

Title

Induction furnace for melting of metals, lining for an induction furnace and method for production of such lining.

5 Technical Field

The present invention relates to an induction furnace for melting of metals, particularly silicon, and more particularly to a lining for such furnace.

Technical background

10 By melting of metals in induction furnaces most metals have such high electrical conductivity that they connect inductively in solid state. For melting of such metals in induction furnaces the electrical properties of the lining in the induction furnace is not important and the lining can be made from electric isolating materials. Metals having a low electrical conductivity when they are in solid state, such as silicon and germanium, will however not connect
15 inductively when they are in solid state. In order to start the melting process it must be used a susceptor which is inserted into the furnace at the start of the melting process of solid silicon or the lining must be made from an electrically conductive material that connects inductively, such as graphite. When using graphite as lining the melting will take place indirectly as the graphite lining
20 will be heated by induction and where the metal is heated by heat radiation from the graphite lining. As graphite also has a higher electrical conductivity than molten silicon, the heat transfer during the whole melting period, also when part of the silicon is in molten state, will be based on inductive heating of the graphite lining. This has disadvantages as the graphite lining during the
25 whole melting period will be the hottest part of the induction furnace. This requires a very comprehensive cooling of the graphite lining causing high heat losses. Further the graphite lining, the induction coil and the cooling system for the lining will be subjected to high thermal stress.

30 By the present invention it is provided an induction furnace for metals having a low electric conductivity, particularly silicon, where the lining is heated by induction at the start of melting of solid metal, while the main part of the

heating when at least a part of the metal has melted, is done by inductive connection to the molten metal and not to the lining. It is further provided a lining for an induction furnace where the electrical conductivity of the lining
5 can be tailormade during the production of the lining in such a way that the electrical conductivity of the lining is adjusted according to the metal that shall be melted in the induction furnace.

Description of the invention

The present invention thus relates to an induction furnace for melting of
10 metals that do not connect inductively in solid state, said induction furnace having a lining comprising of a mixture of graphite and silicon carbide and has an electric conductivity higher than the electrical conductivity of the metal to be melted when metal is in solid state, but lower than the electrical conductivity of the metal to be melted when the metal is in molten state.

15 The lining preferably comprises 80-20 % by weight of graphite and 20-80 % by weight of silicon carbide and more preferably the lining comprises 70-30 % by weight of graphite and 30-70 % by weight of silicon carbide.

The electrical conductivity of the lining can be tailormade to an electrical conductivity relative to the electrical conductivity for the metal to be melted by
20 regulating the content of silicon carbide in the lining, as the electrical conductivity in the lining will be reduced with increasing content of silicon carbide.

The present invention further relates to a lining for use in induction furnaces for melting of metals which do not connect inductivity in solid state, which
25 lining has a higher electrical conductivity than the metal to be melted when the metal is in solid state, but lower than the electrical conductivity for the metal to be melted when the metal is in molten state.

The lining preferably contains 80-20 % by weight of graphite and 20-80 % by weight of silicon carbide and more preferably the lining contains 30-70 % by
30 weight of graphite and 70-30 % by weight of silicon carbide.

The lining can be in the form of a self-sustaining crucible that can be exchanged very easily.

When using the induction furnace according to the present invention for melting of metals having a low electrical conductivity which do not connect inductively in solid state, such as silicon, the lining in the induction furnace at the start of a melting cycle when the furnace at the start is filled with solid metal, will connect inductively and thereby be heated. The solid metal in the furnace will thereby be heated by radiation from the lining. When part of the metal has melted the molten metal which has a far higher electrical conductivity than the solid metal, will connect inductively and the heat energy will be supplied directly to the molten metal. Thus the lining will only be subjected to very high temperature at the start of each melting cycle. A far better energy utilization will thereby be achieved as the heat energy is transferred directly to the molten metal in the furnace and consequently the heat stress on the lining will be substantially reduced. The need for cooling of the lining and of other parts of the furnace will thus also be reduced. This results in a substantially increased lifetime of the lining.

The lining according to the present invention further has the advantage that it can be made from very clean materials.

The present invention further relates to a method for making a lining for induction furnaces where the electrical conductivity for the lining can be adjusted to fit the metal that is to be melted in the furnace, which method is being characterized in that a mixture of graphite particles, silicon carbide particles and a carbon-based binder is formed to a lining whereafter the formed lining is cured and baked at a temperature above 1100°C where the electrical conductivity of the lining is adjusted by adjusting the ratio between the graphite particles and the silicon carbide particles.

