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(54) **A composite prebaked carbon electrode intended to be used in electric arc furnaces.**

(57) A prebaked carbon electrode intended to be used in electric arc furnaces and, more particularly, in submerged arc furnaces such as the furnaces normally used for the production of silicon metal, phosphorus, ferro-alloys, and other metals, having a body and one or more joints to create an electrode column, the electrode having a composite construction comprising an outer portion or "rind" made from a first material and an inner portion or "core" made from a second material, wherein for example the first material is an an electrographite based material and the second material is an anthracite based material, the electrode being obtained by extrusion, vibration, molding or by any other suitable process known in the art. Quite generally, both the "rind" and the "core" can consist of any type of carbonaceous material.

"A composite prebaked carbon electrode intended to be used in electric arc furnaces."

This invention refers to prebaked carbon electrodes used in arc furnaces and, more particularly, in submerged arc furnaces for electrometallurgic processes.

As it is known in the art, in the electrometallurgical practice of submerged arc furnaces the elements supplying the current to the reaction area consist of electrode columns made from a carbon material.

These electrode columns consist of individual components, the electrodes, generally of a cylindrical shape, and connected to each other at their ends by suitable joints which ensure the mechanical and electrical continuity of the columns.

As far as the cylindrical electrodes are concerned, the type of electrode known in the art and traditionally used at present consists of either, a solid cylindrical body, or an axially bored body made from a carbon material of substantially uniform characteristics throughout the body.

During the furnace operation, the bottom of the electrode column is submerged to a certain extent into the charge of the furnace, while at a higher level the column carries current supplying metallic blocks called "contact clamps", provided with forced water cooling. Accordingly, the current-flows through the column lenght comprised between these "contact clamps" and the lower end of the column.

It is known that for the industrial practice of electric furnaces it is important both for technical and economical reasons that the electrodes are able to work at high current intensity and density.

It is also known that if the current exceeds a certain intensity for a given electrode, this electrode is subject to quick deterioration and breaking.

In the zone of the column which is comprised between the "contact clamps" and the lower end, the temperature within the electrode is not constant and significant temperature differences are not in the different areas due to the heat developed by the Joule effect within the electrodes through which the current flows and due to the transfer of this heat from the electrode to the outside.

These temperature differences cause thermo-mechanical stresses in the electrodes. These stresses are variously distributed in the electrode and act on the material also in the absence or external forces.

The magnitude and distribution of these thermo-mechanical stresses are mainly related to the following factors:

a) - current density in the electrode;

b) - electrical resistivity of the electrode;

c) - thermal conductivity of the electrode;

d) - thermal transfer coefficients between the outer surface of the electrodes and the surroundings;

e) - temperatures of the surroundings;

f) - coefficient of thermal expansion of the electrode;

g) - elastic modulus of the electrode.

Factors "a" - "e" determine the temperature values in the electrodes, while factors "f" and "g" determine the value of the internal stresses due to the temperature distribution.

Since, as described above, the stress values are related to the above mentioned parameters, it may happen that in particular operating conditions the highest values of these internal stresses axceed locally the mechanical strength of the material, thus causing the formation of cracks which prevent the electrode column from normally operating.

The presence of these cracks generally forces the furnace operators to either slow down the furnace operation, thus causing a production loss, or to adopt such measures as are deemed necessary, tiresome or not, so as to avoid the total breaking of the electrode.

In the event of a stubbing the furnace operators are forced, as is known, to stop the furnace operation, take out the broken portion of the electrode slipp the column by a new portion equivalent to the broken portion.

These operations cause a production loss and require additional work in difficult environmetal conditions and upon the restarting of the furnace create more dangerous conditions for the electrodes (thermal shock).

It is evident from the above that the efficiency level of the electrodes is very important, this efficiency level being the electrode capacity to supply high intensity current and withstand the chemical attacks and mechanical and thermo-mechanical stresses to which the electrode is subjected during its use in the electric furnace operation, both in steady and in transient conditions.

In any case, even if the electrode does not break, it is evident that the presence of internal stresses is a limiting factor for the use of the electrodes, and both the furnace operators and the electrode manufacturers have always tried to limit the maximum values of these stresses.

