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[54] CONSUMABLE ELECTRODE MELTING

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[63] Continuation-in-part of Ser. No. 616,700, Feb. 16, 1967, abandoned.

[52] **U.S. Cl.** .....**164/52,** 75/10 C

[51] **Int. Cl.** **B22d 27/02**

[58] **Field of Search** .....75/10 R, 12, 10 C; 164/50, 164/52, 250, 252

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[57] **ABSTRACT**

A method for producing a metal ingot having a diameter of at least 17 inches, which comprises the steps of: arranging a consumable electrode within a consumable electrode furnace structure; connecting the consumable electrode to the positive terminal of a direct current power supply; establishing a partial pressure of from 30 to 2,000 microns of non-oxidizing gas within the furnace structure; melting the consumable electrode in the partial pressure of from 30 to 2,000 microns by passing an electrical current of at least 5,000 amperes between the consumable electrode and a second electrode which is connected to the negative terminal of said direct current power supply; and casting the molten metal in a mold having a diameter of at least 17 inches.

6 Claims, No Drawings

CONSUMABLE ELECTRODE MELTING

This application is a continuation-in-part of now abandoned copending application Ser. No. 616,700 filed Feb. 16, 1967.

The present invention relates to a consumable electrode melting process for producing high quality, large ingots and more particularly to a consumable electrode melting process for producing ingots having a diameter of at least 17 inches and a low incidence of segregation.

Consumable electrode melting processes involve the remelting of a cast or forged electrode in a protective environment and casting of the remelted electrode into an ingot. Depending upon the circumstance they can employ various operating conditions. For example, the protective environment can be a vacuum, an atmosphere of inert gas, a nitrogen atmosphere or a protective blanket layer of molten slag and power for melting can take the form of straight polarity direct current (electrode negative), reverse polarity direct current (electrode positive) or alternating current. All consumable electrode melting processes are, however, aimed at producing high quality metal in an efficient manner.

An indication of the quality of a metal ingot is its segregation level. More specifically, segregation refers to "freckles" and "white spots." Freckles show up as dark spots or specks in the microstructure of the ingot, and appear to be concentrations of eutectic carbides. White spots, on the other hand, appear to be zones of carbide depletion. While both are undesirable, the appearance of freckles seems to be the most frequently recurring defect. In any event, the incidence of segregation increases as the pool depth increases; i.e., the depth of molten remelted metal which has not solidified.

The efficiency of consumable electrode melting processes is often measured in terms of ingot sizes. It is clearly more efficient to cast one large ingot rather than a number of small ones. Unfortunately, segregation is more pronounced in large ingots than in small ones. Large ingots solidify at a slower rate than do small ingots, and hence, their melting is accompanied by a deeper pool of molten metal which, as stated above, causes a greater incidence of segregation.

The present invention provides a highly efficient consumable electrode melting method for producing high quality, large ingots. More specifically, it relates to a method of producing ingots having a diameter of at least 17 inches and a low incidence of segregation. Melting is accomplished with reverse polarity direct current in a furnace structure having a partial pressure of from 30 to 2000 microns of non-oxidizing gas. Reverse polarity direct current melting was found to produce a considerably shallower pool than straight polarity direct current melting, and hence a lower incidence of segregation, at the same current level. A minimum pressure was found to be necessary in order to protect the melt in which the ingot is cast and a maximum pressure of 2,000 microns is imposed as pool depths and segregation levels were found to increase with increasing pressure.

A 1956 article entitled *The Effect Of Variables On The Melting Rate Of Metals In The Consumable Electrode Arc Furnace*, by W. H. Smith, appeared on pages 41 – 56 of Arcs In Inert Atmospheres And Vacuum (Edited by W. E. Kuhn, John Wiley and Sons) and discussed the electrical and melting characteristics of both straight and reverse polarity melting. The article does not, however, discuss the quality and more specifically the segregation level of the ingot cast. In fact, the largest cast ingot discussed therein is only 4 inches in diameter and segregation is not a problem with ingots of such a small size, as shown hereinafter in the examples. Very significantly, the article does not show that ingot size affects segregation. Furthermore, it does not show, as do the examples appearing hereinafter, that large ingots cast from electrodes melted with reverse polarity have a lower incidence of segregation than do ingots of the same size cast from electrodes melted with straight polarity, and that ingots cast at a pressure below 2,000 microns have a lower incidence of segregation than do ingots cast at a pressure in excess of 2,000 microns. Moreover, the article does not disclose the need for a minimum pressure limitation and that minimum pressure limitations permit the use of larger electrodes and, in turn, higher electrode diameters to ingot diameter ratios. In summary, the article does not disclose a reverse polarity consumable electrode melting process for producing ingots having a diameter of at least 17 inches and a low incidence of segregation.

