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(54) **Method for melting of aluminium**

Verfahren zum Schmelzen von Aluminium

Procédé de mélange d'aluminium

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Description

[0001] The invention relates to a method for heating and melting of a starting material in a furnace by means of at least one burner which is operated with a fuel and an oxygen-containing gas, wherein said starting material contains a metal, especially aluminium, comprising the steps of

- a) heating said starting material up to the melting point of said metal,
- b) transforming said metal from the solid phase to the liquid phase, and
- c) superheating said liquid phase metal.

[0002] The invention relates in particular to the heating and melting of aluminium in reverberatory furnaces heated by means of fuel-fired burners. The process is typically a batch process. The material to be melted, for example scrap or ingots, is charged through large doors into the furnace. Typically a furnace is charged one or more times during a process cycle. The scrap is heated to the melting point, melted and the resulting liquid aluminium is superheated to the specified end temperature. An example of an end temperature is 720°C.

[0003] For reverberatory furnaces, as described in WO 2004/07924 A2, it is state of the art to measure the temperature in the furnace so that the burner power can be reduced when the maximum allowed working temperature of the refractory has been reached. That means, the measuring devices are mainly used to protect the refractory. A typical example of such a maximum working temperature is 1100°C.

[0004] Known thermodynamic data show that about 94% of the theoretical energy needed for that process is for heating and melting of the aluminium and the remaining 6% of the theoretical energy is for superheating of the liquid metal.

[0005] The oxidation of liquid aluminium is temperature dependent. The rate of oxidation increases with increasing temperature, especially at metal temperatures above 780°C the oxidation increases rapidly. Owing to this in the prior art the process is divided in two steps:

Step 1, Heating and melting: The maximum installed burner power is used and the burner power is only controlled based on the allowed working temperature of the refractory as noted above.

Step 2, Superheating: A lower burner power is used and the burner power is controlled by the temperature of the liquid metal. The temperature of the liquid aluminium is limited in order to minimize the oxidation rate.

[0006] However, prior art processes treat the heating and melting of the aluminium as one single process step with the same burner power control during heating and melting. This means that the burner power control used

is not optimised for each of the process steps heating and melting.

[0007] This is a disadvantage for two reasons:

- 1. Too low power is used during heating which limits the productivity.
- 2. Too high power is used during melting which could result in aluminium oxidation and dross formation.

[0008] Thus it is an object of the present invention to provide an optimized method for heating and melting a metal, in particular aluminium.

[0009] This object is achieved by a method for heating and melting of a starting material in a furnace by means of at least one burner which is operated with a fuel and an oxygen-containing gas, wherein said starting material contains a metal comprising the steps of

a) heating said starting material up to the melting point of said metal, wherein step a) ends when the phase transformation begins and liquid metal starts to form

b) transforming said metal from the solid phase to the liquid phase, and

c) superheating said liquid phase metal,

characterized in that at least during a part of step b) the output power of said burner is controlled depending on the furnace temperature, wherein during said part of step b) the output power of said burner is a monotonically decreasing function of the furnace temperature and that the furnace temperature is kept substantially constant at least during a part of the phase transformation step b) and that during step c) the output power of said burner is controlled depending on the temperature of the liquid metal.

[0010] In the following the term "at least during a part of step b)" shall mean a time interval which is at least 30%, preferably 50%, more preferred 75% of the time needed for the phase transformation of the metal from the solid to the liquid state. Even more preferred, this term comprises the time interval when 10% of the starting material, more preferred 5% of the starting material, has been melted until 90% of the starting material, more preferred 95% of the starting material, has been melted.

[0011] The purpose of the invention is to optimise the energy input during the heating and melting phase individually and independent of each other and thereby increase the productivity and reduce metal oxidation.

[0012] The invention is in particular useful for heating and melting aluminium. In the following the invention will be described with reference to aluminium heating and melting. But the man skilled in the art will acknowledge that the invention as well as the different inventive embodiments can also be used for heating and melting of other metals, such as copper, lead and iron.

[0013] It is known that aluminium in solid state is not sensitive to oxidation. In fact, oxidation during heating up to the melting point of aluminium can be neglected. The theoretical energy for heating the metal to the melting point represents 59% of the total theoretical energy needed for heating up, melting and superheating.

