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HOW TO IMPROVE THE PIG IRON SEALING OF METALLIC BARS IN CATHODE CARBON BLOCKS

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The investigation shows the decreasing of the contact voltage drop when preheating of cathode carbon block and metallic bar is carried out at suitable temperatures and under conditions which do not alter the original structure of the cathode carbon block. Wing cracks (WC) in the cathode carbon block can be reduced by modifying the slot geometry and decreasing the pouring temperature of the pig iron. Corner cracks (CC) are reduced if thermal gradients in the cathode carbon block during the preheating and the cooling processes are kept within a very narrow range.

Introduction

The sealing of metallic bars to cathode carbon blocks (henceforth called "bar" and "cathode", respectively) is generally carried out in the following ways:

1) by pouring pig iron between the bar and the slot,
2) by ramming a paste, which can consist mostly of carbonaceous material or metallic powder,
3) by casting a fluid carbon mass (1, 2).

The most widely used method is still the one consisting in pouring pig iron. This is generally carried out as follows:

- the cathodes are spaced out on the ground, with the slots upwards,
- the bars are introduced into the slots by laying them on metal spacers,
- the bars are gas-preheated at a rate of about 5 to 7°C/min., up to the desired temperature (normally 600÷700°C),
- pig iron is poured into the slots,
- the cathode system is allowed to cool naturally.

The described sealing procedure must be carried out most carefully to avoid permanent damage to the cathode system. In fact it can cause:

- carbon combustion, mainly in the slot area,
- corner crack (CC) or wing crack (WC) formation on the cathodes (see Fig. 1 and Fig. 2),
- poor electrical contact, and consequently high voltage drop (VD) between the bar and the cathode.

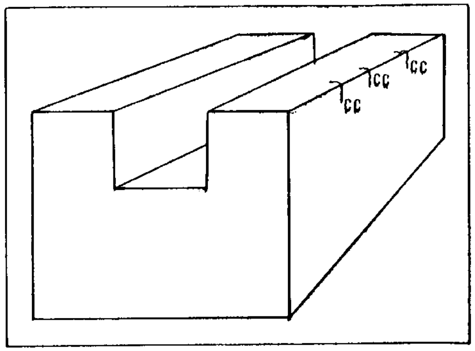


Figure 1 - Draft of corner crack (CC) formation.

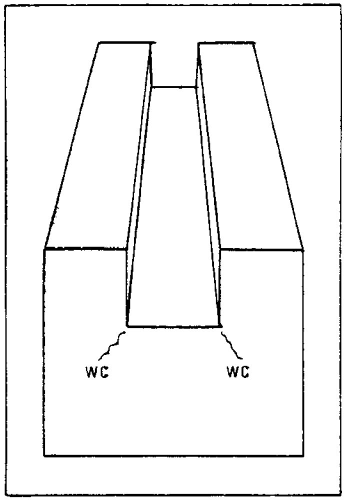


Figure 2 - Draft of wing crack (WC) formation.

1.- Effects of partial combustion of the cathode

A non-appropriate preheating of the bar can cause surface combustion of the cathode and, consequently, falling off of its physical characteristics and of the electric contact of the bar/pig iron/cathode system.

We have investigated the effect of an intentionally provoked surface combustion of the cathode on the VD of the cathode system and on the expansion behaviour during a lab electrolysis test, known as Rapoport test (3). Fig. 3 shows the arrangement we used in the laboratory to simulate the gas-preheating.

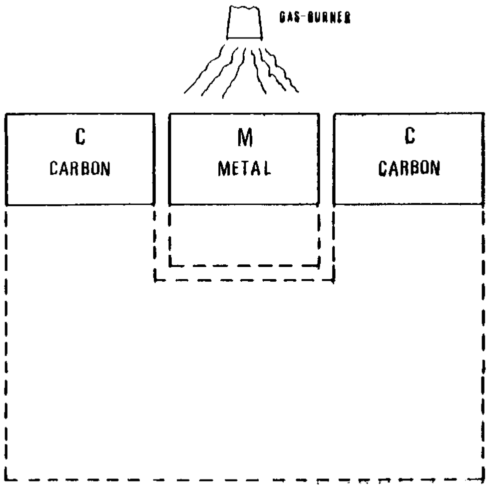


Figure 3 - Sample arrangement used in the laboratory to simulate a gas-preheating.