Preferably the mixture comprises 20-80 % by weight of graphite particles and 80-20 % by weight of silicon carbide particles and carbon-based binder in an

amount of 10-25 % based on the weight of the mixture of graphite particles silicon carbide particles.

5 More preferably the mixture comprises 30-70 % by weight of graphite particles and 70-30 % by weight of silicon carbide and a carbon-based binder in an amount of 11-18 % based on the weight of the mixture of graphite particles and silicon carbide particles.

10 The carbon-based binder is selected among natural resins, synthetic resins such as fenol formaldehyd resin, furfuryl alcohol or tar-based binders such as petroleum coke pitch or tar pitch.

When a synthetic or natural harpiks is used a binder, a curing agent selected among hexamine and organic or inorganic acids are preferably added to the binder.

15 When the carbon-based binder is added to the mixture of graphite particles and silicon carbide particles this will provide a good strength at low temperatures. During heating and baking the binder will carbonize and form a solid carbon. In addition the use of carbon-based binder results in a more dense lining which prevents penetration of molten metal into the lining.

20 It is further preferred to add silicon particles to the mixture of graphite particles, silicon carbide particles and carbon-based binder in an amount sufficient for the carbon that forms during carbonization of the binder to react to SiC.

Short description of the Drawing

25 Figure 1 shows a vertical cut through an induction furnace according to the invention.

Detailed description of Invention

In Figure 1 there is shown an embodiment of the induction furnace according to the present invention, comprising an insulating lining 1 which on the outside

has an induction coil 2 embedded in a refractory material 3. The insulation lining 1 can consist of a refractory material that does not react with carbon, such as Al_2O_3 . On the inside of the insulation lining 1 it is arranged a lining 4 according to the invention comprising a mixture of graphite, silicon carbide, carbon-based binder and optionally silicon particles. An inner steel form part 5 is used when tamping the lining 4. The lining is cured at a temperature between 150 and 600°C and is baked at a temperature above 1100°C. The curing temperature is dependent on the type of carbon-based binder that is used.

The amount of silicon carbide is adjusted to obtain an electrical conductivity that one wants in the lining. Generally the amount of silicon carbide is adjusted in such a way that the electrical conductivity of the baked lining 4 is higher than the electrical conductivity of the metal that is to be melted in the induction furnace when the metal is in solid state, but lower than the electrical conductivity for the metal to be melted when the metal is in molten state. The amount of silicon carbide in the baked lining 4 is between 20 and 80 % by weight, and more preferred between 30 and 70 % by weight.

Before start up of a melting cycle the induction furnace is filled with solid metal. When supplying electric energy to the coil 2 the lining 4 will connect inductively, while the metal to be melted will not connect inductively. In this first period of the melting cycle the lining 4 will therefore be heated due to induction and heat will be transferred by heat radiation from the lining to the solid metal. When the metal starts to melt the electrical conductivity of the molten metal will be higher than the electrical conductivity of the lining 4. The molten metal will thereby connect inductively and a part of the supplied energy will thereby be transferred directly to the molten metal. When further amounts of metal melts, a larger and larger part of the electrical energy supplied will be transferred directly to the molten metal. The thermal stress on the lining 4 will thus be substantially reduced during the remaining part of the melting process.

When the melting is finished the molten metal is poured from the furnace, but in such a way that a pool of molten metal remains in the induction furnace, for instance 25 %. Thus at the start of the next melting cycle this pool of molten metal will connect inductively.

Example

Production of lining

A lining for a 75 kW induction furnace operating at a frequency of 3000 Hz was produced as follows: On the inside of the refracting layer 3 with the embedded coil 2 (Figure 1) an insulating refractory layer 1 was cast. The insulating refractory layer 1 consisted of 96 % by weight of Al_2O_3 , the remaining being impurities such as SiO_2 , CaO and FeO . The thickness of the insulating refractory layer 1 was 25 mm. On the inside of the insulating refractory 1 it was tamped a lining 4 consisting of a powder mixture of 40 % by weight graphite powder, 49 % by weight silicon carbide and 11 % by weight of silicon particles. To this mixture it was added 14.3 % fenol formaldehyd resin binder based on the weight of the mixture of graphite particles, silicon carbide particles and silicon particles. To the binder it was added hexamin as a curing agent. The lining was thereafter cured and baked by placing a susceptor in a form of a graphite cylinder in the center of the furnace together with a thermocouple. The curing and baking of the lining 4 was done at a heating rate of maximum 100°C per hour to a temperature of 1500°C.

