INVESTIGATING THE CONSTRICTION OF STEEL CASTING NOZZLES

A. K. Karklit, V. P. Shevchenko,
N. M. Lapotyshkin, M. G. Chigrinov,
and N. M. Frolovskii

UDC 666.76:621.746.27

The main conditions for obtaining high quality metal with the proper processing in continuous steel casting is a definite ratio between the velocity of the hardening ingot and the rate of casting liquid metal in the crystalizer, the result of which maintains a practically constant metal level.

However, during casting even with normal heating of the liquid metal its consumption diminishes because of clogging of the nozzles in the intermediate ladles. The constriction of nozzles disturbs the stability of the casting process and impairs the quality of the continuous ingot. The present authors studied the clogging process in production conditions. The study results somewhat supplement data published previously on the same problem [1, 2].

Research Method. To determine the sources of the formation of crusts on the surface of the casting channel, models were constructed for the reaction between components soluble in the liquid metal with oxides of the refractory by incorporating radioactive isotopes, refractory indicator, and aluminum.

Use was made of isotope zirconium-95, emitting γ-radiation with energies of 0.738 MeV and β-radiation with energies of 0.38 MeV, and with a half-life of 65 days. The quantity of zirconium was 14 mCi per 140 ton heat, that is 0.1 mCi per ton of metal. The isotope was incorporated into the ladle with the metal during discharge of the heat after filling the ladle to one third of its depth, simultaneously with an addition of aluminum. At the end of the casting (the intermediate ladle still contained the metal residue) the casting gate had frozen up in the nozzle. The nozzle with the casting gate was cut along the axis to take radiograms. The arrangement of the marked atoms on the photograph made it possible to evaluate the nature of the reaction of the components soluble in the metal with the oxides of the refractory.

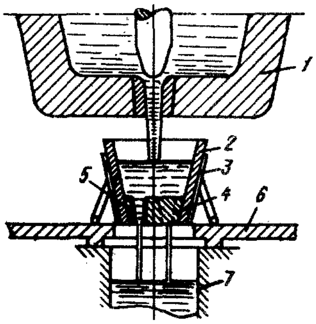

Fig. 1. Device for modelling the process of clogging of nozzles. 1) Intermediate ladle; 2) funnel; 3) metallic housing; 4) ring; 5) inserts under test; 6) crystallizer plate; 7) crystallizer.

The use of radioactive isotopes in production conditions is complex, so only one heat was done with this technique. Further studies were done by incorporating refractory indicator, by means of which the behavior of

TABLE 1. Properties of Inserts*

Grade of insert	Apparent density, g/cm³	Porosity, %	Composition, †%					
			SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	ZrO_2
19a	3,36	24,9	32,0	4,0	3,0	0,56	0,58	56,3
19b	3,37	13,6	35,4	2,9	2,0	0,44	0,50	55,8
K	3,42	3,5	42,8	3,2	2,8	1,22	0,60	47,9
2c	3,41	17,6	37,0	3,0	1,4	0,81	0,90	54,36
37	3,40	21,4	36,6	2,5	1,4	0,91	1,1	56,35

* Refractoriness of inserts >1750°C.

† Traces of MnO were present.

All-Union Institute of Refractories. Donets Metallurgical Factory. I. P. Bardin Central Research Institute of Ferrous Metals. Translated from Ogneupory, No. 5, pp. 28-33, May, 1971.

TABLE 2. Chemical Analysis of the Experimental Inserts after Service

Indicator	Sample	Composition,*%							
		SrO	SiO_2	Al_2O_3	Fe_2O_3	MnO	CaO	MgO	ZrO_2
Funnel No.1									
Not added	19a	—	32,0/29,8	4,0/8,0	3,0/2,4	Traces/3,8	0,56/0,69	0,58/0,98	56,3/52,5
	19b	—	35,4/31,4	2,9/10,4	2,0/4,1	Traces/1,8	0,44/0,54	0,50/0,90	55,8/48,97
	37	—	36,6/31,8	2,5/11,2	1,4/5,4	Traces/2,8	0,91/0,81	1,1/1,5	56,35/45,54
Funnel No.2									
14.2 g/ton added	19a	—/0,39	32,0/32,4	4,0/7,7	3,0/1,8	Traces/2,2	0,56/0,81	0,58/0,78	56,3/51,8
	2c	—/0,61	37,0/32,0	3,0/4,7	1,4/5,7	Traces/2,6	0,81/0,91	0,90/0,88	54,36/50,3
	K	—/0,45	42,8/40,8	3,2/6,8	2,8/1,4	Traces/2,6	1,22/1,35	0,60/1,0	47,9/44,58

* The numerator indicates the results of studies on the least change zone, and the denominator the working zone.