C = carbon sample (drawn from a cathode),
M - metallic sample (drawn from a bar).

We have investigated two different thermal situations, i.e.:

a) the metallic sample "M" reached a temperature of 700°C in 3 hours, while the carbon samples "C" did not exceed a temperature of 450°C,
b) the metallic sample "M" reached a temperature of 700°C in 3 hours, while the temperature of the carbon samples "C" was brought up to 650°C.

The carbon samples heated up to 650°C show evidence of oxidation, with ash deposits on the surface. No evidence of such deposits is shown on the carbon heated up to 450°C.

Before and after the preheating operation, the room temperature VD as a function of the contact pressure (CP) was measured. The results are shown in the diagram of Fig. 4. Curves 1 and 2 show that VD decreases when CP is increased, while it does not change with the oxidized carbon (curve 3), even triplicating the pressure. It is advidable, therefore, that the carbon temperature during preheating does not reach the values at which oxidation is shown.

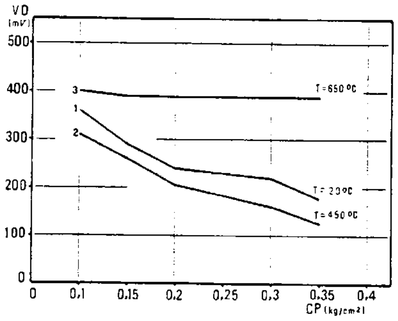


Figure 4 - Contact voltage drop as a function of pressure at different temperatures reached by the carbon samples during a gas preheating simulation.

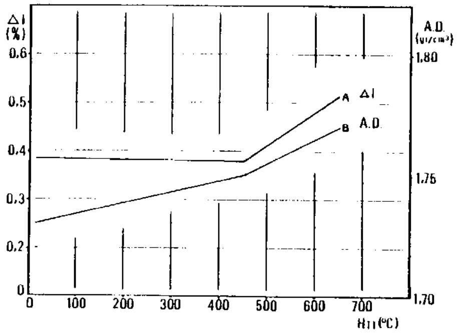


Figure 5 - A) Linear expansion of carbon samples, heat treated at different temperatures under a gas preheating simulation, during the Rapoport test;
B) Apparent density of carbon samples, heat treated as per A, after the Rapoport test.

The expansion measurements during the Rapoport test of the carbon samples "C", before and after preheating treatment, are shown in the diagram of Fig. 5, as well as the values of apparent density (AD) after electrolysis.

In comparison with the sample heated up to 450°C, the sample heated up to 650°C shows:

- larger per cent elongation (+40%),
- greater absorption of electrolytic salts.

Therefore, if temperatures higher than 450°C have to be reached in cathodes, it is indispensable to protect them from oxidation, particularly in the slot area. This can be achieved either by putting metallic screens into the slot, or using siliceous wool. Other expedients, such as the application of a layer of colloidal graphite on the slot surface, have shown that the consequent VD is higher than that of carbon materials protected by means which can be removed later.

2.- Effect of bar/cathode sealing conditions on bar/cathode voltage drop and wing crack formation

The contact VD is about 1/4 of the total cathode voltage loss (4). To reduce such a VD, it is advisable to:

a) avoid carbon oxidation during the sealing of the bar (see Section 1),
b) increase the CP between the bar and the cathode.

The VD changes between bar and cathode with the CP were measured. The results are shown in the diagram of Fig. 6.