[0014] The theoretical energy needed for the phase transformation from solid to liquid aluminium represents 35% of the total theoretical energy needed. As noted above aluminium in liquid state is more sensitive to oxidation. The oxidation rate is temperature dependent. During the phase transformation, the metal consumes energy without increasing its temperature. However, if the energy input is too high the first formed liquid metal will increase its temperature. The temperature of the liquid aluminium might increase to such a value that is critical for oxidation.

[0015] Thus, the idea of the invention is to divide the process into three steps a), b) c) instead of two steps as in prior art. The first step a) is characterized by heating up the starting material to the melting point of aluminium. During step a) a very high energy input can be used without any risk of oxidation.

[0016] The second step b) is the phase transformation from solid aluminium to the liquid phase. During step b), a new way of controlling the burner power based on a variable power limitation is introduced. The burner power is preferably as high as possible without overheating and oxidising the liquid aluminium that is formed. This is achieved by controlling the output power of the burner depending on the furnace temperature.

[0017] The third step c) is the phase of superheating the liquid aluminium. During step c), the output power of the burner is preferably controlled depending on the temperature of the liquid metal as already known from the prior art.

[0018] According to the invention the energy input is optimised individually for step a) and b), and preferably also for step c). Once phase transformation begins and liquid metal starts to form and further during the phase transformation from solid to liquid (step b) the energy input into the furnace is controlled depending on the furnace temperature.

[0019] According to an embodiment of the invention the furnace temperature is kept substantially constant at least during a part of the phase transformation step b). The energy supply to the furnace corresponds to what the starting material can utilize for the phase transformation at any time interval. The term "substantially constant" shall mean that the furnace temperature fluctuates less than 10%, preferably less than 5%. The maximum temperature deviation ΔT shall be less than 10 %, preferably less than 5% of the average furnace temperature during that part of the phase transformation step. For example, in the time interval from 10% of the starting material being melted to 90% of the starting material being melted the furnace temperature is kept within the temperature range from 900 °C to 980 °C.

[0020] If the furnace temperature drops too little energy is supplied and the phase transformation steals energy from the furnace refractory and the process slows down. On the other hand, if the furnace temperature increases, this indicates that too much energy is supplied and that formed liquid metal could use this excess energy to increase its temperature and, if this continues, oxidation may start. By keeping the furnace temperature constant the productivity can be maximized and at the same time aluminium oxidation can be minimized.

[0021] According to a preferred embodiment, at least during a part of step b) the output power of said burner is a continuous function of the furnace temperature. Continuous function shall mean a function for which, intuitively, small changes in the input result in small changes in the output. That is, small changes in the furnace temperature shall only result in small changes of the energy input into the furnace. In particular, the functional relation between burner power and furnace temperature is no step function, that is the burner power is not changed stepwise in response to small changes of the furnace temperature.

[0022] As described above too high temperatures promote the oxidation of liquid aluminium. Therefore, with increasing furnace temperature the output power of the burner and thus the energy input into the furnace is reduced. On the other hand, it is preferred to increase the burner power if the furnace temperature decreases.

[0023] According to another embodiment at least during a part of step b) the output power of said burner is a monotonically decreasing function of the furnace temperature. A function f is called monotonically decreasing if, whenever $x \leq y$, then $f(x) \geq f(y)$, so it reverses the order. When the furnace temperature increases the burner power and thus the energy input are reduced and when the furnace temperature decreases the burner power and the energy input are increased.

[0024] It is preferred to use one or more oxyfuel burners for heating the furnace. Oxyfuel burners have much higher potential to supply energy than air fuel burners. Especially at the beginning of a batch when the temperature of the furnace is low, there is a process window when the oxyfuel burners could be operated at much higher powers than is state of the art today. However, it is important to reduce the power once liquid metal starts to form in order to avoid oxidation.

[0025] The term oxyfuel burner shall mean a burner which is operated with a fossil fuel, in particular a liquid or gaseous fuel, and a gas containing more than 21 % oxygen. Preferably, the gas contains at least 80% oxygen. The oxyfuel burner can also be operated in the all oxyfuel mode meaning that the oxygen containing gas is technical pure oxygen.