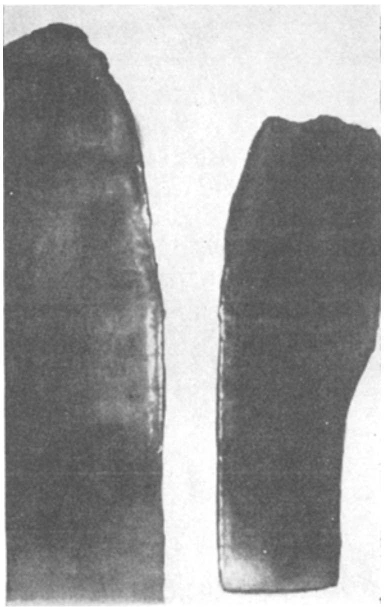

Fig. 2. Automatic radiogram of the longitudinal section of the zircon nozzle with the casting gate.

the inclusions was traced during their transmission through the nozzle. The indicator consisted of finely dispersed powdered strontium oxide (SrO) obtained by calcining $SrCO_3$. The composition of the zirconia nozzle does not include this oxide, and its appearance is easy to detect by spectral and chemical analyses. The high melting point of strontium oxide (2430°C) suggests that it will be in the solid state after having passed through the nozzle. In order to explain the identical natures of the behavior of the indicator and the actual inclusions it was necessary to determine the heating time for the added indicator up to the temperature of the surroundings, which was determined from the following equation

$$\tau = \frac{\delta\gamma R^2}{\sigma\lambda(t_c - t)},$$

where τ is the heating time for the inclusion, sec; δ is the specific heat of fusion of the inclusion, cal/deg; γ is the density of the inclusion, g/cm^3; R is the dimension of the inclusion, cm; t_c is the temperature of the surroundings, °C; t is the temperature of the surrounding air, °C; λ is the coefficient of thermal conductivity of the inclusion, cal/cm·sec·deg; and σ is the surface tension on the boundary of the phases coming into contact, erg/cm^2.

Approximate calculations show that the heating time is less than 1 sec; therefore it can be considered that as regards its physical state the indicator SrO is equivalent to real inclusions.

To incorporate strontium oxide into the liquid metal during the casting use was made of a device shown in Fig. 1. The firebrick funnel was placed in a metal housing, and a ring was inserted into it with three zircon inserts. The rings and the insert were prepared by the All-Union Institute of Refractories.

The properties of the inserts are given in Table 1.

For 15-20 min prior to completion of casting of the heat, the assembled funnel was placed under a jet of metal, leaving the intermediate ladle on one of the machines. The diameter of the insert was hydrodynamically calculated so that inside the funnel a metal level was maintained at a height of 150-200 mm. This is achieved with a metal level in the intermediate ladle at a height of 550 mm, the diameter of the nozzle channel in it is 22 mm, and the funnel contains three inserts with the diameter of the channel being 16 mm.

TABLE 3. Changes in the Diameter of the Inserts during Service

Heat No.	Content of carbon in the finished steel, %	Temperature of metal in intermediate ladle, °C	Additional consumption of aluminum, g/ton	Casting time, min	Quantity of cast metal, ton	Reduction in the insert diameter after 15 min casting, mm				
						19a	19b	K	2c	37
4262	0.17	1548	1450	7.0	1.400	6.86	Not determined			4.28
8285	0.16	1562	577	12.5	4.625	5.28	6.12	4.92	Not determined	
8390	0.17	1552	1058	7.5	4.020	Not determined	7.4	Not determined	10.8	4.80
8390	0.17	1552	0	17.0	9.56	The same	0	The same	1.4	0