As far as the manufacturers were concerned, the numerous attempts carried out during the years were mainly related to the following criteria:

1) - Obtaining more favourable values of the electrodes' physical characteristics which have an influence on the values of the internal thermo-mechanical stresses (electrical resistivity, thermal conductivity, coefficient of thermal expansion and elastic modulus);

2) - Creating in the electrode body longitudinal slits of various sizes intended to release the internal stresses which would occur if the electrodes were not provided with these openings;

3) - Forming the electrode body with a co-axial hole intended to reduce the maximum values of the in-

ternal stresses.

In reference to point (1) it can be said that an improvement of the electrodes physical characteristics having an influence on the values of the internal stresses can be obtained by operating on the raw materials used and on the manufacturing technology. This improvement, however, cannot exceed certain limits of economical convenience, due to the cost thereof. However, good characteristics have already been obtained by using materials containing high percentages of electrographite and electrically calcined anthracite which, as known, have low electrical resistance, high thermal conductivity, low coefficient of thermal expansion and low elastic modulus.

The mechanical strength of the material can be equally improved by acting on the raw materials and the production technologies to reduce the risk of cracks, the internal stresses having the same values.

In reference to point (2) the following patents are known: U.S. Patents No. 1,058,057 to A. Hinchley referring to an electrode provided with a longitudinal slit and a hole and No. 2,527,295 to B.L. Bailey referring to an electrode having threaded ends and provided with one or more longitudinal slits ; Federal Germany Patent No. 2,554,606 to F. Schieber referring to an electrode provided with a helicoidal slit and U.S. Patent No. 2,603,669 to C.H. Chappel referring to an electrode provided with several longitudinal internal and external slits.

Furthermore, many patents are known which refer to slits made in the areas of the threaded joints and in the threaded nipples of graphite electrodes used in arc furnaces for steel production.

With reference to point (3) the following patents are known: U.S. Patent No. 1,058,057 to A. Hinchley mentioned above; Federal Germany Patent No. 2,113,465 to G.A. Sixel referring to an electrode having a hole and U.S. Patent No. 2,063,669 mentioned above.

Other patents are also known which refer to electrodes having holes, but these holes are intended to stabilize the arc on the electrode tip.

Federal Germany Patent No. 1,790,172 to Sigri Co. is also known which refers to a bored electrode having a tube made from a chemically resistant material fitted in the bore, in order to allow a gas to be fed in the tube and the bore to be protected against chemical attack and oxidation.

It is known, however, that in spite of the abovementioned inventions, the electrodes used at present for electrometallurgical purposes still comprise almost exclusively either conventional solid cylindrical bodies or cylindrical bodies having an axial bore of small size.

However, for production purposes in modern furnaces, the current density in the electrodes is always high and the electrode working conditions become ever more critical and closer to the safety limits. It is extremely important, therefore, to obtain electrodes which can be electrically charged to a higher extent than the electrodes used at present and generally have a higher resistance to the aforementioned thermo-mechanical stresses.

It is an object of this invention to provide electrodes with the above-mentioned characteristics.

In this invention the increased resistance of the electrodes to the cracks caused by internal mechanical stresses is obtained by using "composite" electrodes. These electrodes consist of two coaxial cylinders joined to each other (Fig. 1): an outer cylinder from a material A (hereinafter called the "rind") and an inner cylinder from a different material B (hereinafter called the "core").

As will become apparent from the following description the use of two different materials having suitable characteristics is intended to reduce the maximum values of the mechanical stresses which are the direct cause of the cracks. Furthermore, in the "composite" electrodes of this invention the use of two different materials is intended to reduce the maximum stresses at the outer surface since, as it is known, these maximum stresses generally occur in the electrodes at this outer surface.

In order to work out the above mentioned subject and better evaluate the advantages which can be obtained, the applicant has determined, through accurate measurements, the values of the electric and thermal conductivity, the mechanical properties and the coefficients of thermal expansion at the operating temperatures on electrodes obtained from different raw materials and using different manufacturing technologies and thermal baking cycles. Moreover, the applicant has carried out studies of the most typical transient thermal cycles which the electrodes are subject to during operation.

