Essential Readings in Light Metals: Electrode Technology for Aluminum Production.
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LOW ELECTRICAL RESISTIVITY AND HIGH THERMAL CONDUCTIVITY

CARBON PRODUCTS : THE SOLUTION FOR CELL LINING

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Semi-graphite, very often used in some other industries, was tested 25 years ago as a cathodic material for the aluminum cell. To-day, since energy costs have increased, semi-graphite becomes again a good solution for the cell lining. In this text, we have described its production process and its characteristics are given according to the temperature. Compared to pure graphite, it has got better mechanical characteristics (the same as standard carbon), a lower thermal conductivity, roughly the same resistivity and a lower cost. Computer studies and trials show that the use of semi-graphite leads to a good cell productivity, a low energy consumption and a long potlife.

Introduction

Because of continually higher power costs, energy savings has become a matter of major concern for aluminum producers.

The average power consumption in an aluminum cell at the turn of the century was approximately 28.000 kWh/t. In 1970 it was approximately 15.500 kWh/t and to-day it's about 14.000 kWh/t. Some cells are already consuming less than 13.000 kWh/t. Significant progress has already been achieved. We can envisage that still further reductions can be made since theoretically the power consumption is as low as 6.340 kWh/t (Faraday efficiency equals to 1, neither overvoltage nor thermal losses).

One possibility to lower the specific power consumption of a cell is to reduce the ohmic drop. Carbon producers can participate in this type of power saving by developing low resistivity cathode products designed to help achieve a reduction in the cathodic ohmic drop.

In previous years, the primary purpose of using graphite as a cathode material in the aluminum electrolytic cells had been to extend the service life. An improved resistance of the cathode of the cell could be expected, considering the outstanding behavior of graphite in relation to sodium expansion. However this was not the case because the poor resistance of graphite to erosion resulted in an earlier erosion of the cathode surface.

At that point, both consumers and producers lost interest to develop graphite as an alternative cathode because energy was cheap in those days, and there was no economic reason to use a graphite block whose price was twice as high as that of standard carbon.

However, as the cost of power has risen dramatically in the last decade, the use of graphite blocks with a lower resistivity can and must be seriously considered as a means toward energy savings.

There are several ways to approach this question but in general they can be categorized in two classifications :

- Reduction in resistivity of the block by increasing the maximum temperature of thermal treatment. This category includes the so-called "semi-graphitized" grades of carbon which are baked to 2.400°C, as well as actual graphite which is baked to more than 2.700°C. The initial raw material in this category of material is mainly petroleum coke or coal tar pitch coke.

- In the second category the resistivity of the block can be lowered by using graphite grain as the raw material in lieu of calcined anthracite, and still use the conventional manufacturing techniques of standard carbon. We term these products "semi-graphite" rather than the "semi-graphitized" products we spoke about in the first category.

We want to emphasize that there are very important distinctions between the 2 processes and so now we want to explain why S.E.R.S., a company by the way which produces both graphite and carbon, has chosen to gear its technology in the direction of semi-graphite grade rather than the graphite or the semi-graphitized grades of carbon previously mentioned.

A - The manufacturing processes

1 - Manufacturing semi-graphite

Semi-graphite is manufactured much in the same way as amorphous carbon, except that the

- anthracite, which is used to make amorphous carbon blocks, is entirely replaced by artificial graphite.

Artificial graphite, which is the raw material used to manufacture semi-graphite blocks is the product of :

- either grains of petroleum coke or coal tar pitch coke which are directly graphitized in a furnace or

- a synthetic graphitized grain which consists of grains of petroleum coke or coal tar pitch coke bound by coal tar pitch coke ; this compound is subsequently graphitized.

By using synthetic graphite as a raw material, we have been able to achieve properties in the finished product that are far superior to those obtained with a product that utilizes graphitized petroleum coke grain as its raw material. Specifically, we're talking about resistance to erosion and compressive strength.

The standard technique for the manufacture of carbon and semi-graphite is illustrated in Figure 1.

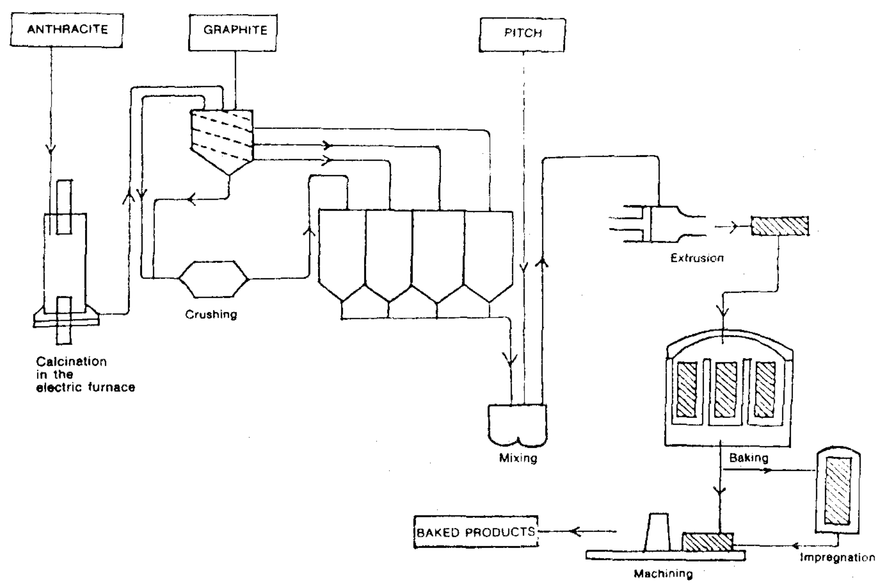

Fig. 1 - Production Flowsheet for Standard Carbon and Semi-graphite

After crushing and screening the raw materials are mixed in the hot state with coal tar pitch, and then the compound is extruded into conveniently shaped logs.

