Aug. 4, 1959 SEIJI NISHIKIORI 2,897,555

STEEL INGOT MAKING COMPOSITION, METHOD AND APPARATUS

Filed Oct. 22, 1957

Fig. 1.

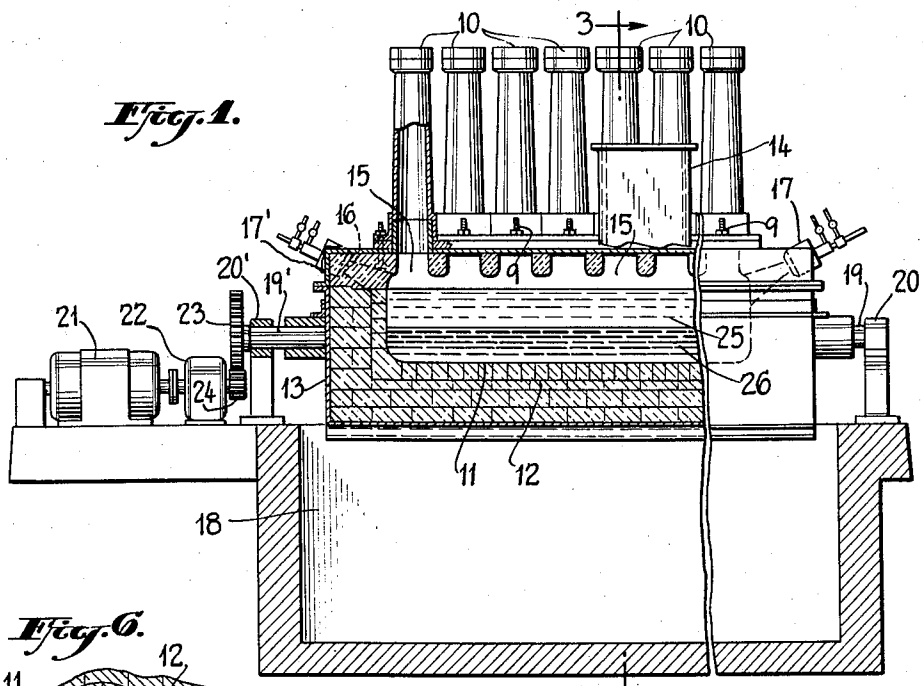


Fig. 6.

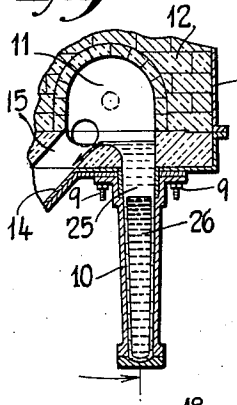


Fig. 3.

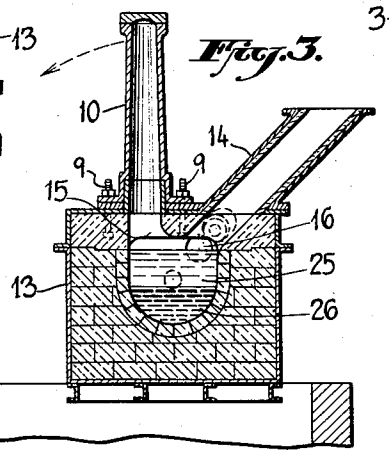


Fig. 2.

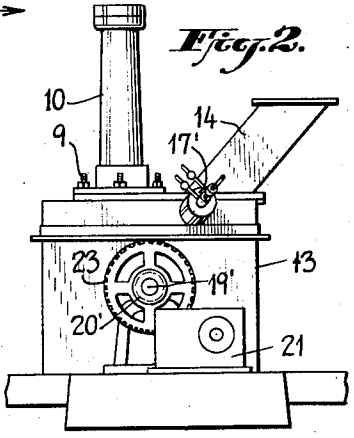


Fig. 4.

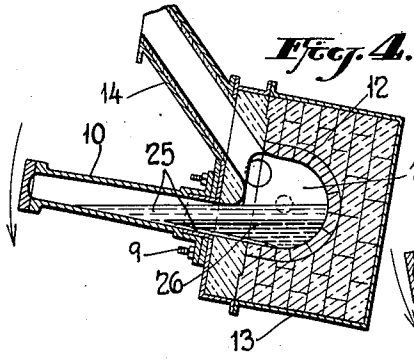
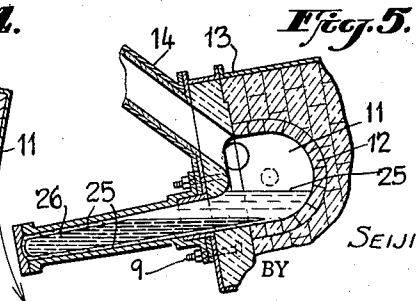


Fig. 5.



