes that are used to cast steel into ingots at Russian plants.

Keywords: *casting, large forging ingot, evacuation, degassing, ingot mold.*

The growth of the energy sector and the industries that build heavy machinery and transportation equipment and the increase that has occurred in the size and weight of monoblock parts are making it necessary to master the production of forgings with a weight of up to 400–500 tons. These forgings are made of ultraclean steels which are often of complex composition.

One aspect of the production process which is key and which to a large extent determines the quality characteristics of the ingots is the casting technology that is used. The chosen technology should ensure that the purity of the melt remains at the same level achieved in previous processing operations and, if possible, is elevated even further. Despite the significant constraints on the feasibility of refining steel during the casting operation, the use of certain technological and design-based measures at this stage can prove very effective and substantially improve the quality characteristics of the finished product.

The development of the technology that is used to produce the largest forging ingots made in Russia (see Table 1) has always involved the participation of scientists in the Large-Ingot Laboratory at the Central Research Institute of Machine Building Technology (TsNIITMASh). This has allowed TsNIITMASh to accumulate a wealth of knowledge and practical experience in this area, and both the knowledge and the experience were used in this investigation to analyze trends in the development of ingot-casting technology in Russia and abroad and make recommendations on further improving this production operation.

Multi-ladle casting. One of the techniques often used in the production of large ingots is so-called multi-ladle casting. Multi-ladle casting is essential when making ingots whose weight exceeds the maximum capacity of the individual pouring ladles available at the given metallurgical plant. When this practice is employed, it is best if the equipment in the shop include a rotating stand with a tundish. It is preferable that the stand also be equipped with a hoist to secure the system that protects the metal from secondary oxidation when it is poured from the ladle into the tundish. The presence of such a stand appreciably simplifies the logistics of the ladle feed and provides greater flexibility in the casting operation.

In addition, when multi-ladle casting is employed, the ladles should be fed in a sequence that is consistent with the carbon content of the steel. The first ladle delivered for casting should contain the steel with the highest carbon content, while the ladle having the steel with the lowest carbon content should be sent to the tundish stand last. Experience shows that it is best if the carbon content of the steel in the first ladle be equal to 1.1–1.6 of the average carbon content specified for the ingot. The carbon content of the steel in the last ladle should be equal to 0.4–0.9 of the average specified carbon content.

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TABLE 1. Chronology of the Casting of Large Ingots in Russia

Year	Weight of ingot, tons	Geometric characteristics			Manufacturer
		H/*D*	conicity, %	hot top, %	
1952	80	1.8	3.50	19.8	UZTM, NKMZ
1953	Hollow ingot 25	2.5[*]	2.0	25.0	UZTM
1955	Hollow ingot 60	2.5[*]	3.0	25.0	Barrikady
1972	235	1.6	14.7	22.8	Izhorsky Zavod (IZ)
1973	142	1.0	16.0	25.4	IZ
1981	290	1.0	13.5	26.2	IZ
1984	360	1.3	13.6	21.2	IZ
1992	420	1.2	14.1	24.0	IZ
–	520	1.2	14.0	22.0	Plan

[*] Ratio of the height of the body of the ingot to its wall-thickness.

However, simply differentiating the ladles with respect to carbon content does not make it possible to make the chemical composition of the steel more uniform, since the density of the molten steel changes when its carbon content changes. Thus, to achieve the desired effect, any decrease in the carbon content of the steel should be partially compensated for by increasing its content of another, heavier element such as molybdenum. It has been proposed that the change in the content of this element be determined for each portion of the steel by means of the following formula based on the difference between the steel's specified average contents of carbon and molybdenum:

$$\Delta[\mathrm{Mo}] = (1.3\text{–}1.5)\Delta[\mathrm{C}], \tag{1}$$

where $\Delta[\mathrm{Mo}]$ and $\Delta[\mathrm{C}]$ are the changes in the contents of molybdenum and carbon, %.

Having the contents of the various alloying elements change in this manner from one ladle to the next makes it possible to most efficiently alter the composition of that part of the ingot which is formed at the beginning of the solidification process – specifically, during casting of the steel in the first ladle. The molten steel poured into the ingot mold first is the steel that is least affected by segregation, and the composition of the first portions of solid metal that are formed is close to the composition of the steel that was poured into the mold. The thickness δ (mm) of the layer of crystallized steel that is formed (with it taking about 20 min to empty a 150-ton pouring ladle) can be determined from the square-root law:

$$\delta = k\tau^{0.5}, \tag{2}$$

where k is the coefficient that characterizes the solidification of the steel in the ingot mold, mm/min$^{0.5}$; and τ is the solidification time, min.

Considering that the average value of k for an ingot mold is within the range 22–25 mm/min$^{0.5}$ (we are using the maximum value here, since we have to evaluate the solidification of the initial portions of steel – when the rate of growth of the solid phase is maximal), we find that the thickness of the solid layer which is formed during the teeming of one ladle is about 110 mm. This amount is just 5–10% of the radius of an ingot 2.0–4.0 m in diameter. However, even this result is positive and helps in stabilizing the chemical composition of the ingot metal. It also thus helps make that metal's properties more uniform. Consequently, it is expedient to use the approach described above.

Optimizing the geometry of the ingots. Changing the geometry of ingots makes it possible to effectively control the parameters that characterize their chemical, physical, and structural nonuniformity. However, due to the countervailing effects