The green block is then baked at temperatures over 950°C which is above its normal service temperature. After baking, the block can then be machined to the specific dimensions required by the customer.

Impregnation

If necessary semi-graphite can also be impregnated, and in exactly the same way, as standard carbon. This operation consists of driving coal tar pitch into the semi-graphite porosity. After pyrolysis, coal tar pitch leaves a carbon residue which has the effect of reducing the porosity of the material. This operation is carried out after removing gases from the material.

By impregnating the semi-graphite, we can strengthen the mechanical properties, and improve the thermal and electrical properties.

2 - Manufacturing graphite

The manufacture of graphite differs from the production of amorphous carbon and semi-graphite in the following ways :

- First, we use a different raw material, namely, petroleum coke or coal tar pitch coke instead of calcined anthracite.

- Second, we have the additional step of graphitization. This operation is performed after baking, usually about 800°C, and even possibly an impregnation. Graphitization takes place in an electric furnace, at temperatures that range from 2.700 to 3.000°C.

3 - Manufacturing "semi-graphitized" grade

As mentioned previously, the "semi-graphitized" utilizes petroleum or pitch coke as a raw material. The manufacturing process is actually the same as that used to manufacture graphite, but its final treatment temperature ranges from 2.100 to 2.400°C, which is an intermediate level between that used for standard carbon (about 1.100°C) and graphite (2.700/3.000°C).

4 - Comparison of the various processes

To summarize, we illustrate in Table 1 the differences between the production of standard carbon, semi-graphite, graphite, and semi-graphitized materials :

Table 1

Product	Raw material	Baking temperature	Graphitization (°C)
Standard carbon	Calcined anthracite	> 950°C	-
Semi-graphite	Artificial graphite	> 950°C	-
Graphite	Petroleum coke or	800°C	2700/3000
Semi-graphitized	coal tar pitch coke	800°C	2100/2400

When we compare semi-graphite with the graphite or semi-graphitized grades, we can see some interesting features of the semi-graphite that result

- from the kind of raw material we use, namely a synthetic graphite grain, and
- from the nature of the binding agent between the grains which is only baked pitch coke.

If we consider the manufacturing process and the raw material used, we observe that semi-graphite has a relationship to standard carbon in terms of its mechanical properties, while on the other hand, it has the characteristics of graphite in terms of its electrical and thermal properties.

B - Properties of semi-graphite, graphite and standard carbon

1 - Thermal and electrical properties

The thermal and electrical properties of the various qualities we are speaking about should be considered in terms of the service temperature, since the behavior of graphite is quite different from that of carbon or semi-graphite.

1-1 - Electrical Resistivity

For example, whereas the electrical resistivity of graphite is not very much affected by temperature variations between ambient temperature and 1000°C, the resistivity of carbon and semi-graphite grades decreases significantly as the temperature rises.

Thus, at the service temperature in the aluminum cell, the resistivity of semi-graphite is quite similar to that of graphite, and although graphites with a lower resistivity can be produced, they are not economically suitable for applications as cathode blocks because of their high cost.

In Figure 2 we see the resistivity of carbonaceous products at various temperature levels before putting them into service in the cell. In order to make an evaluation on the expected improvement of the low resistivity grades, one must observe how the difference between standard block and low resistivity block changes through the service life of the cell.

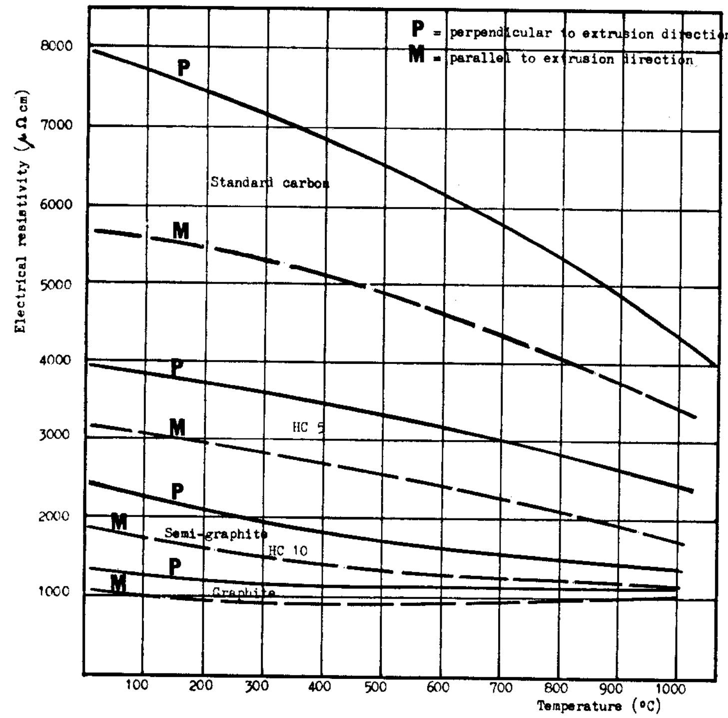

Fig. 2 - Electrical resistivity of carbon versus temperature

Evolution of resistivity all through cell service life

It's well known that standard carbon is actually graphitized during the course of cell service life, and this results in a significantly lower resistivity.