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STEEL INGOT MAKING COMPOSITION, METHOD AND APPARATUS

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6 Claims. (Cl. 22—64)

This invention relates to a method and apparatus for making steel ingots as well as to a metal oxide coating composition for use in casting. More particularly, it relates to a method of casting molten steel into ingots free from the contamination of foreign matter and gases with the aid of a mold coating composition.

In conventional practices a flow of the molten steel of a certain thickness is poured into the mold from a ladle held immediately thereabove. Under these conditions, the molten steel falling from a height upon the bottom of the mold envelops gases from the turbulent current of gases produced as the flow of liquid steel violently hits the surface of the pool of liquid metal in the mold. As a result, flaws and blowholes inevitably occur inside the ingot due to inclusion of foreign matter and gases.

The principal object of the present invention is to provide a method and apparatus for producing uniform steel ingots with minimum possible flaws and blowholes, the surfaces of which are so clean that no conditioning is required. It is also an object of the invention to insure above average yields. Further objects and advantages will be apparent from the following description.

According to the general method of the present invention, steel together with a lighter metal oxide coating composition, both in liquid state, are introduced to a ladle, which is then rotated slowly together with an inverted mold which is mounted thereon so as to permit the coating composition to flow from the said ladle into the said mold, and in consequence, said coating composition solidifies upon contact with the cool walls of the mold and coats the same. The surplus coating composition in the mold still in liquid state is replaced by the heavier liquid steel which follows the same into the mold as the mold is rotated to an upright position. The steel is then allowed to solidify into an ingot having clean surfaces and free from flaws and blowholes.

In the drawings:

Fig. 1 is a front view partly in section of the casting apparatus of the present invention;

Fig. 2 is the side view of the apparatus of Fig. 1;

Fig. 3 is a vertical section of the apparatus of Fig. 1 taken on the line 3—3 thereof;

Fig. 4 is a view similar to Fig. 3 but with the assembly rotated in the direction of the arrow;

Fig. 5 is a view similar to Fig. 4 with the assembly still further rotated; and

Fig. 6 is a view similar to Figs. 4 and 5 with the assembly fully rotated as at the end of casting.

As illustrated in the drawings in Figs. 1, 2 and 3 inverted molds **10** are detachably mounted as at **9** on a ladle **11**, the interior **12** of which is lined with fire and insulation brick, with the exterior being covered with steel plate **13**. For pouring liquid steel and coating composition, ladle **11** is provided with an upwardly extending inlet or spout **14** servicing the upper portion **15** of the ladle. This latter portion is provided with openings as at **16** (Fig. 3) for burners **17** and **17'** which maintain the said metal and coating substances in a molten condition when necessary. The assembled body including ladle, molds, inlet and burners is supported above a pit **18**, adapted to accommodate the assembly when inverted, by trunnions **19** and **19'** residing in rigidly mounted holders **20** and **20'**. The assembled body is rotated about 180° by means comprising motor **21**, speed-limiting device **22**, and reduction gears **23** and **24**.

The following constitutes a representative description of the present method and the operation of the above-described apparatus. After completion of the refining operation in the open hearth, converter, or electric furnace, the molten steel is poured into the ladle **11** through the inlet **14** either alone or together with the molten coating composition, described in detail hereinafter, which has been liquefied independently of the steel. It is to be understood that the molten coating composition is present with the steel in the ladle prior to casting and may also be added to the ladle prior to the steel. The coating composition comprises between about 15 and 25%, preferably about 20%, by weight and about 60 to 80%, preferably about 70% by volume respectively of the molten steel.