It is accordingly an object of this invention to provide a consumable electrode melting process for producing high quality large ingots.

It is a further object of this invention to provide a consumable electrode melting process for producing ingots having a diameter of at least 17 inches and a low incidence of segregation.

The method of the present invention comprises the steps of: arranging a consumable electrode within a consumable electrode furnace structure; connecting the consumable electrode to the positive terminal of a direct current power supply; establishing a partial pressure of from 30 to 2,000 microns, generally 1,000 – 2,000 microns, of non-oxidizing gas within the furnace structure; melting the consumable electrode in the partial pressure of from 30 to 2,000 microns by passing an electrical current of at least 5,000 amperes between the consumable electrode and a second electrode which is connected to the negative terminal of the direct current power supply; and casting the molten metal in a mold having a diameter of at least 17 inches.

Reverse polarity melting (electrode positive) produces a considerably shallower pool than straight polarity melting (electrode negative) and hence a lower incidence of segregation, at the same current level. As a result, it allows a metal producer to increase efficiency by employing higher currents to cast larger ingots. For example, a 9 inch electrode melted at 10,000 amperes with reverse polarity produced a pool depth 20 percent shallower than a similar 9 inch electrode melted at a lower current of 6,000 amperes with straight polarity.

The non-oxidizing atmosphere must be maintained at a partial pressure of from 30 to 2,000 microns. A minimum pressure limitation is necessarily imposed to protect the mold in which the ingot is cast and a maximum pressure of 2,000 microns is imposed as pool depths and, in turn, segregation levels increase with increasing pressures. The minimum pressure is always in excess of 30 microns and varies with interrelated varia-

bles such as ingot size, electrode size, current level and electrode makeuup. At pressures below the minimum, the arc is not sufficiently constricted and molten metal adheres to the mold. This adhering metal necessitates an operation in which the ingot is forcibly removed from the mold, an operation which almost always leaves the mold in disrepair. Illustrative non-oxidizing atmospheres are nitrogen and inert gases such as argon. In short, the particular gaseous atmosphere of this invention, allows the use of reverse polarity melting with its segregation free aspects while precluding mold damage.

A consumable electrode furnace structure of any suitable or conventional design can be employed. Consumable electrode furnaces are well known in the art, are commercially available and form no part per se of this invention. The furnaces will ordinarily include means for controlling the gradual lowering of the electrode and a cooled mold. The mold will generally, but not necessarily, serve as the second electrode. An illustrative furnace structure is described in U.S. Pat. No. 3,187,078 which issued on June 1, 1965.

The arc current is at least 5,000 amperes and preferably 10,000. A current of 5,000 amperes is necessary as the surface quality of the cast ingot is not as good with lower current levels. Current levels in excess of 10,000 amperes are preferred as arcs constrict themselves to a greater degree at higher currents. Maximum currents are dependent upon desired segregation levels as higher current are accompanied by deep pools and, in turn, a higher incidence of segregation. The current is, however, always reverse polarity and never straight polarity, or alternating which generally cannot be used at low pressures without the addition of an ionizing substance; as the ionized gases which provide the current path are removed when the voltage passes through zero and the arc is extinguished.

The electrode diameter to ingot diameter ratio is at least 0.6. Ratios lower than 0.6 are impractical from a commercial standpoint and adversely affect segregation levels, as pool depths increase with decreasing ratios.

The following examples are illustrative of the invention. They are directed to alloy steel embodiments despite the fact that the invention is believed to be adaptable to a wide variety of alloys, including nickel and cobalt alloys, as alloy steels probably constitute its most important use.

EXAMPLE I

M–2 steel ingots having diameters of 4 to 7 inches were cast from consumable electrodes with both straight and reverse polarity melting. The ingots were examined after casting to determine the degree of segregation. Neither freckles nor white spots were evident.

Seven additional, M–2 tool steel, ingots having a diameter of 17 inches were cast from consumable electrodes and evaluated as to their degree of segregation. Three of the consumable electrodes were melted with straight polarity direct current and the remaining four with reverse polarity direct current. Preparation for evaluation included the steps of pressing the 17 inch ingots into billets having a 7 inch square cross section, and macro-etching discs from selected portions thereof. Evaluation involved the step of giving the discs a freckle and white spot rating from 0 to 4, with 0 standing for no obvious freckles or white spots and with 4 standing for a high degree of segregation. The results of the evaluation are given below in Table I along with the polarity and current employed to cast the ingots.