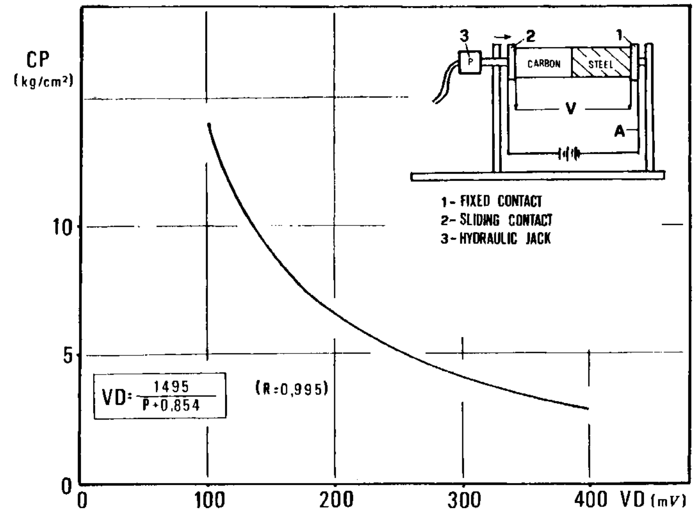


Figure 6 - Contact voltage drop vs. contact pressure for a carbon/steel system at room temperature.

The correlation can be expressed by equation (1):

$$VD = \frac{1495}{CP + 0{,}854} \qquad (R = 0{,}995) \qquad (1)$$

For VD values of about 90 mV an asymptote is shown; therefore when CP increases a substantial decrease in VD is no longer noticed. In practice, CP higher than 14 kg/cm^2 have no effect on VD decrease.

Of course when CP increases, the stress on the cathode wing increases too; such a stress could cause WC formation in the cathode. Therefore, strain measurements were carried out as a function of the cathode wing load up to breaking; the results are shown in the diagrams of Fig. 7.

In the electrolysis operating conditions, the CP bar/cathode is generated from the different thermal expansion of the two materials. The bar expands more than the cathode; the latter will deform in a nearly elastic way and therefore on the contact surface the desired CP will be obtained. The elastic strain of the cathode wing will be expressed by the equation (2):

$$\Delta l_{ES} = \Delta l_{TB} - \Delta l_{TC} - g \qquad (2)$$

where:

Δl_{ES} = elastic strain of the two cathode wings,
Δl_{TB} = transverse thermal expansion of the bar in steady state,

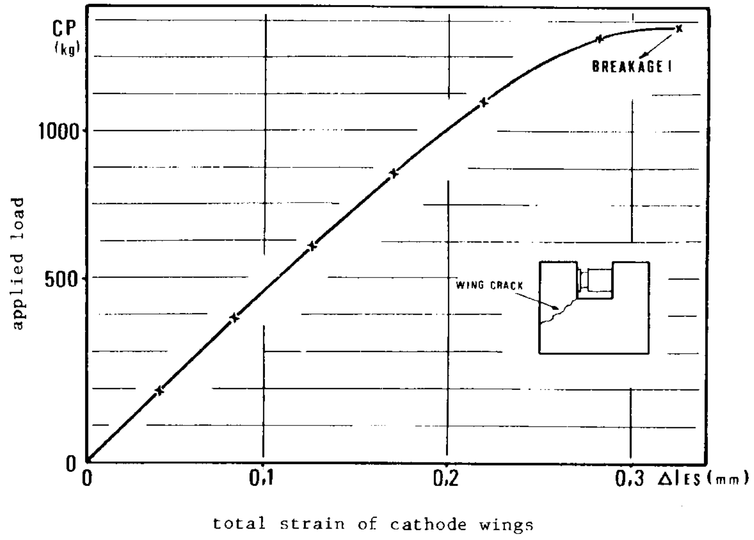


Figure 7 - Average cathode wing strain as a function of applied load.

Δl_{TC} = transverse thermal expansion of the cathode in steady state,
g - gap between the metallic system (bar/pig iron) and the cathode at room temperature: henceforth it will be simply called "gap". Such a gap is a function of:

- cathode material,
- bar quality and pig iron type,
- temperature of the bar when pig iron solidification begins,
- temperature of the cathode when pig iron solidification begins,
- geometry of the cathode and the bar.

In order to avoid WC formation it is necessary to verify that:

$$\Delta l_{ES} < \Delta l_{Breakage}$$

$\Delta l_{Breakage}$ is the breakage strain of the two cathode wings; for the geometry and the material considered, $\Delta l_{Breakage}$ is equal to 0,33 mm (Fig. 7).