The degree of graphitization of carbon can be determined through an X-ray measurement of the mean distance between the (002) planes as illustrated in Figure 3. The distance from the position of pure graphite expresses the extent of actual graphitization.

That graphitization of carbon can also be evidenced through a microscope investigation.

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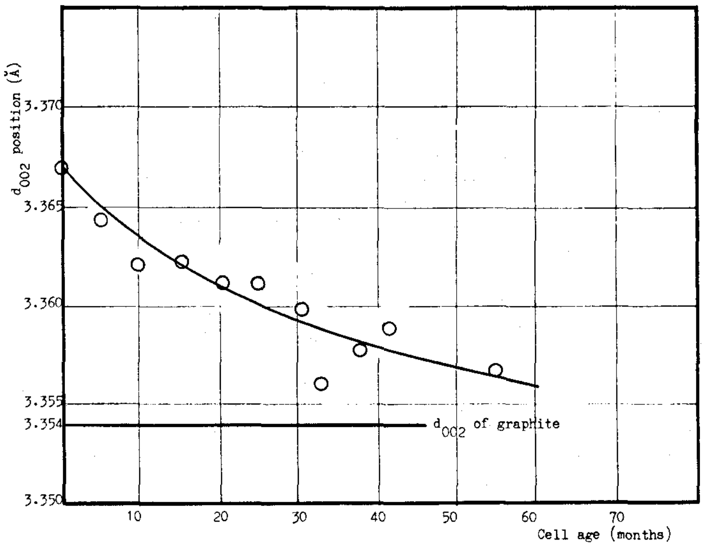

Fig. 3 - Interplanar distance d (002) versus cell age

Now, in Figure 4, we illustrate the cold resistivity of standard carbon versus cell age.

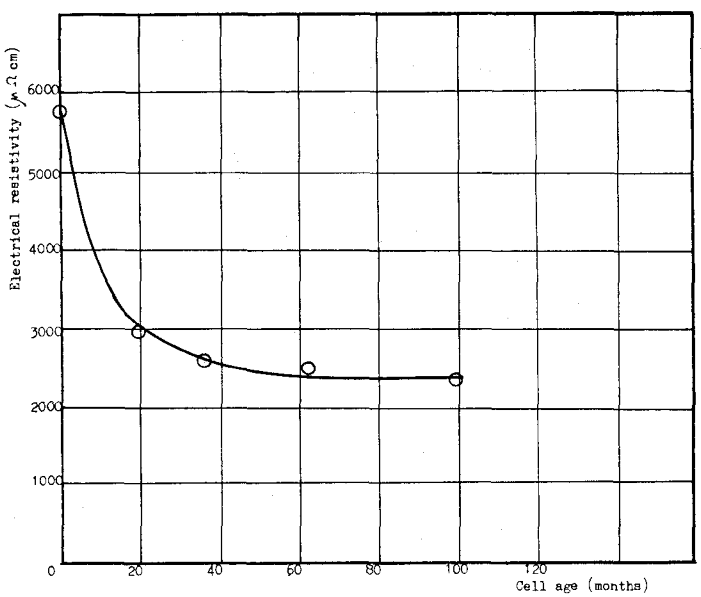

Fig. 4 - Resistivity of carbon versus cell age

The evolution of the cathodic drop is the addition of several factors, mainly :

- lowering of cathode resistivity, which is very fast during the first 20 months of the cell service life ; and

- enhanced contact resistances which occur due to infiltration of the bath and wearing of the cathode.

The combination of these factors generally induces a greater cathodic drop in the course of cell service life (1).

If the cell is lined with semi-graphite or graphite blocks, the evolution of cathodic drop merely depends upon the increase of contact resistances, since the bottom block is already graphitized.

The difference in cathodic drop between a cell lined with standard carbon blocks and a cell lined with semi-graphite blocks is rather important just after the start up. It quickly decreases during the first two years of cell service life, and then tends to remain unchanged thereafter. The level at which the drop stabilizes is related to the wear of electric contacts and to the condition of the cathode.

The residual gain can only be evaluated by industrial tests on each type of cell, but it is noteworthy that taking into account the improvements we observe by using semi-graphite in terms of :

- sodium expansion,
- thermal properties, and
- electrical properties,

the wearing of the cathode block and electrical contacts should be reduced. In particular, when the isotherm of fluoride crystallization passes inside the block, using a block with higher thermal conductivity makes it possible to repel that isotherm towards the outside of the block.

1-2 - Thermal conductivity

Whereas the thermal conductivity of a carbon increases as the temperature increases, conversely, it decreases in graphite and semi-graphite, as you can see in Figure 5.