TABLE I

Ingot No.	Melting Conditions	Disc Positions	Freckle Rating	White Spot Rating
A	Straight polarity	Top	1	0.5
	5000 amperes	Mid.	0	1
		Bot.	0	0
B	Straight polarity	Top	0	1
	5000 amperes	Top, mid.	1	1
		Mid.	0	3
		Bot., mid.	1	1
		Bot.	0	2
C	Straight polarity	Top	0	4
	5000 amperes	Mid.	0	3
		Bot.	0	2
D	Reverse polarity	Top	0	0
	10,000 amperes	Mid.	0	0
		Bot.	0	0
E	Reverse polarity	Top	0	0
	10,000 amperes	Mid.	0	0
		Bot.	0	0
F	Reverse polarity	Top	0	0
	10,000 amperes	Top, mid.	0	0
		Mid.	0	0
		Bot., Mid.	0	0
		Bot.	0	0
G	Reverse polarity	Top	1	0
	15,000 amperes	Top, mid.	0	0
		Mid.	0.5	0
		Bot., mid.	2	0
		Bot.	0.5	0

A study of the results of Example I reveals:

1. That the incidence of segregation increases with increasing ingot size; and
2. That large ingots cast from electrodes melted with reverse polarity direct current have a lower incidence of segregation than do ingots of the same size cast from electrodes melted with straight polarity direct current.

For example, the 4 and 7 inch ingots were free of freckles and white spots whereas larger ingots were not. Furthermore, 17 inch ingots (ingots A, B and C) cast with straight polarity had a higher incidence of segregation than 17 inch ingots (ingots D, E and F) cast with reverse polarity despite the fact that the reverse polarity casting was done with a considerably higher current which, as stated hereinbefore, adversely affects segregation (all else being the same). Moreover, ingot G cast with reverse polarity at a higher current level than that used to cast ingots D, E and F, had a comparable or lower incidence of segregation than did ingots A, B and C.

EXAMPLE II

Three additional M–2 tool steel, ingots (ingots H, I and J) were cast with reverse polarity and evaluated as to their degree of segregation along with one ingot (ingot K) of a manganese, chromium, nickel, molybdenum, titanium and vanadium containing steel known as A–286. Preparation for the evaluation and the evaluation itself were the same as described above in Example I. The results of the evaluation are given below in Table II along with the size of the ingot cast,

the crucible material, and the current and partial pressure employed. The partial pressure was maintained with argon.

TABLE II

Ingot No.	Ingot Size (Inches)	Pressure Level (Microns)	Current and Crucible Material	Disc Position	Freckle Rating	White Spot Rating
H	20	2000	10,000 Amperes Aluminum	Top	0	0
					3.5	0
					3.5	0
					0.5	1
					0	0
				Bot.	0	0.25
I	20	30	10,000 Amperes Aluminum	Top	0	0
					0	0
					0	0
					0	0
					0	0
				Bot.	0	0
J	17	2000	10,000 Amperes Copper	Top	0	0
				Mid.	0	0
				Bot.	0	0
K	28	30	18,000 Amperes Copper	Top	0	0
					0	0
					0	0
					0	0
				Bot.	0	0

A study of the results of Example II reveals that pressure affects the quality of the ingot. For example, ingot I cast with a partial pressure of 30 microns had a lower incidence of segregation than did ingot H cast with a partial pressure of 2,000 microns. Moreover, the results reveal that 17 inch ingots with a low incidence of segregation can be produced with a pressure as high as 2,000 microns (see ingot J) and that ingots considerably larger than 17 inches can also be produced with a low incidence of segregation (see ingot K).

From the above paragraphs it will be apparent to those skilled in the art that the novel principles of the invention disclosed herein in connection with specific examples thereof will suggest various other modifications and applications of the same. It is accordingly desired that in construing the breadth of the appended claims they should not be limited to the specific examples described herein.

We claim:

1. A method for producing an alloy steel ingot having a diameter of at least 17 inches, and a low incidence of segregation which comprises the steps of: arranging a consumable electrode within a consumable electrode furnace structure, said consumable electrode and said ingot having a consumable electrode diameter to ingot diameter ratio of at least 0.6; connecting said consumable electrode to the positive terminal of a direct current power supply; establishing a partial pressure of from 30 to 2,000 microns of non-oxidizing gas within the furnace structure; melting said consumable electrode in said partial pressure of from 30 to 2,000 microns by passing an electrical current of at least 5,000 amperes between said consumable electrode and a second electrode which is connected to the negative terminal of said direct current power supply; and casting said molten metal in a mold having a diameter of at least 17 inches.

2. A method according to claim 1 wherein said partial pressure is from 1,000 to 2,000 microns.

3. A method according to claim 1 wherein said non-oxidizing gas is an inert gas.

4. A method according to claim 1 wherein said non-oxidizing gas is nitrogen.

5. A method according to claim 1 wherein said electrical current is at least 10,000 amperes.

6. A method according to claim 1 wherein said partial pressure is from 1,000 to 2,000 microns and wherein said non-oxidizing gas is argon.

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