Fig. 8 shows the curves of Fig. 6 and Fig. 7 on the same graph. So, it will be easier to determine which VD is obtained at a certain Δl_{ES} and vice versa.

What has been said so far and equation (2) lead to the assumption that, once the cathode material and geometry as well as the bar have been decided on, both Δl_{ES} and VD bar/cathode depend on the gap existing before the starting-up of the cell.

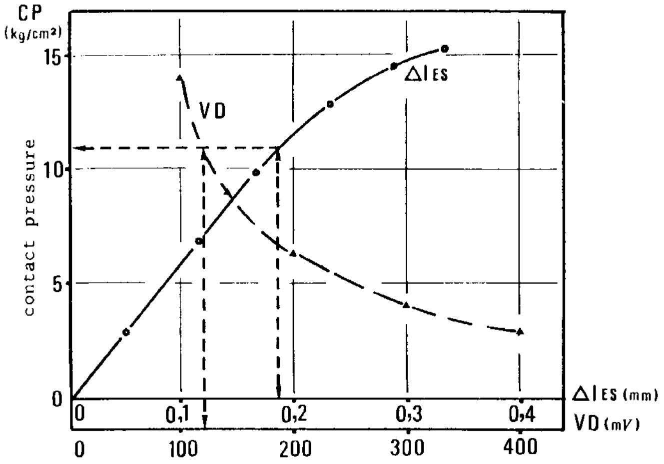


Figure 8 - Carbon/steel contact voltage drop and cathode wing strain as a function of contact pressure between bar and cathode (in case of square slot). Δl_{ES} = strain of the two wings; VD = voltage drop carbon/steel

Theoretically, the gap (g) can be calculated by equation (3):

$$g = L_o \left\{1 - \left[1 - \alpha_B (T_{BC} - T_a)\right] \times \left[1 + \alpha_C (T_{CC} - T_a)\right]\right\} \qquad (3)$$

where:

L_o = distance between the two cathode wings,
α_B = coefficient of thermal expansion of the bar/pig iron system,
α_C = coefficient of thermal expansion of the cathode,
T_a = room temperature,
T_{BC} = bar temperature when pig iron solidification begins (such a temperature has been considered as uniform for the whole bar),
T_{CC} = cathode temperature when pig iron solidification begins (such a temperature has been considered as uniform for the whole cathode).

In equation (3), pig iron shrinkage due to solidification has not been taken into account.

Assuming the cathode to be a non-constrained system, Δl_{ES} can be calculated knowing the thermal conditions when pig iron solidifies, as well as the cell steady state:

$$\Delta l_{ES} = L_o \left\{\left[1 + \alpha_B (T_{SS} - T_a)\right] \times \left[1 - \alpha_B (T_{BC} - T_a)\right] \times \left[1 + \alpha_C (T_{CC} - T_a)\right] - \left[1 + \alpha_C (T_{SS} - T_a)\right]\right\} < \Delta l_{Breakage} \qquad (4)$$

where:

T_{SS} = temperature at bar level when the electrolytic cell is in a steady state.

Calculations were made, assuming T_{SS} = 850°C, for several thermal conditions during pig iron solidification. The results are shown in Fig. 9.