The ladle thus filled with molten steel and coating composition is permitted to remain undisturbed for a few minutes so that the latter composition may separate from the molten steel, owing to its lower specific gravity, and rise to the surface. The assembled body

including the ladle **11**, molds **10** and supporting trunnions is rotated slowly in the direction indicated by the arrows in Figs. 3–5 by means of motor **21**. During this slow rotation, the lighter molten coating composition **25** (Figs. 4 and 5) enters the mold and contacts the bottom and side walls thereof. Upon contact with the cool mold it begins to solidify thus coating the interior surfaces thereof to a thickness of approximately 5 mm. As the assembly is rotated further, the molten steel **26** then moves into the ingot mold, replacing unsolidified liquid coating composition and forcing the same toward the upper open end of the mold. Since the open end of the mold adjoining the ladle is covered with the coating composition, the steel does not come in contact with the mold walls. As revolution proceeds, the molds **10** are brought to the vertical position (Fig. 6) and are completely filled with molten steel. The liquid coating composition is displaced to zone **15** of the ladle, covering the upper part of the molds. Any excess liquid coating composition is discharged by gravity flow through inlet spout **14** and collected in pit **18**. It is kept at a high temperature by radiant heat from the ladle **11** or by firing the burners **17, 17'** when necessary. Meanwhile the heat of the molten steel is conveyed toward the exterior of the molds **10** very slowly by virtue of the inferior heat conductivity of the solid coating on the inside walls of the mold.

With the molds in upright position in pit **18**, following solidification of the steel the molds may be detached from the ladle and conveyed from the scene and the ingots removed therefrom in a conventional manner.

Conventional ingot casting methods usually give rise during solidification of the molten steel to growth of columnar crystals approximately 40 to 80 mm. in thickness adjacent the walls of the molds. These crystals frow at right angles to the interior surface of the mold in the outer part of the ingot which is subject to rapid cooling through contact with the mold. In accordance with the method of the present invention, crystals of free orientation are formed in the ingot by reason of slower cooling caused by the coating of low heat conductivity which lines the interior of the mold. Accordingly, steel ingots produced by the present method are of uniform structure with the least possible segregation. Furthermore, since the molten steel when poured into the mold only very slowly replaces the liquid coating composition already in the mold, neither gases nor the molten coating substance are enveloped by the steel. Thus, and through slow cooling, the present method permits the steel ingot to free itself of blowholes and flaws prior to solidification. In addition, the liquid coating composition displaced from the mold by the steel serves to keep the upper part of the ingot at a high temperature for a considerable time, which prevents piping in the ingot at this point, since solidification of the molten steel proceeds gently upward from the bottom of the mold.

Only the upper 5% of ingots cast in accordance with the present invention need be discarded prior to rolling as compared with about 15% lost as the result of conventional casting methods. The surfaces of the ingots produced by the present method are so clean that no conditioning is required prior to rolling. From these standpoints the invention provides an ingot casting method which is more efficient from a yield standpoint.

In accordance with this invention, one or a plurality of molds may be employed and several ingots cast simultaneously from the same heat which eliminates heterogeneity in the ingot products. In conventional methods on the contrary where teeming of the steel is made into individual molds in succession, even though the same heat of steel be used, dissimilarity in the qualities of the individual ingots cannot be avoided because of differences in the teeming velocities and temperatures. Further in accordance with the present apparatus and method, losses are reduced since all ingots cast simultaneously are of substantially uniform size and weight. In the conventional method the last mold is usually not filled either to the full scale or to the same height to which the other molds were filled with the same heat of molten metal.

Thus, the present invention constitutes an improvement in almost every phase of conventional ingot casting methods. A substantially flawless ingot is produced which has no blowholes or non-metallic inclusions and the yield is at least 10% better than that possible heretofore.

Referring now to the coating composition in detail, this material must have a specific gravity sufficiently low that it will not be rolled into the molten steel. It must consist of substances that do not affect the composition of the steel, that is, it must be chemically inert at the temperatures of molten steel. It must have a low melting point and a high fluidity. It must neither crystallize during solidification in contact with molten steel nor gasify at these temperatures. The composition must also be capable of absorbing oxygen and other gases contained in the molten steel as well as non-metallic inclusions.

In accordance with the present invention, the coating composition comprises a mixture of metal oxides, with the principal components being silica, alumina and calcium oxide. The remainder of the composition includes small amounts of other metal oxides, while the aforementioned principal ingredients account for about 75–85% and preferably about 80% by weight of the mixture. The principal components comprise:

	Percent
SiO_2	50–80
Al_2O_3	10–30
CaO	15–35

A typical coating composition having a melting point of about 1100% C. analyses in percentages by weight:

SiO_2	FeO	Al_2O_3	CaO	MgO	MnO	TiO_2	Fe_2O_3	Na_2O	B_2O
45.0	3.5	7.9	20.7	0.20	10.0	3.8	Trace	2.1	4.8

Extensive tests were conducted on steel ingots produced by the method and in the apparatus of the present invention. Heats of high carbon-low chromium steel (KK2) and heats of case hardenable low alloy chromium-molybdenum steel (XEIM) were employed using the coating composition. KK2 and XEIM are the tradenames of steels manufactured by Daido Steel Company Ltd., a corporation of Japan.