The lining 4 can alternatively be made separately outside the induction furnace by tamping the lining 4 between outer and inner mould parts. After tamping, the inner mould part is removed whereafter the lining is cured. The outer mould part is thereafter removed and the cured lining is placed in a suitable furnace or heating reactor where it is baked at temperature of above 1100°C.

The lining was tested for inductivity at 1000°C. At start of the supply of electric energy to the induction coil 2 the furnace took maximum effect of 75

- 5 kW at once. Thereafter solid silicon was supplied to the furnace and melted. After melting and pouring of the silicon from the furnace, the lining was allowed to be cooled to 200°C and again tested for inductivity at maximum effect of 75 kW. The lining then took 65 kW. The effect taken by the lining was thus reduced by 15 %. This shows that during curing and baking of the lining the conductivity of the lining is increased such that it connects inductively.

Melting of silicon

- 10 Chunks of silicon was filled into the furnace and heated to 1550°C. Melting started when the supplied effect reached 45 kW. A total of 15 kg silicon was melted in 55 minutes. A good movement of the molten bath was observed which shows that a major part of the energy supplied was transferred directly to the molten silicon.

Claims

1. Induction furnace for melting of metals that do not connect inductively
5 in solid state, c h a r a c t e r i z e d i n that induction furnace has a lining comprising a mixture of graphite and silicon carbide and has an electric conductivity higher than the electrical conductivity of the metal to be melted when metal is in solid state, but lower than the electrical conductivity of the metal to be melted when the metal is in molten state.
- 10 2. Inducting furnace according to claim 1, c h a r a c t e r i z e d i n that the lining comprises 80-20 % by weight at graphite and 20-80 % by weight of silicon carbide.
- 15 3. Induction furnace according to claim 2, c h a r a c t e r i z e d i n that the lining comprises 70-30 % by weight of graphite and 30-70 % by weight of silicon carbide.
- 20 4. Lining for use in induction furnaces for melting of metals which do not connect inductively in solid state, c h a r a c t e r i z e d i n that lining comprises a mixture of graphite and silicon carbide and that the lining has a higher electrical conductivity than the metal to be melted when the metal is in solid state, but lower than the electrical conductivity for the metal to be melted when the metal is in molten state.
- 25 5. Lining according to claim 4, c h a r a c t e r i z e d i n that the lining preferably contains 80-20 % by weight of graphite and 20-80 % by weight of silicon carbide.
6. Lining according to claim 5, c h a r a c t e r i z e d i n that the lining contains 30-70 % by weight of graphite and 70-30 % by weight of silicon carbide.
7. A method for making a lining for induction furnaces where the electrical conductivity of the lining can be adjusted to the electrical conductivity of the

metal that is to be melted in the furnace in such way that the lining has a higher electrical conductivity than the metal when the metal is in solid state, but lower electrical conductivity than the metal when the metal is in solid state,
5 c h a r a c t e r i z e d i n that a mixture of graphite particles, silicon carbide particles and a carbon-based binder is formed to a lining whereafter the formed lining is cured and baked at a temperature above 1100°C.

8. Method according to claim 7, c h a r a c t e r i z e d i n that the electrical conductivity of the lining is adjusted by regulating the ratio between
10 graphite particles and silicon carbide particles.

9. Method according to claim 7 and 8, c h a r a c t e r i z e d i n that the mixture comprises 20-80 % by weight of graphite particles and 80-20 % by weight of silicon carbide particles and carbon-based binder in an amount of 10-25 % based on the weight of the mixture of graphite particles and silicon
15 carbide particles.

10. Method according to claim 9, c h a r a c t e r i z e d i n that the mixture contains 30-70 % by weight of graphite particles and 70-30 % by weight of silicon carbide particles and a carbon-based binder in an amount of 11-18 % based on the weight of the mixture of graphite particles and silicon
20 carbide particles.

11. Method according to claim 7, c h a r a c t e r i z e d i n that the carbon-based binder is selected among natural resins, synthetic resins and tar-based binders.

12. Method according to claim 11, c h a r a c t e r i z e d i n that the carbon-based binder is selected among fenol formaldehyd resin and furfuryl alcohol.
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13. Method according to claim 12, c h a r a c t e r i z e d i n that a curing agent is added.

14. Method according to claim 12, c h a r a c t e r i z e d i n that the curing agent is selected among hexamine and inorganic acids.
15. Method according to claim 11, c h a r a c t e r i z e d i n that the
5 binder is petroleum coke pitch or tar pitch.
16. Method according to claims 9-14, c h a r a c t e r i z e d i n that silicon particles is added to the mixture of graphite particles, silicon carbide particles and carbon-based binder in an amount sufficient for the carbon that forms during carbonization of the binder to react to SiC.