Using the above mentioned information a suitable mathematical model has allowed an evaluation to be carried out of the distribution of the mechanical stresses in each section of the electrode column, both in the electrode's normal working conditions, that is in steady thermal conditions, and in particular conditions such as the periodical slipping of the electrode, a power blackout or a restarting of the operation, that is in transient thermal conditions.

The distribution of the mechanical stresses has been calculated at various current densities and for different electrode diameters also in the area of the joints of the electrode columns.

The correct knowledge of how the stresses are developed and composed has allowed the applicant to design and manufacture electrodes according to a basic concept of the invention which will be described hereinafter.

The reduction of the stresses on the electrode surface is obtained by making the "rind" from a material having a higher electrical and thermal conductivity in respect to material "B" used for the internal "core"; material "B" of the internal "core" should also have a lower coefficient of thermal expansion and a lower modulus of elasticity as compared with material "A" of the "rind" at the operating temperatures used in practice.

Of course, the ratio between the "rind" and the "core" radius should be suitably chosen.

Comparing the "composite" electrode with two traditional electrodes, one made only from material "B" and the other made only from material "A", in the "composite" electrode the difference between the axis temperature and the periphery temperature has an intermediate value with respect to the temperatures obtained in the electrodes made from materials "A" and "B", and the maximum stress has a lower value.

In other words, the new composite electrode is different from a conventional electrode of the same size and subjected to the same operating conditions, because the maximum values of the mechanical stresses (expressed in N/mm^2) occurring therein are lower than the maximum values of the mechanical stresses occurring in a conventional electrode made from only one of the materials from which the composite electrode is made.

This fact is the basis upon which we note the following important practical points:

- In the same operating conditions the composite electrode is more reliable than a conventional electrode;
- If the reliability level is the same, the composite electrode is able to carry a current of higher intensity as compared to the conventional electrode;
- The composite electrode is able to better withstand the thermal stresses which occur in transiert conditions, such as in the case of stopping and restarting the furnace operation.

By way of an example, which however should not limit the field of the invention, we refer to the case of three different electrodes having a diameter of 1,200 mm. The first electrode is a "composite" electrode (rind "A" and core "B"), the second and third electrodes are conventional and made from materials "A" and "B", respectively. The three electrodes being supplied with a total current of 68,000 Amperes.

Material "A" is an electrographite based material and has the following main characteristics at room temperature:

- Electrical resistivity : 25$\Omega\mu$m;
- Thermal conductivity : 24W/mK;
- Coefficient of thermal expansion : 3.10^{-6}/K;
- Modulus of elasticity : 6×10^{3} N/mm^{2}.

Material "B" is an anthracite based material and has the following main characteristics at room temperature:

- Electrical resistivity : 35$\Omega\mu$m;
- Thermal conductivity : 12 W/mK;
- Coefficient of thermal expansion : 2.5 10^{-6}/K;
- Modulus of elasticity : 5×10^{3} N/mm^{2}.

The above mentioned characteristics of the materials vary in a known way according to the temperature variations.

The "composite" electrode consists of a "rind" made from material "A" having a tickness of 150 mm and a "core" made from material "B", having a radius of 450 mm.

In practice this composite electrode is manufactured by placing, on the shaping step, the green mixture of material "B" in the axial area of the cylinder and then filling completely the cylinder with the green mixture of material "A". The raw electrode cylinder is then subjected to a normal baking cycle.

The results of the following calculations are limited, for reasons of conciseness, to a single transversal section of an electrode installed in a submerged arc electric furnace, the furnace is of the open or semiclosed type such as a furnace for the production of silicon metal.

In these conditions, using a suitable mathematical/ physical model it is possible to evaluate the distribution of temperature and internal stresses in the three cases, in various conditions and for the section of the electrode column below the contact clamps (Fig. 2).

This section has been closed because, as is known by the technicians operating the electric furnaces, it is the area where the breakages generally occur.

The following table I shows the calculation results obtained for the temperature in the three above mentioned electrodes at the axis and the periphery thereof. These results refer to an electrode section which is placed between the lower edge of the contact clamps and the upper surface of the charge since this is the section where the highest thermal stresses generally occur in the electrodes and the brekages are more likely to take place.