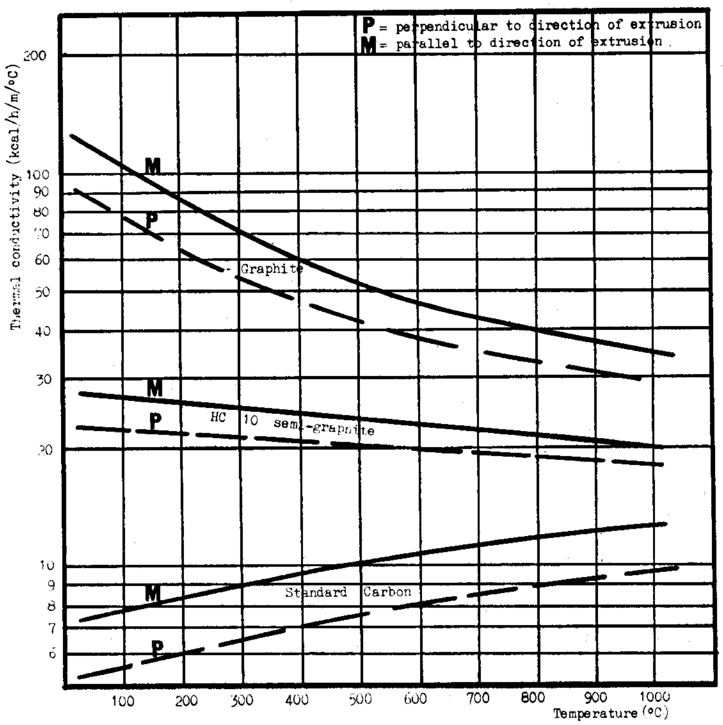

Fig. 5 - Thermal conductivity of carbon versus temperature

At 1000°C, the thermal conductivity of graphite is 35 kcal/h/m/°C whereas it is only 20 kcal/h/m/°C for semi-graphite and 12 kcal/h/m/°C for carbon.

Therefore, it should be noted that use of a cathodic block with a low thermal conductivity is profitable, since less heat is released by the cell; consequently the heat losses, particularly through the bars, can be more easily reduced.

2 - Mechanical properties

In table 2, appendix 1, we give a general view of the mechanical properties of the following carbons and graphites :

	S.E.R.S. Grade
. Standard carbon	CF 1
. Impregnated standard carbon	CICA 1
. Mixed : 50 % anthracite calcined in an electric furnace 50 % artificial graphite	HC 5
. Semi-graphite	HC 10
. Impregnated semi-graphite	HC 10 1
. Graphite	KO 6

When developing the semi-graphite grades, we endeavored to reach low electrical resistivities while at the same time maintaining the mechanical properties of standard carbon, particularly, crushing strength and resistance to erosion.

2-1 - Resistance to erosion : selection of the raw material

There are two types of erosion phenomena than can be observed in the aluminum cell, and they are chemical and mechanical.

Chemical erosion

The chemical erosion of the cathode is the result of the interaction between liquid aluminum and cathode carbon, expressed by the theoretical equation :

$$4\ Al_{(1)} + 3\ C_{(s)} = Al_4\ C_{3(s)}$$

Because there is a film of oxide on the surface of aluminum as well as a significant interfacial tension between alumina and carbon, chemical erosion would normally be very slow. As a matter of fact, the formation of aluminum carbide is promoted by the presence of cryolite melts (2) which results in a reduced aluminum/carbon interfacial tension (3). A reaction involving sodium and cryolite might also account for the formation of aluminum carbide (4) expressed in the equation :

$$4\ Na_3\ AlF_6 + 12\ Na + 3\ C = Al_4C_3 + 24\ NaF$$

A film of aluminum carbide appears at the aluminum/carbon interface. This film, which melts very slowly in aluminum, would normally stop the reaction. However, when the metal movements are intense, the cathodic surface is continuously washed and that protective film tends to disappear. The reaction then continues and erosion can destroy the cathode block.

The rate of formation of aluminum carbide as a function of the type of cathodic material used was studied (3), and it was found that the rate of erosion increases as the porosity of the material increases. In particular, graphite, whose overall porosity is greater than that of amorphous carbons, tends to react more easily. These results corroborate the industrial tests we mentioned before.

Thus, the resistance of semi-graphite (which has an overall porosity equal to 20 %) to chemical erosion should be rather similar to that of standard carbons which have an overall porosity ranging from 15 to 19 %. At the same time, semi-graphite should have a markedly better resistance to erosion than semi-graphitized or graphite grades which have an overall porosity of about 28 %.

The reason that semi-graphite is so low in porosity is because we use a synthetic grain whose pores are filled in by pitch during two successive mixings :

- the first when preparing the petroleum coke/coal tar pitch coke primary compound which is subsequently graphitized, and

- the second during the manufacturing of the semi-graphite via the conventional process of producing amorphous carbon.

The advantage of using these synthetic grains is evidenced by studying

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the pore spectra as illustrated in Table 3 :

Table 3

Material	Porosity* (%)
Graphitized synthetic	22
Graphitized petroleum coke	37
Graphitized coal tar pitch coke	36

(*) determined by means of the mercury porosisimeter

Thus, a product free of the disadvantages of graphite can be obtained by using a synthetic grain and applying the conventional process of producing amorphous carbon.