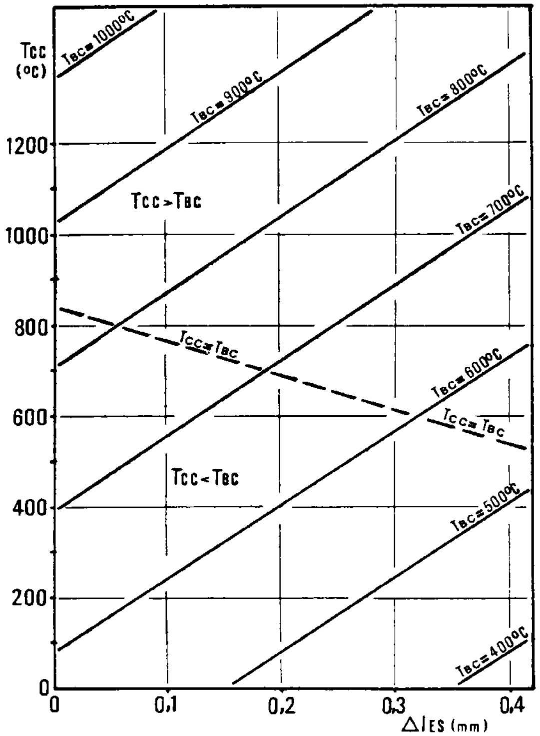


Figure 9 - Cathode wing strain as a function of possible different temperatures reached by bar (T_{BC}) and cathode (T_{CC}) when the poured pig iron solidifies. The wing strain is referred to std. operating conditions of the cathode (i.e., at 850°C).

Knowing the thermal conditions during the pouring of pig iron, therefore, Fig. 8 and Fig. 9 will allow us to determine, respectively, the corresponding Δl_{ES} and the VD at steady state. On the contrary, to obtain a certain VD, Fig. 8 and Fig. 9 will allow us to determine, respectively, Δl_{ES} and the required thermal conditions when pig iron solidifies. Such thermal conditions can be verified by measuring the gap at room temperature and calculating Δl_{ES} by equation (5):

$$\Delta l_{ES} = 1{,}08 - 0{,}9933\ g \qquad (5)$$

which is valid for T_{SS} = 850°C and for fixed physical and geometrical characteristics of bar and carbon. Sinthetically, on the basis of the measurements and calculations carried out it is possible to:

a) prevent WC due to thermomechanical causes,
b) optimize the thermal conditions during the pouring of pig iron in order to get lower VD bar/cathode,
c) verify that thermal conditions during the pouring of pig iron have been the desired ones.

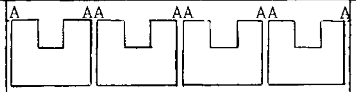
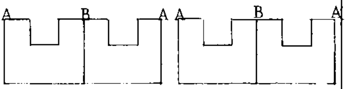
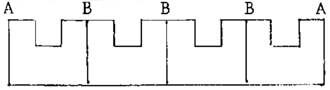
3.- Suggestions to reduce corner crack (CC) and wing crack (WC) formation during the pouring of pig iron

3.1.- Corner cracks (CC)

During the pouring of pig iron, small transversal cracks on the outer corners of the cathode can occur (Fig. 1), which sometimes can hardly be noticed after cooling. Such cracks depend on thermal shock. In order to prevent them, Dumas and Vallon (5) suggest that a counterpressure should be applied to the heads of the cathodes during the pouring of pig iron. According to our experience, such cracks can be reduced by placing the cathodes so as to reduce the thermal stresses during the pouring of pig iron and the cooling of the whole system.

The results of some tests we carried out corroborate what we have said above. The scheme of Table I shows CC percentages obtained with cathodes placed in different ways during the pouring of pig iron.

Table I.

Position	Position of the cathodes during the pouring of pig iron	Percentage and position of CC
1 (cathodes spaced out)		20% of cathodes show CC
2 (cathodes placed two by two)		40% of cathodes show CC 90% of CC are on the corners AA
3 (cathodes in touch with each other)		5% of cathodes show CC 90% of CC are on the corners AA

The temperature of corners A of the cathodes in positions 2 and 3 during the pouring of pig iron is generally lower than that of corners B. However, cracks on corners A appeared when their temperature was higher than that of corners B, too. Position 3 appears to be the most suitable one in order to reduce CC formation, probably for the following reasons: - higher and more uniform temperatures of the corners of the cathodes, due to lower loss of heat during preheating; - lower cooling rate of the inner corners.

3.2.- Wing cracks (WC)

The so-called WC occur at the bottom of the slot and extend towards the lower corners of the cathodes, as previously shown in Fig. 2. WC are generally attributed to mechanical stresses which take place during metal bar expansion. WC can occur at two moments:

a) during the pouring of pig iron and the following cooling of the whole system (in this case WC can be seen with the naked eye),
b) during the starting-up of the cell in the preheating stage (in this case WC can not be seen since the cathode is already inside the cell).