TABLE 4. Chemical Composition of Metallic Part of the Crust Formed in the Insert during Constriction

Heat No.	Sampling site	Composition, %					
		C	Si	Mn	S	Al_{sol}	Al_{bond}
4262	Ladle sample	0,17	0,22	0,64	0,032	0,005	0,001
	Crust..............	0,076	0,47	0,53	0,010	0,020	0,220
8390	Ladle sample	0,17	0,22	0,54	0,033	0,0074	0,001
	Crust..............	0,017	0,43	0,49	0,030	0,510	3,800

To determine the sources of the crust formation in the channel of the inserts, in one case refractory indicator was incorporated, and in the other case aluminum; for comparison metal was cast through the funnel without any additives. The strontium oxide was incorporated through a quartz tube into the jet from the intermediate ladle. The aluminum in the form of wire was added at different velocities to the funnel under the jet. Observations were made of the flow of metal from the inserts of the funnel into the crystallizer with the additions, and samples were also taken of the metal jet from the intermediate ladle, and from the jet of one of the inserts in the funnel. The inserts after casting were extracted from the funnel, and spectral and chemical analyses of the working and central zones were made.

Analysis of Study Results. The automatic radiograms of the inserts with the casting gate shows that the activated particles are arranged in little chains in the zone of contact between the casting gate and the channel of the insert (Fig. 2). This indicates the deep position of nonmetallic inclusions situated in the liquid steel on the surface of the channel during transmission of metal.

Spectral analysis of the inserts after casting with the incorporation of refractory indicator showed the presence in the working zone of strontium when powdered strontium oxide had been introduced. Chemical analyses were also made of the working and least-changed zones of the inserts after service in both funnels (Table 2).

The refractory indicator was detected in the zone of the insert coming into contact with the metal during casting. Consequently, nonmetallic inclusions located in the liquid metal in the solid form react with the surface of the insert channel.

For analysis of the metal incorporating the aluminum into the jet, samples were taken from the jet in front of the funnel, and from the jet of one of the inserts in the funnel. In all cases the incorporation of aluminum into the jet of metal from the intermediate ladle caused overfilling of the funnel. The flow of metal from the inserts was clearly reduced, which caused a reduction in the rate of tightening up of the slab (from 4.5 to 2.0 m/min). During the casting of metal through the funnel with the same assembly of inserts without any additives, normal flow of metal was observed.

The inserts after service were extracted from the funnels, measured, and examined in the zone of contact with the metal during casting. The results of the measurements before and after service are given in Table 3.

In all cases with the incorporation of aluminum there was a reduction in the diameter of the insert. The appearance after service is shown in Figs. 3-5. On the transverse sections of the inserts there are buttons of metal, tightly inserted into the wall of the channel.

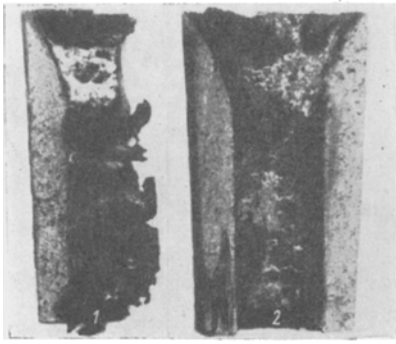

Fig. 3

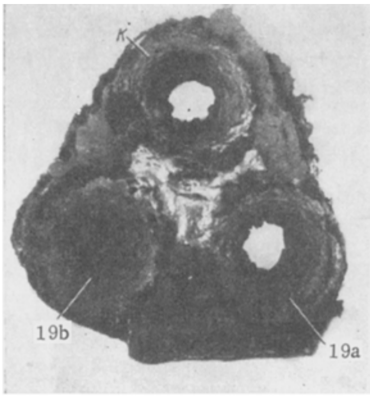

Fig. 4

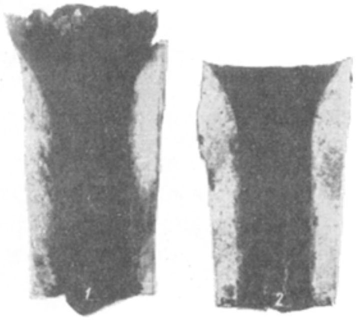

Fig. 5

Fig. 3. Section of the insert after casting metal additionally reduced with aluminum in amounts of 1.45 kg /ton. 1) Regular nozzle; 2) nozzle 37 with minimum concentration of Al_2O_3 (2.5%).