Mechanical erosion

When it is difficult to compensate for the magnetic fields, there is another type of erosion phenomenon that takes place. This is mechanical erosion which is caused by the movements of metal and which causes actual holes to be worn in the carbon (5) (4).

We have developed a testing method in our laboratory to determine the resistance of materials to mechanical erosion as we show in Table 4. We measure the abrasion-induced weight loss of a carbon sample rotating it with a planetary motion in a tank filled with abrasive particles.

Table 4 : Erosion resistance test

Sample : diameter	30 mm
length	110 mm
Length submitted to abrasion	55 mm
Abrasive material .... Electrofused corundum 5-10 mm and 2-5 mm	
Duration of test	30 minutes

Figure 6 shows that if we replace calcined anthracite with a synthetic graphite grain, there is no significant increase of weight loss due to mechanical erosion.

- Standard carbon .... 4.5 %
- Semi-graphite .... 6.0 %
- Graphite .... 12.0 %

Thus, in the aluminum cell, the behavior of semi-graphite relative to mechanical and chemical erosion stresses should be similar to that of standard carbon and markedly better than that of graphite.

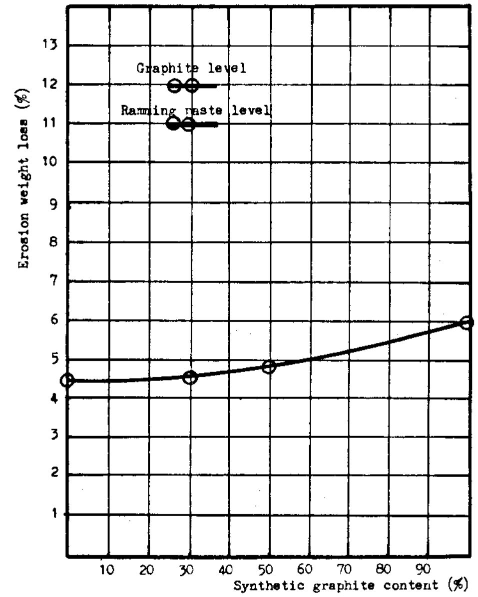

Fig. 6 - Erosion weight loss of carbon versus synthetic graphite content. Comparison with pure graphite and ramming paste.

2-2 - Mechanical properties

By using synthetic grain we can maintain the remarkable crushing strength of standard carbon. The level remains above 300 kg/cm2 whereas with graphite it drops to about 200 kg/cm2.

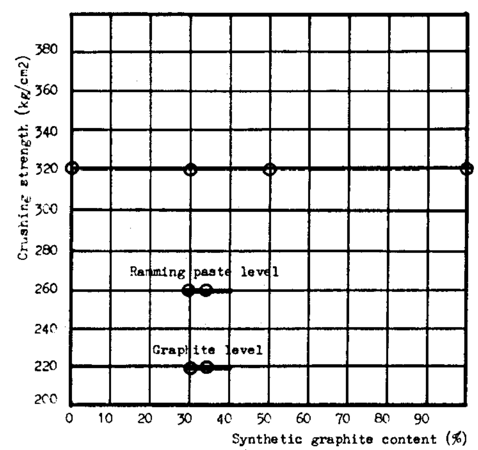

Fig. 7 - Crushing strength of carbon versus graphite content. Comparison with pure graphite and ramming paste.

Actually, in this family of products, it seems that there is a relationship between resistance to erosion and crushing strength.

In terms of bending and tensile strengths, the good properties of graphite are wellknown, but we can see in Figures 8 and 9 that semi-graphite reaches approximately the same level and is significantly better than standard carbon. On the other hand, the crushing strength and resistance to erosion of semi-graphite are significantly better than those of graphite and are roughly equivalent to standard carbon.

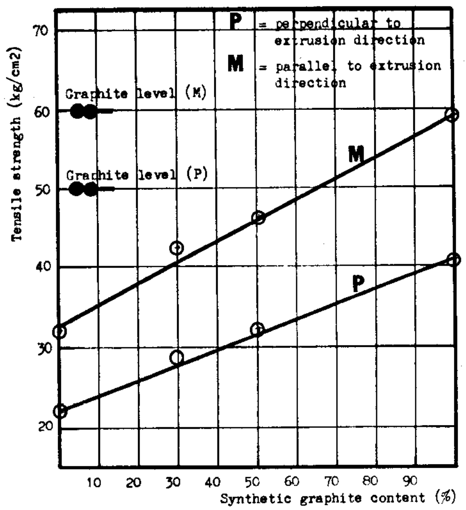

Fig. 8 - Tensile strength of carbon versus synthetic graphite content. Comparison with pure graphite.