TABLE I

	Temperature (°C) in steady-state conditions		
radius (mm)	electrode of mat. "A"	electrode of mat. "B"	"composite" el. of mats. "A"+"B"
0	942	1513	1080
600	676	743	705
Temperature difference between r=0 and r=600 mm (°C)	266	770	375

As is evident, the temperature difference between the axis and the periphery of the "composite" electrode has an intermediate value with respect to electrodes "A" and "B" but, however, it is quite close to the temperature difference of electrode "A".

The following table II shows the values resulting from the calculation of the highest axial tensile stresses occurring at the electrode periphery.

TABLE II

	Axial stress σ_z (N/mm^2) in steady-state conditions		
	electrode of mat. "A"	electrode of mat. "B"	"composite" el. of mats. "A" + "B"
Peripheral area (r = 600 mm) (tensile stress)	2.0	3.0	1.7

As is evident, the lowest value of the tensile stress at the electrode periphery is obtained in the "composite" electrode.

It is possible to show that the advantage of the "composite" electrodes with respect to conventional electrodes increases both with the increase of the electrode diameter and with the decrease of the modulus of elasticity of the core material. Furthermore, this advantage is present also in transient conditions (stopping and restarting of the furnace operation).

As another significant example we report hereunder a case where material "A" still has the same characteristics as in the former example, whereas material "B" has the following characteristics:

- Electrical resistivity : 45 $\Omega\mu m$
- Thermal conductivity : 11 W/mk

- Coefficient of thermal expansion : $2,5 \times 10^{-6}$/K
- Modulus of elasticity : $3,8 \times 10^{3}$ N/mm^2

The composite electrode is 1,200 mm in diameter, with a "rind" of material "A" 150 mm thick, and a "core" of material "B" with a radius of 450 mm. The total current is 68,000 Amperes. In this case the steady-state calculation gives the following characteristics:

TABLE III

radius (mm)	Temperature (°C) in steady-state conditions: electrode of mat. "A"	electrode of mat. "B"	"composite" el. of mats. "A" + "B"
0	942	1669	1079
600	676	779	717
Temperature difference between r=0 and r=600 mm	266	890	362
	Axial stress σ_z (N/mm^2) in steady-state conditions		
Max tensile stress	2,0	2,2	1,0
Radius at which max tensile stress occurs	600	600	0

As can be seen, in this case the advantage given by the "composite" electrode is really remarkable, since the maximum tensile stress is practically reduced to a half.

Taking into considerations, for the electrode of this example, the thermal transient-state conditions which occur during the column cooling following any furnace stop, the following results are obtained:

TABLE IV

	Temperature (°C) in cooling conditions		
radius (mm)	electrode of mat. "A"	electrode of mat. "B"	"composite" el. of mats. "A" + "B"
0	862	1595	1045
600	569	645	634
Temperature difference between r=0 and r=600 mm	293	950	411
Time (hours) (after furnace stop)	0,7	0,7	0,7
	Axial stress σ_z (N/mm^2) in cooling conditions		
Max tensile stress	2,8	2,4	1,7
Radius at which max tensile stress occurs	600	600	0
Time (hours) (after furnace stop)	0,7	0,7	0,7

As can be seen, also here the advantage given by the composite electrode is remarkable.

The above mentioned general description and examples refer to the electrode body in general, but this invention refers also to the joint, regardless of the type of joint used. The "composite" electrodes as per the invention can be used with particular advantage in the field of arc furnaces for the production of silicon metal. This, however, should not limit the field of the invention.

The drawing clearly shows an axial sectional view of a composite electrode according to the invention. The "composite" electrodes of the invention can be obtained by extrusion, vibration, molding or by any other suitable proces known in the art. The "rind" "A" and the "core" "B" can consist of any carbonaceous material, with no restriction.