[0026] Tests have shown that in aluminium melting inventive process step b) should preferably start at a furnace temperature between 850 and 970 °C, preferred at 850 °C, more preferred at 900 °C, more preferred at 920 °C. The starting temperature for process step b) may also

be within a temperature range of $\pm 10^\circ\text{C}$ of the above mentioned temperatures.

[0027] According to a preferred embodiment step c) commences at a furnace temperature between 930°C and 1000°C , more preferred between 940°C and 970°C . Then the burner control is preferably changed from a control depending on the furnace temperature to a control depending on the temperature of the liquid aluminium.

[0028] It is advantageous to have a very high burner power during step a) when the phase transformation has not yet started. Preferably the power introduced into the furnace by the burner or the burners exceeds 220 kW/m^2 furnace bath area, more preferred the power is at least 260 kW/m^2 furnace bath area. Furnace bath area shall mean the area of the furnace floor, that is the area which is covered by the molten starting material at the end of the melting process.

[0029] During step b) the burner power preferably varies between 90 kW/m^2 and 260 kW/m^2 depending on the furnace temperature. The burner power input is again related to the furnace bath area. The functional relation between burner power and furnace temperature is preferably linear, that is

$$P = P_0 - a T_F$$

wherein

P: burner power
 P_0 : burner power in step a)
 T_F : furnace temperature
 a: coefficient

[0030] The invention as well as preferred embodiments of the invention shall be described with reference to the following example and the attached drawings.

Figure 1 shows an exemplary relation between the burner power and the furnace temperature and

Figure 2 shows the accumulated fuel energy and the furnace temperature as a function of time.

Example:

[0031] An aluminium melting furnace is fired with oxy-fuel burners which are operated with a gaseous fossil fuel and oxygen. In the beginning all the aluminium containing starting material is in the solid state. The starting material is charged to a furnace and heated by means of oxyfuel burners. At this stage oxidation of aluminium can be neglected. Thus the oxyfuel burners are operated at a high power of 3000 kW (step a).

[0032] When a certain furnace temperature has been reached, e.g. 900°C , process step b) commences. The maximum burner power is chosen as a function of the

furnace temperature. This data is programmed in the PLC or an equivalent system. The furnace temperature is the temperature read from a thermocouple located at the inside of the furnace and close to the furnace roof refractory.

[0033] According to the invention, the maximum burner power is fixed (in this example 3000 kW) as long as there is only solid aluminium present. With reference to figure 1 the oxyfuel burner is operated at maximum power at temperatures lower than 900°C .

[0034] During the phase transformation from solid to liquid aluminium (step b), that is between 900°C and 950°C , the burner power limitation is variable. The PLC calculates the burner power limitation as a function of the furnace temperature. Between these two temperatures, the power limitation is continuously and linearly reduced from 3000 kW at 900°C down to 1200 kW at 950°C .

[0035] According to the prior art heating and melting would have a fixed power limitation, for example 2000 kW , and control the power based on the signal from a thermo couple. When the furnace temperature approaches the set point (e.g. 1100°C) the burner power is reduced by the controller.

[0036] Figure 2 shows the furnace temperature and the accumulated burner energy curves for a batch of 9t aluminium. First the solid Al is heated with 3000 kW . After 0.57h the temperature has reached 900°C and the variable power limitation according to the invention starts. Also the phase transformation starts (step b). The temperature curve (bold line) becomes almost flat. There is established a balance between the energy supplied and the energy consumed for the phase transformation solid to liquid.

[0037] Should the process at any time require more energy the temperature decreases. The consequence of this temperature decrease is that the inventive power limitation will immediately increase burner power and the process is again in balance. Should on the other hand the furnace get more energy than the process can use, the temperature will increase and the variable power limitation will immediately reduce the burner power and the process is again balanced.

[0038] The temperature increase after 1.37h indicates that most of the metal is molten and that the temperature of the liquid metal is increasing. In the example the burner was shut off after 1.55h .