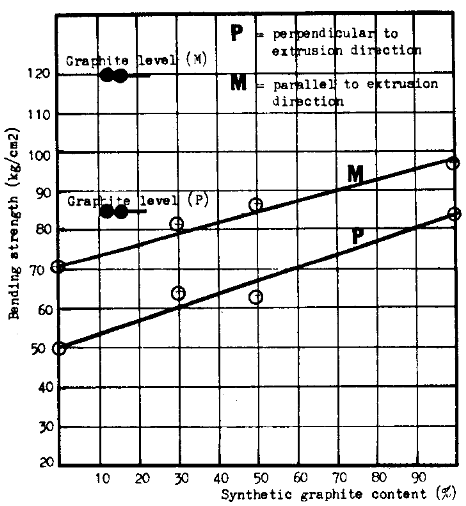

Fig. 9 - Bending strength of carbon versus synthetic graphite content. Comparison with pure graphite.

3 - Resistance to sodium

There are many studies (6) to (11) that discuss the phenomena induced by sodium penetration into carbon lattice.

The range of industrial carbons in decreasing order of resistance are :

- Graphite.
- Electrically calcined anthracite-base carbon.
- Gas-calcined anthracite-base carbon.
- Petroleum coke and coal tar pitch coke-base carbon.

We can determine in our laboratory the resistance of carbon to sodium expansion by the linear deformation of a sample immersed cathodically when performing electrolysis of alumina in a test cell. This is demonstrated in Table 5.

Table 5 : Sodium expantion test

Sample	
Diameter	40 mm
Length	150 mm
Dimensions of measuring holes	6 × 140 mm 6 × 80 mm
Measuring distance	60 mm
Immersed length	80 mm
Bath	
Artificial cryolite	
Alumina content	10.8 %
Molar NaF/AlF_3 ratio	2.5
Current density	0.30 A/cm2
Bath temperature	975°C
Electrolysis time	120 minutes
Atmosphere	Nitrogen

The expansion of semi-graphite at 0.35 % ranges between a good standard electrically-calcined anthracite-base carbon which is 0.65 % and a graphite which is less than 0.08 %.

This intermediate range can be easily explained, since semi-graphite is a blend of :

- pure graphite which is practically not affected by any expansion, and

- coal tar pitch coke originating from the binder, which causes such expansion.

Semi-graphite therefore has a good resistance to sodium effect.

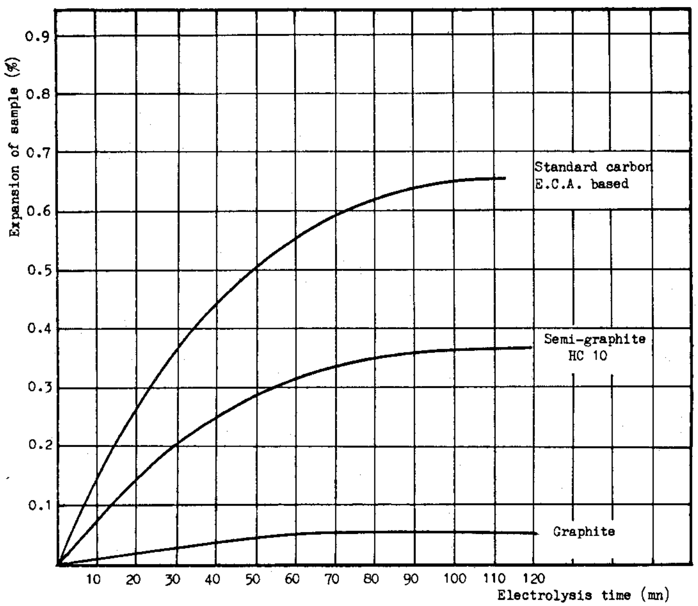

Fig. 10 - Expansion of sample versus electrolysis time

C - Semi-graphite and its relationship to savings of power

Our evaluation was conducted on a thermo-electrical model.

We replaced a standard carbon lining with blocks of higher thermal and electric conductivity which resulted in :

- a smaller Joule effect in the cell, and
- more heat losses.

These two modifications should be compensated by :

- either improving the heat insulation of the cell, in order to reduce the heat losses across the shell or
- by a higher intensity of the cell,
- or by increasing the interpolar distance.

Thus, the thermal parameters of the cell must be completely modified before replacing a standard carbon lining with a more conductive block.

Table 6 shows the typical results achieved in a 150 KA cell using the criteria developed in our thermo-electric model.

Table 6

		Heat losses (kW)					Cathodic drop (mV)		Difference in pot voltage (mV)
		Bottom 1	Bar 2	Side 3	Total 1+2+3	Difference (%)	Amount	Gain	
Basic case Standard carbon Case N°1		25.4	27	53.6	106	—	329	—	
No modification of pot	Semi-graphite Case N°2	25.8	27.9	55.2	108.9	+ 2.7	239	90	+16
	Graphite Case N°3	26.3	29	56.7	112	+ 5.7	236	93	+34
Increase in pot heat insulation	Semi-graphite Case N°4	20.1	25.2	48.8	94.1	−11.2	246	83	−72
	Graphite Case N°5	20.4	26.1	49.6	96.1	− 9.3	238	91	−60
Increase in amperage (2.9%)	Semi-graphite Case N°6	20.4	28.1	55.5	104	− 1.9	245	84	−96
	Graphite Case N°7	20.7	29.1	56.8	106.6	+ 0.6	239	90	−81

The replacement of a standard carbon lining by a graphite or semi-graphite lining has the following effect :

- Reduction of cathodic drop by about 90 mV. We observed that there is only a very minor difference in the gain achieved by using graphite instead of semi-graphite.