CLAIMS

1.- A prebaked carbon electrode intended to be used in electric arc furnaces and, more particularly, in submerged arc furnaces such as the furnaces for the production of silicon metal, phosphorus, ferro-alloys and other metals, consisting of a body and one or several joints to create an electrode column, characterized in that said electrode has a "composite" construction since it consists of an outer portion or "rind" made from a first material (A) and an inner portion or "core" made from a second material (B) having mechanical and/or thermal and/or electric characteristics different from the characteristics of said first material (A).

2.- The electrode according to claim 1, characterized in that said two portions of the electrode made from different materials have a cylindrical shape and are coaxial to each other, said material (A) forming an electrode portion comprises between the outer radius R of the electrode and a radius r shorter than R and said second material (B) forming an electrode portion comprises between said radius r and the electrode axis.

3.- The electrode according to claim 2, characterized in that the ratio R/r can have any value >1.

4.- The electrode according to claims 1 and/or 2, characterized in that said two materials (A and B), which can consist of any carbonaceous material, are different from each other in the raw materials used and/or in the recipe, it being possible to use only one type of raw material.

5.- The electrode according to claims 1 and/or 2 and/or 3, characterized in that said two materials are different from each other in the technological cycle of production used for the manufacture thereof.

6.- The electrode according to any of the preceding claims, characterized in that also the joints connecting the adjacent electrodes to each other have a "composite" construction according to the preceding claims, regardless of the type of joint used.

7.- The electrode according to any of the preceding claims, wherein said first material (A) is an electrographite based material and said second material (B) is an anthracite based material.

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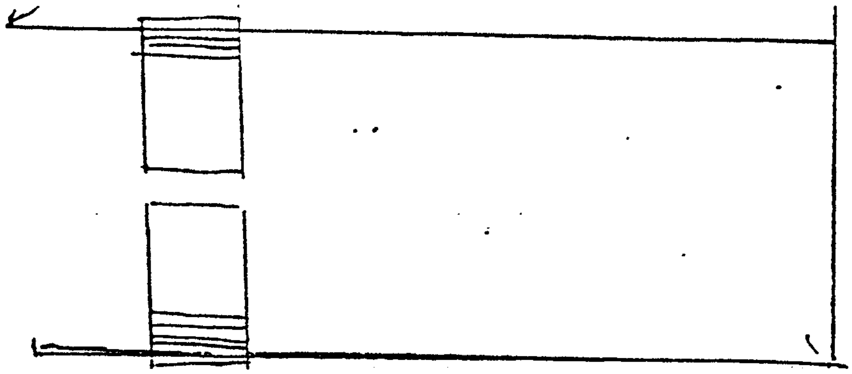

FIG. 2

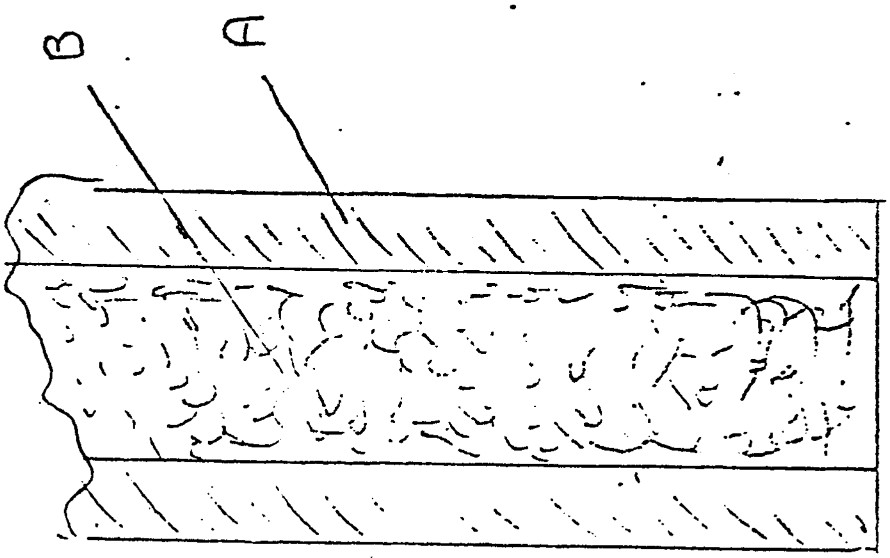

FIG 1