Claims

1. Method for heating and melting of a starting material in a furnace by means of at least one burner which is operated with a fuel and an oxygen-containing gas, wherein said starting material contains a metal comprising the steps of

a) heating said starting material up to the melting point of said metal, wherein step a) ends when

the phase transformation begins and liquid metal starts to form

b) transforming said metal from the solid phase to the liquid phase, and

c) superheating said liquid phase metal,

characterized in that at least during a part of step b) the output power of said burner is controlled depending on the furnace temperature, wherein during said part of step b) the output power of said burner is a monotonically decreasing function of the furnace temperature and that the furnace temperature is kept substantially constant at least during a part of the phase transformation step b) and that during step c) the output power of said burner is controlled depending on the temperature of the liquid metal.

2. Method according to claim 1, **characterized in that** said at least part of step b) comprises the time interval when 10% of the starting material has been melted until 90% of the starting material has been melted.

3. Method according to any of claims 1 or 2, **characterized in that** during said part of step b) the output power of said burner is a continuous function of the furnace temperature.

4. Method according to any of claims 1 to 3, **characterized in that** during said part of step b) the output power of said burner is reduced with increasing furnace temperature.

5. Method according to any of claims 1 to 4, **characterized in that** during said part of step b) the furnace temperature fluctuates less than 10%.

6. Method according to any of claims 1 to 5, **characterized in that** said oxygen-containing gas contains more than 21% oxygen.

7. Method according to any of claims 1 to 6, **characterized in that** said starting material contains aluminium and that the output power of said burner is controlled depending on the furnace temperature at temperatures above 850 °C.

8. Method according to any of claims 1 to 7, **characterized in that** during step a) the output power of said burner(s) is at least 220 kW per m² furnace bath area, preferably at least 260 kW per m² furnace bath area, and/or that the output power during said part of step b) is between 260kW per m² furnace bath area and 90kW per m² furnace bath area.

9. Method according to any of claims 1 to 8, **characterized in that** said starting material contains aluminium.

10. Method according to any of claims 1 to 9, **characterized in that** said oxygen-containing gas contains more than 80% oxygen.

Patentansprüche

1. Verfahren zum Erhitzen und Schmelzen eines Ausgangsmaterials in einem Ofen mittels mindestens eines mit einem Brennstoff und einem sauerstoffhaltigen Gas betriebenen Brenners, bei dem das Ausgangsmaterial ein Metall enthält, wobei das Verfahren die folgenden Schritte umfasst:

a) Erhitzen des Ausgangsmaterials bis zum Schmelzpunkt des Metalls, wobei Schritt a) endet, wenn die Phasenumwandlung einsetzt und sich flüssiges Metall zu bilden beginnt;

b) Umwandeln des Metalls aus der festen Phase in die flüssige Phase; und

c) Überhitzen des in der flüssigen Phase befindlichen Metalls,

dadurch gekennzeichnet, dass mindestens während eines Teils des Schritts b) die abgegebene Leistung des Brenners abhängig von der Ofentemperatur kontrolliert wird, wobei während des Teils des Schritts b) die abgegebene Leistung des Brenners in Abhängigkeit von der Ofentemperatur gleichförmig abnimmt, dass die Ofentemperatur mindestens während eines Teils des Phasenumwandlungsschritts b) im Wesentlichen konstant gehalten wird, und dass während des Schritts c) die abgegebene Leistung des Brenners abhängig von der Temperatur des flüssigen Metalls kontrolliert wird.

2. Verfahren nach Anspruch 1, **dadurch gekennzeichnet, dass** der Mindestteil von Schritt b) die Zeitspanne umfasst, während der 10% des Ausgangsmaterials bis zu 90% des Ausgangsmaterials geschmolzen werden.

3. Verfahren nach einem der Ansprüche 1 oder 2, **dadurch gekennzeichnet, dass** während des Teils von Schritt b) die Leistung des Brenners fortlaufend in Abhängigkeit von der Ofentemperatur abgegeben wird.

4. Verfahren nach einem der Ansprüche 1 bis 3, **dadurch gekennzeichnet, dass** während des Teils von Schritt b) die abgegebene Leistung des Brenners mit zunehmender Ofentemperatur reduziert wird.

5. Verfahren nach einem der Ansprüche 1 bis 4, **dadurch gekennzeichnet, dass** während des Teils von Schritt b) die Ofentemperatur weniger als 10% schwankt.