- Increase of heat losses through the shell and through the collector bar. This increase is higher for a material of higher thermal conductivity (the case for graphite).

As a first step, we endeavored to compensate for the increase of heat losses and the reduction of the Joule effect by only modifying the heat insulation of the cell. Even though the heat insulation was very much improved by replacing firebricks with insulating bricks (cases 4 and 5, Figures 11, 12, 13), we did not fully recover the difference and so the interpolar distance must be slightly extended. We decided not to increase the side heat insulation any more because we would not weaken the mechanical properties of the sides.

The second step consisted of increasing the cell intensity while modifying very slightly the heat insulation of the bottom (cases 6 and 7). With this arrangement, the specific power consumption was reduced while the cell productivity was improved through a 2.9 % higher intensity.

In so far as temperatures inside the cell are concerned, the isotherms move towards the bottom of the block when a graphite or semi-graphite block is used.

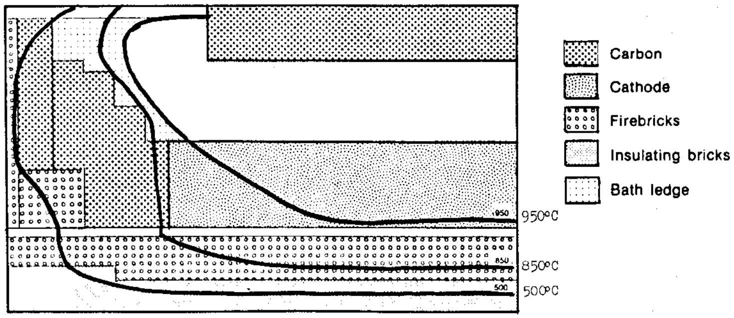

Fig. 11 - Thermal study : Standard Carbon

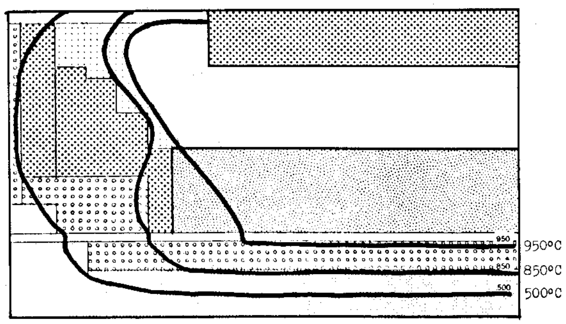

Fig. 12 - Thermal study : Semi-graphite

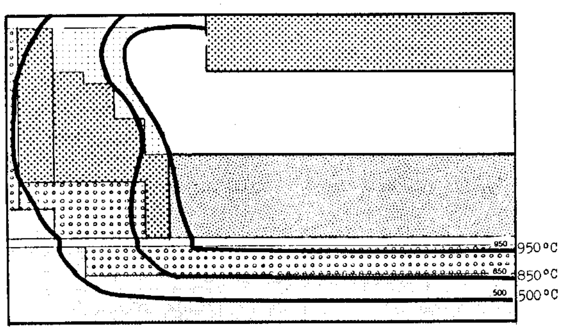

Fig. 13 - Thermal study : Graphite

Conclusion

Thus, the use of graphite or semi-graphite makes it possible to reduce the cathodic drop by about 90 mV in a new cell.

The greatest benefit is obtained with semi-graphite, whose thermal conductivity is lower than that of graphite.

In all cases, the replacement of standard carbon must be combined with a modification of the cell thermal parameters.

D - Industrial Experimentation

1 - Trials during the 1960's

Semi-graphite was first tested 25 years ago in 40 KA cells with pre-baked anodes.

When these cells were put into service, the difference in cathodic drops in the test cells and the reference cells was (see Fig. 14) about 200 mV.

This gain however decreased during the first year and stabilized at about 100 mV, and then it remained nearly constant all through the cell service life.

These results corroborate the evolution of block resistivity versus cell age as illustrated in Figure 14.

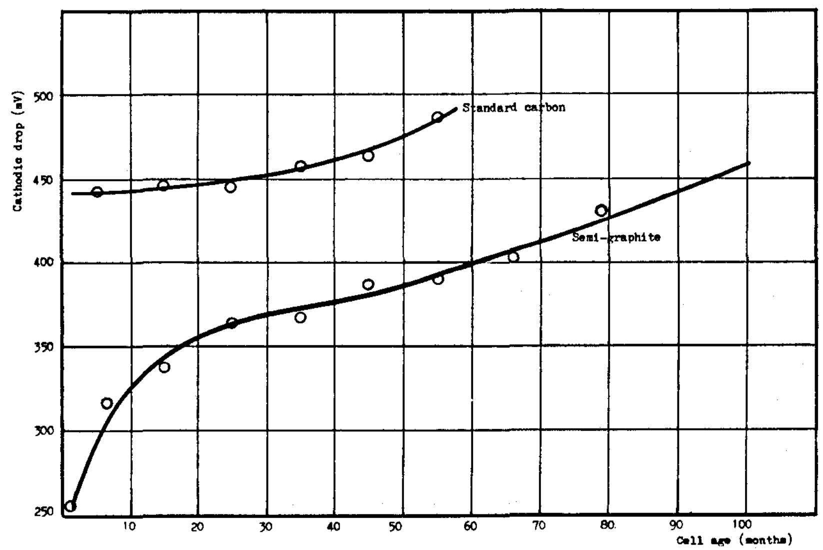

Fig. 14 - Cathodic drop versus cell age

During this test, we recorded a marked increase in the service life of the cell namely :
- 60 months in reference cells, versus
- 105 months in test cell.