The following Table I sets forth casting temperatures of the metal oxide coating composition and the steel for five heats of KK2 and five heats of XEIM in the production of 200 kg. steel ingots by the method of the present invention.

Table I

Heat Number	Kind of Steel	Teeming Temperature in ° C.	
		Coating	Steel
1	KK2	1,400	1,660
2	KK2	1,510	1,600
3	KK2	1,580	1,580
4	KK2	1,580	1,610
5	KK2	1,540	1,620
6	XEIM	1,450	1,600
7	XEIM	1,520	1,600
8	XEIM	1,450	1,670
9	XEIM	1,550	1,690
10	XEIM	1,560	1,600

Table II

Heat Number	Diameter of Roll in mm.	Tested Place [1]	3-Stage Flaw Detection [2]			Macro-Corrosion [3]									Non-Metallic Inclusions						Grain Size Number
															A-Type			B-Type			
			1st	2nd	3rd	T	L	S	Sc	Se	D	B	Bs	H	Cleanness	Average Thickness	Maximum Thickness	Cleanness	Average Thickness	Maximum Thickness	
1	70	T	2 (1.5)	(1)	0	1	1	1	1	1	2	1	1	1	0.18	3.1	50 5	2.09	3.2	5	G 4.6
		B	6 (9.5)	0	0	1	1	1	1	1	2	1	1	1	0.27	4.1	80 6	2.56	3.7	5	G 4.8
2	95	T	0	0	0	1	2	1	1	1	2	1	1	1	0.53	4.2	50 6	2.97	4.0	6	G 5.0
		M	0	0	0	1	1	1	2	1	2	1	1	1	0.46	4.6	80 6	2.92	4.5	7	G 5.2
		B	0	0	0	1	1	1	2	1	2	1	1	1	0.31	4.5	50 6	3.34	4.4	6	G 5.3
3	95	T	0	0	0	1	1	1	2	1	2	1	1	1	0.94	5.6	90 8	2.93	4.5	7	G 5.0
		M	0	0	0	1	1	1	2	1	2	1	1	1	0.32	4.3	50 6	2.89	4.7	6	G 4.6
		B	0	0	0	1	1	1		1	2	1	1	1	0.25	3.4	40 4	2.97	4.4	6	G 4.5
4	95	T	0	0	0	1	2	1	2	1	2	1	1	1	1.02	4.5	100 7	2.54	3.6	6	G 5.5
		M	0	0	0	1	2	1	2	1	2	1	1	1	0.93	5.1	150 8	2.38	4.1	6	G 5.5
		B	0	0	0	1	1	1	2	1	2	1	1	1	0.97	4.5	70 7	2.31	4.4	6	G 5.3
5	95	T	0	0	0	1	3	1	2	1	1	1	1	1	0.76	4.6	120 7	2.89	4.2	6	G 5.9
		M	0	0	0	1	3	1	2	1	1	1	1	1	0.86	5.0	80 7	2.54	4.4	7	G 5.4
		B	0	0	0	1	2	1	2	1	2	1	1	1	0.56	4.7	80 6	2.73	4.7	7	G 5.5
6	55	T	2 (2)	0	0	1	3	2	1	1	1	1	1	1	0.93	3.5	70 5	2.73	4.5	6	G 4.6
		M	0	0	0	1	2	2	1	1	1	1	1	1	0.70	4.1	80 4	2.16	3.6	6	G 4.7
		B	0	0	0	1	1	1	1	1	1	1	1	1	0.87	3.2	60 7	1.94	3.1	5	G 4.6
7	55	T	0	0	0	1	2	2	1	1	1	1	1	1	0.72	3.7	80 5	2.75	3.6	4	G 5.4
		M	0	0	0	1	3	2	1	1	1	1	1	1	0.54	3.4	60 6	2.14	3.0	5	G 6.4
		B	0	0	0	1	2	1	1	1	1	1	1	1	0.77	3.1	50 4	2.31	3.2	5	G 4.8
8	60	T	0	0	0	1	2	2	1	1	1	1	1	1	1.00	4.2	100 8	2.73	3.8	6	G 4.3
		M	0	0	0	1	3	1	1	1	1	1	1	1	0.92	4.5	60 7	2.92	3.9	6	G 3.9
		B	0	0	0	1	1	1	1	1	1	1	1	1	0.54	3.4	50 6	3.13	4.3	6	G 4.1
9	60	T	0	0	0	1	2	1	1	1	1	1	1	1	0.63	4.5	70 7	3.00	4.7	7	G 5.4
		M	0	0	0	1	3	1	1	1	1	1	1	1	0.63	4.6	50 7	2.81	4.6	6	G 5.6
		B	0	0	0	1	2	1	1	1	1	1	1	1	0.70	3.5	60 6	3.09	4.2	6	G 5.0
10	60	T	0	0	0	1	2	1	1	1	1	1	1	1	1.11	3.3	50 4	1.86	3.2	5	G 4.3
		M	0	0	0	1	2	1	1	1	1	1	1	1	1.12	3.1	80 4	1.99	3.0	4	G 3.7
		B	0	0	0	1	1	1	1	1	1	1	1	1	0.94	3.2	50 4	2.02	3.3	5	G 3.6