6. Verfahren nach einem der Ansprüche 1 bis 5, **dadurch gekennzeichnet, dass** das sauerstoffhaltige Gas mehr als 21% Sauerstoff enthält.
7. Verfahren nach einem der Ansprüche 1 bis 6, **dadurch gekennzeichnet, dass** das Ausgangsmaterial Aluminium enthält und dass die abgegebene Leistung des Brenners abhängig von der Ofentemperatur bei Temperaturen von mehr als 850°C kontrolliert wird.
8. Verfahren nach einem der Ansprüche 1 bis 7, **dadurch gekennzeichnet, dass** während des Schritts a) die abgegebene Leistung des Brenners/der Brenner mindestens 220 kW pro m² Ofenbadfläche, vorzugsweise mindestens 260 kW pro m² Ofenbadfläche beträgt, und/oder dass die abgegebene Leistung während des Teils von Schritt b) zwischen 260 kW pro m² Ofenbadfläche und 90 kW pro m² Ofenbadfläche liegt.
9. Verfahren nach einem der Ansprüche 1 bis 8, **dadurch gekennzeichnet, dass** das Ausgangsmaterial Aluminium enthält.
10. Verfahren nach einem der Ansprüche 1 bis 9, **dadurch gekennzeichnet, dass** das sauerstoffhaltige Gas mehr als 80% Sauerstoff enthält.

Revendications

1. Procédé pour chauffer et faire fondre un matériau de départ dans un four au moyen d'au moins un brûleur qui est alimenté avec un combustible et un gaz contenant de l'oxygène, dans lequel ledit matériau de départ contient un métal, comprenant les étapes suivantes:
 - a) chauffer ledit matériau de base jusqu'au point de fusion dudit métal, dans lequel l'étape a) se termine lorsque la transformation de phase commence et que le métal liquide commence à se former;
 - b) transformer ledit métal de la phase solide à la phase liquide; et
 - c) surchauffer ledit métal en phase liquide,

caractérisé en ce qu'au moins pendant une partie de l'étape b), la puissance de sortie dudit brûleur est commandée en fonction de la température du four, dans lequel, pendant ladite partie de l'étape b), la puissance de sortie dudit brûleur est une fonction à décroissance monotone de la température du four, et **en ce que** la température du four est maintenue sensiblement constante au moins pendant une partie de l'étape de transformation de phase b), et **en ce que**, pendant l'étape c), la puissance de sortie

audit brûleur est commandée en fonction de la température du métal liquide.

2. Procédé selon la revendication 1, **caractérisé en ce que** ladite au moins une partie de l'étape b) comprend l'intervalle de temps pendant lequel 10 % du matériau de départ ont été fondus jusqu'à ce que 90 % du matériau de départ aient été fondus.
3. Procédé selon l'une des revendications 1 ou 2, **caractérisé en ce que**, pendant ladite partie de l'étape b), la puissance de sortie dudit brûleur est une fonction continue de la température du four.
4. Procédé selon l'une quelconque des revendications 1 à 3, **caractérisé en ce que**, pendant ladite partie de l'étape b), la puissance de sortie dudit brûleur est réduite lorsque la température du four augmente.
5. Procédé selon l'une quelconque des revendications 1 à 4, **caractérisé en ce que**, pendant ladite partie de l'étape b), la température du four fluctue de moins de 10 %.
6. Procédé selon l'une quelconque des revendications 1 à 5, **caractérisé en ce que** ledit gaz contenant de l'oxygène contient plus de 21 % d'oxygène.
7. Procédé selon l'une quelconque des revendications 1 à 6, **caractérisé en ce que** ledit matériau de départ contient de l'aluminium, et **en ce que** la puissance de sortie dudit brûleur est commandée en fonction de la température du four à des températures supérieures à 850°C.
8. Procédé selon l'une quelconque des revendications 1 à 7, **caractérisé en ce que**, pendant l'étape a), la puissance de sortie dudit (desdits) brûleur(s) est d'au moins 220 kW par m² de surface de bain du four, de préférence d'au moins 260 kW par m² de surface de bain du four, et/ou la puissance de sortie pendant ladite partie de l'étape b) est comprise entre 260 kW par m² de surface de bain du four et 90 kW par m² de surface de bain du four.
9. Procédé selon l'une quelconque des revendications 1 à 8, **caractérisé en ce que** ledit matériau de départ contient de l'aluminium.
10. Procédé selon l'une quelconque des revendications 1 à 9, **caractérisé en ce que** ledit gaz contenant de l'oxygène contient plus de 80 % d'oxygène.