In those time, power savings were not a crucial question and the tests were not carried on because they had little economic value.

2 - Current tests

However since 1978 aluminum producers around the world have a renewed interest in these products and now S.E.R.S. has equipped about 150 cells in operation using semi-graphite products. These tests are being performed in more than ten factories in cells with a variety of intensities as shown in Table 7.

Table 7 : Distribution of tests according to cell intensity

I < 100 KA	15 %
100 ≤ I < 130 KA	60 %
I ≥ 130 KA	25 %

The test cells are composed of :
- Söderberg or prebaked anodes,
- blocks glued together or with paste joint, and
- collector bars secured with either cast iron or ramming paste.

The thermal insulation of the cell was increased in some factories whereas a higher intensity was selected in other plants.

The importance attributed by aluminum producers to power savings is well evidenced by the number and variety of these tests.

As tests are now under way for over 3 years, it is well established that the use of semi-graphite as the alternative to standard carbon results in a marked reduction of the cathodic drop as shown in Table 8.

Table 8 : Reduction of cathodic drop
Semi-graphite versus amorphous carbon

New pot	80 mV - 120 mV
Pot in service for more than a year	50 mV - 100 mV

Obviously, the improvements of cathodic drop depend on the type of cell and its operation.

The indicated cathodic drop improvements only involve blocks in which the grade was the only modification. Further improvements can be obtained by increasing, for example, the cross section of the collector bar. For instance, increasing the cross section of the bar by 20 % makes it possible to reduce the cathodic drop by another 20 mV in a 150 KA cell, regardless of the grade of cathode block used.

The tests in progress since 1978 are too recent to draw final conclusions. However the 1960's trials have shown that cells using semi-graphite linings have a longer service life than cells equipped with standard carbon cathodes.

E - Conclusion

Due to its low resistivity and its good resistance to sodium effect, graphite might appear to be an excellent material to reduce the cathodic drop in the aluminum cells and to effectively make significant power savings.

But graphite is very soft and has poor resistance to chemical and mechanical erosion. In addition, it costs twice as much as standard carbon.

In summary, we have obtained a material with several interesting properties, namely
- a resistivity equivalent to that of graphite,
- a resistance to sodium effect close to that of graphite,
- a resistance to abrasion and a crushing strength almost equal to that of amorphous carbon, and finally, a
- lower price than graphite.

These targets were reached by using :
- a synthetic graphite grain as raw material, and by using
- the conventional process of manufacturing amorphous carbon blocks.

Studies performed with our thermo-electric model, and also the results of industrial tests conducted over the last 3 years on over 150 test cells have shown that the replacement of standard carbon by semi-graphite makes it possible to reduce the cathodic drop by 80 to 120 mV on a new cell.

Although this reduction decreases during the first year of cell service life, afterwards it remains constant between 60 mV and 100 mV. We can expect that the service life will at least be as long as that of amorphous carbon, and possibly longer, all this being accomplished at a cheaper cost than using graphite.

APPENDIX

Table 2

		CF 1	CICA 1 Impre-gnated	HC 5	HC 10	HC 10 Impre-gnated	Graphite
Real density		1.85	1.85	1.94	2.08	2.08	2.20
Bulk density (g/cm3)		1.57	1.65	1.61	1.66	1.78	1.59
Porosity (%)		15	10	16.9	20.2	15.4	27.7
Ash content (%)		6.5	5.5	3.7	1.3	1.3	0.08
Crushing strength	M	320	500	315	310	460	200
(kg/cm2)	P	305	450	305	300	420	205
Tensile strength	M	32	44	46	59	80	60
(kg/cm2)	P	22	27	32	41	60	50
Bending strength	M	70	90	86	97	110	120
(kg/cm2)	P	50	70	63	84	95	85
Thermal expansion 20°C/525°C	M	2.7	3	3.3	3.3	3.3	1.8
($\times 10^{-6}$.°C-1)	P	3.6	3.7	3.9	3.7	3.7	3.0
Young's Modulus	M	9.2	11	9.5	8.1	11.4	7.8
(kg/cm2) $\times 10^4$	P	4.8	12	6.4	5.9	9.6	5.5
Rapoport (Sodium effect) (‰)		6.5		5.6	3.6	3.9	
Weight loss by erosion (%)		4.5	2.5	5.2	6	3	11.3
Limited elongation (%)	M	0.4		0.6	0.7	0.9	1
	P	0.5		0.7	0.8	1	

M = direction of extrusion
P = perpendicular to direction of extrusion

CF 1 = Standard Carbon
CICA 1 = Impregnated Standard Carbon (rebaked at 1000°C)
HC 5 = 50 % ECA / 50 % Electrographite
HC 10 = Semi-graphite
HC 10 I = Impregnated Semi-graphite (rebaked at 1000°C)

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