WC formation during the pouring of pig iron can be prevented by carefully verifying the following parameters:

- radius of curvature of the slot bottom of the cathodes,
- preheating temperature of the bar,
- position of the cathodes during preheating and pig iron pouring,
- amount of pig iron poured,
- temperature of pig iron poured.

3.2.1.- Radius of curvature (r) of the slot bottom. Lab tests were carried out to determine the influence of the slot design and the radius of curvature (r) value on the slot bottom, in order to prevent WC formation. Samples with slot designs A and B having r = 10 and 20 mm respectively were made (Fig. 10).

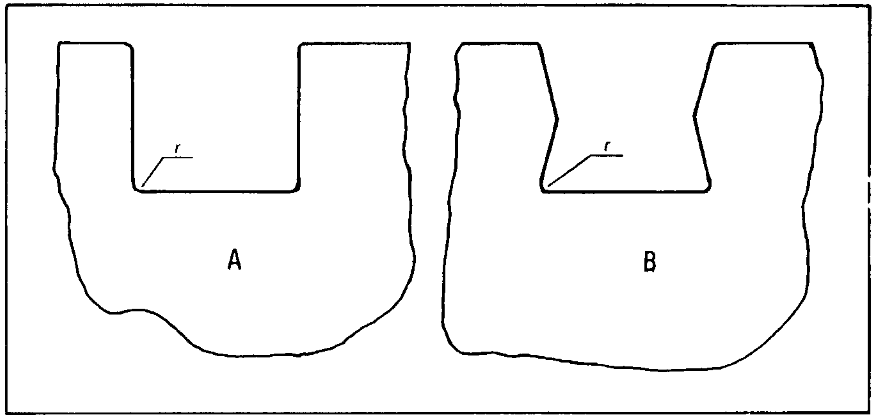


Figure 10 - Example of different slot geometries and radius of curvature.

A flexural stress was applied to the sample slot by means of an hydraulic jack. It was evident that:

- the slot design does not affect its flexural strength, since the samples with slot designs A and B broke at the same flexural stress,
- the samples having r = 20 mm show a flexural strength which is 15% higher than that of the samples having r = 10 mm.

During these lab tests, the strain curve of the cathode wing as well as the breakage angle of the samples having slot design B and r = 20 mm were recorded. They are shown in the diagram of Fig. 7 where, moreover, the area to which the breakage stress was applied is shown.

In conclusion, r = 20 mm should be used to reduce WC formation. At present, greater r values are not used, since it would be difficult to place the bar, which generally has a square section, into a roundish slot.

3.2.2.- Preheating, position of cathodes and amount of pig iron. Tests were carried out with cathodes 400 x 500 mm in cross section, having slot A 160 x 170 mm in cross section and r = 20 mm, and a bar of 140 x 140 mm. The test showed that WC percentage depends on:
- preheating temperature of the bar,
- position of the cathodes during the pouring of pig iron,

as shown in Table II.

Table II.

Preheating temperature of the bar (°C)	350-450	450-550	550-650	650-750
WC in cathodes placed as per Pos. 2 of Table I (%)	50	12	20	18
WC in cathodes placed as per Pos. 3 of Table I (%)	20	0	0	20

As shown in Section 2, the selection of the correct bar and cathode preheating temperature is also important in order to reduce WC formation. The amount of pig iron poured is very important too, as can be seen from Table III.

Table III.

Pig iron section	50 cm^2	75 cm^2	100 cm^2	temperature of pig iron poured (°C)
WC percentage in the cathodes %	0	30	78	1300
	-	-	58	1250

In conclusion, WC formation can be reduced by using:
- r = about 20 mm,
- preheating temperature of the bar around 550°C,
- cathodes placed, during preheating and pig iron pouring, in touch with each other,
- small amount of pig iron poured.

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4) W. E. Haupin, "Cathode Voltage Loss in Aluminium Smelting Cells", paper presented at the 104th AIME Annual Meeting, New York, N.Y., 1975.

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