Fig. 1

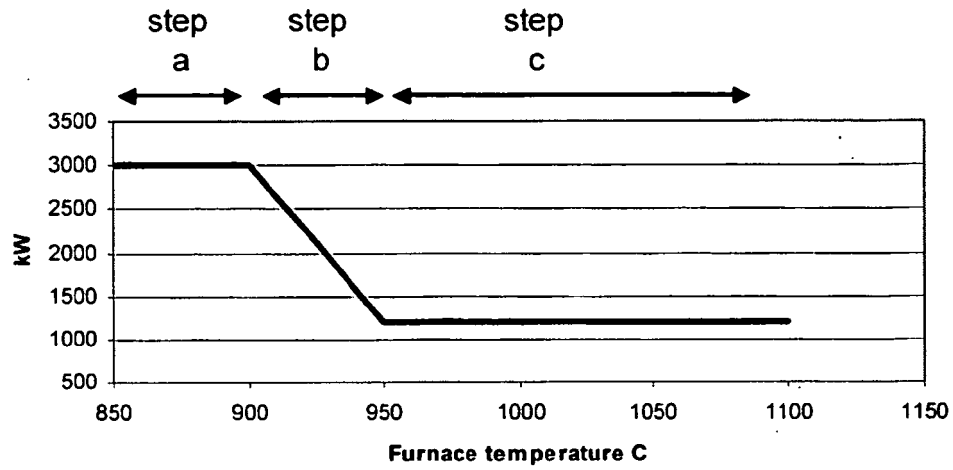
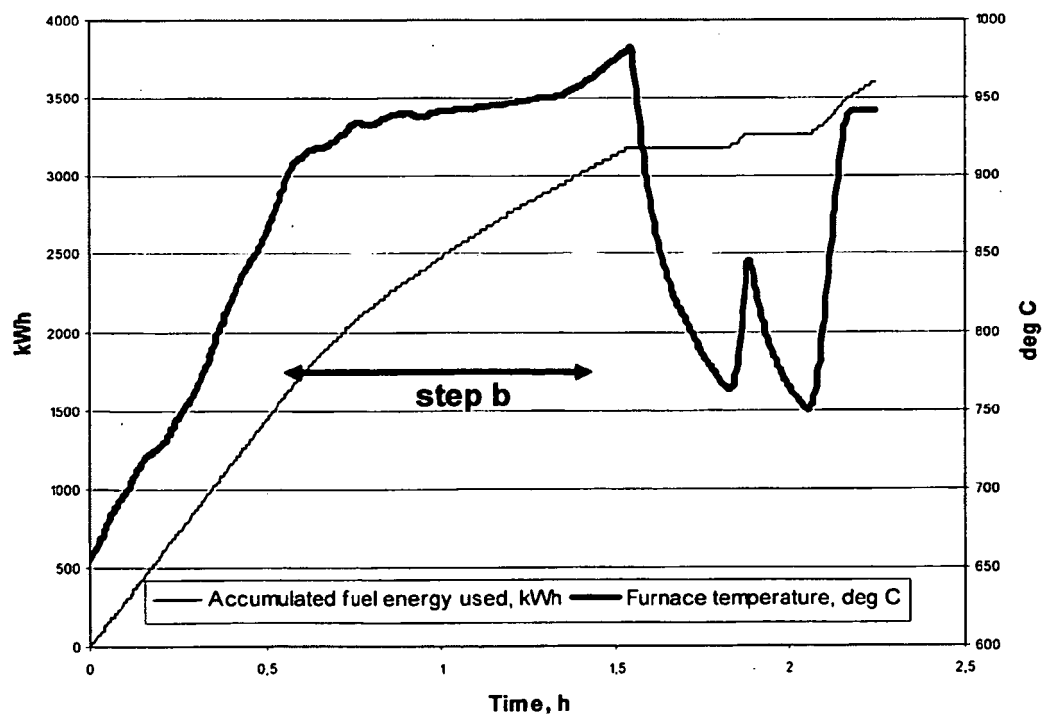


Fig. 2



REFERENCES CITED IN THE DESCRIPTION

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