Fig. 4. Inserts after casting metal in the assembled form. K, 19a, 19b) Grades of inserts.

Fig. 5. Section of inserts. 1) With crust; 2) without crust.

Between the buttons of metal it was possible to note a powder, light-gray in color, brittle, and finely dispersed (see the upper part of the section of the insert in Fig. 3). Spectral analysis of the powder showed that it is mainly comprised of Al_2O_3 (96.6%). Under the microscope the powder had a monomineral composition and consisted of highly dispersed crystals of α-alumina, transparent, colorless, anistropic, with a refractive index of $N_{mean} = 1.760$. The size of the crystals varied from a fraction of a micron to 30 microns. In the large crystals hexagonal basal plates were noted. Less frequently it was possible to detect intergrowths of several crystals. By its nature the corundum is a typical endogenic nonmetallic inclusion formed in the steel during reduction with aluminum, and deposited on the wall of the insert during casting.

Chemical and metallographic studies were done on the metallic crust, forming in the channel, as it were, a metallic hollow carcass (Table 4).

In the magnetic part of the crust formed during the casting of heat No. 8390, the concentration of soluble and bonded silicon was determined as follows: $Si_{sol} = 0.60\%$, $Si_{bond} = 1.83\%$.

The cross section of the crust formed during the casting of heat No. 4262 was examined under the microscope from the zone of contact with the refractory toward the center of the channel. In the zone between the walls of the insert and the dendrites of metal there were pores filled with alumina, collected on the base, apparently consisting of oxides of manganese, aluminum, and silicon. Dendrites of metal growing from the wall of the insert toward the center of the channel were detected. The structure of the metal in the edge zone of the slide was ferritic; and at a distance of about 3 mm from the edge to the center it was ferrite–perlitic, with a predominance of ferrite.

Thus, the clogging of inserts is a complicated process, involving deposition of alumina among the oxide phases of an imprecise composition bonded by dendrites of steel; and furthermore the direction of the dendrite growth indicates the presence of heat removal through the wall of the inserts, contributing to tightening up of the channel. The appearance of alumina in the crust apparently is caused by the reaction between aluminum soluble in the metal with the oxides of the refractory, and the deposition of the products of the reaction on the walls of the nozzle.

The results of the experiments indicate that it is possible to describe the process of crust formation covering the outlet from the channel of the casting nozzle in the following way. This description does not pretend to completeness, but supplements existing ideas and data on the role of iron in this process.

Nonmetallic inclusions situated in the liquid metal in the solid state are deposited on the walls of the nozzle channel. During the erosion of the surface of the channel by the steel containing aluminum, the latter is oxidized and as a result of the reduction of the iron, traps manganese and silicon in the pores of the contact surface. The crystallites of iron formed as a result of the reduction, and becoming strongly bonded to the surface of the channel, become crystallization centers on which the crust can grow. This contributes to an increase in the thermal conductivity along the channel of the nozzle and more intensive removal of heat, which promotes the growth of the crust. The erosion by the liquid steel of metallic crystals on the surface of the channel of the nozzle causes separation on them of a steel with a more refractory phase, α-iron, containing small quantities of impurities (sulfur and carbon).

The more fusible phase containing sulfur and carbon liquefies in the interaxial section of the dendrites, and is eroded by the jets. As a result of this around the jet there forms a shell of iron in which there is a sharp reduction in the sulfur and carbon concentrations.

During constriction of the nozzles the refractories are impregnated in the zone of the channel by iron oxides, the iron is reduced from the oxides and on the contact surface crystals of iron and alumina are formed, here subsequently it is possible for the alumina to separate from the solution in the steel. The process of clogging the nozzle is completed by the growth of iron crystals, covering the outlet from the nozzle channel.

LITERATURE CITED

1. A. K. Karklit et al., Ogneupory, No. 7,27 (1970).
2. V. P. Shevchenko et al., Ogneupory, No. 10, 31 (1970).