Notes to table:

[1] T=upper part of ingot; M=middle part of ingot; B=lower part of ingot.

[2] 1st, 2nd and 3rd signify cylindrical surfaces located 5, 10 and 15 mm. respectively, inside the exterior surface and parallel to the axis. The figures in the columns mean the length of flaws in mm., zero indicating non-existence of flaws.

[3] Symbols: T=overall pit; Tc=central pit; L=porous; S=overall segregation; Sc=central segregation; Se=Eye-ball segregation; D=dendrite; B=blowhole; Bs=skin blowhole; H=hair crack.
The figures 1, 2, and 3 denote best, good and fair results respectively.

The results of the 3-stage flow detection, macro-etching, and non-metallic inclusion tests and the grain size of the crystals in the ingots produced clearly show that the present method of casting steel ingots is highly satisfactory.

What is claimed and desired to be secured by Letters Patent is:

1. A method of casting steel ingots which comprises providing a ladle containing molten steel and a molten metal oxide composition substantially inert with respect to the steel and having a substantially lower specific gravity such that the same rises to the surface of the steel, pouring said composition from the surface of the steel into an inclined mold while decreasing the angle of inclination thereof to bring said composition initially into contact with the interior walls of the mold, allowing the portion of the composition adjacent the mold walls to solidify, and while further decreasing the angle of inclination pouring said steel into said mold over the surfaces thereof coated with solid composition and still further decreasing the angle of inclination until the open end of said mold is beneath the pouring opening in said ladle, and permitting the coating composition remaining molten to rise to the surface of the steel whereby a solid metal oxide barrier is provided between the steel and the ingot mold.

2. A method as set forth in claim 1 wherein said metal oxide composition is one which will absorb gases and non-metallic material in the steel, and will not crystallize during solidification.

3. A method as set forth in claim 1 wherein said molten metal oxide composition comprises about 60–80% of the volume of said molten steel.

4. A method as set forth in claim 1 wherein said molten metal oxide composition comprises about 15–25% by weight of said molten steel.

5. A method as set forth in claim 1 wherein said metal oxide composition comprises about 75–85% by weight of

a mixture of SiO_2, Al_2O_3 and CaO in the following proportions: 50–80% SiO_2, 10–30% Al_2O_3 and 15–35% CaO.

6. A method of casting steel ingots which comprises providing in a ladle quantities of molten steel and molten metal oxide composition substantially inert with respect to said steel and of substantially lower melting point and specific gravity than said steel, pouring said metal oxide composition into an inclined ingot mold, while changing the angle of inclination of the mold, to bring said composition into contact with the interior walls of the mold, allowing the portion of said composition contacting said walls to solidify, and pouring said molten steel into said mold in contact with said solidified composition, and further changing said angle of inclination until said ingot is in an upstanding position at the termination of steel pouring, thereby avoiding direct contact between the ingot walls and the steel, and permitting the portion of said composition remaining molten to rise to the surface of the ingot, thereby providing a solid metal oxide barrier between the steel and the walls of the mold.

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