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EXPERIMENTAL COMPARISON OF CATHODE RODDING PRACTICES

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Abstract

Interference calculations using thermal expansion coefficients over the temperature range of interest for collector bar, cast iron and different types of bottom blocks, indicate that poor preheating prior to rodding may seriously damage blocks during cathode preheat and startup. In spite of this there are still plants using no or poor block preheating and rodding practices, *e.g.* section-wise casting of the bar where heat from each cast section slowly dissipates and "preheats" the neighboring section. Experimental verification of interference calculations for different bottom block rodding situations, included mechanical testing after simulated pot preheating and startup, is described and discussed.

Introduction

Sealing of collector bars to cathode bottom blocks is normally done by one out of three methods: carbonaceous glue, ramming paste, or cast iron (Figure 1). Ramming paste rodding is the fastest and least expensive method to seal the bars to blocks but the resulting cathodic voltage drop (CVD) is usually higher over the entire life of the pot than with the other rodding methods. Of the remaining methods CVD measurements tend to show comparable values for young pots but with cast iron rodding giving slightly lower numbers as pots age. While sealing bars with paste and glue can be performed at ambient temperature, cast iron rodding necessitates temperatures >1400ºC of molten iron and normally a preheat station for bars and blocks.

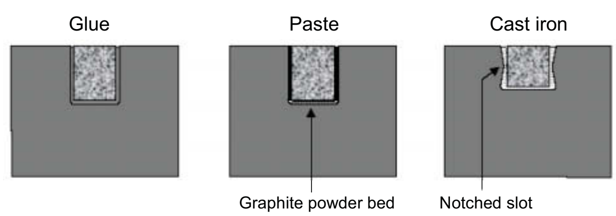

Figure 1. A schematic view of the most common cathode rodding methods.

No matter which rodding method is used it needs to take into account the geometric cross section of slot and bar together with the thermal dilation of block, bar and rodding materials from room temperature to cell operating temperature[1-5]. The thermal dilation interference between block, bar and rodding materials decides the quality of the seal and hence the block-to-bar contact resistance. Wrongly designed this interference may lead to poor contact or breakage of block wings, while an optimum fit should result in a contact pressure sufficient to give a low contact resistance/CVD without cracking the wings of the block. The coefficient of thermal expansion (CTE) for steel is about 4 times higher than for a typical cathode bottom block in the temperature range from ambient to 700ºC ($15.3 \cdot 10^{-6}$ m/mºC for steel/$14.0 \cdot 10^{-6}$ m/mºC for cast iron vs. $3.6 \cdot 10^{-6}$ m/mºC for a typically 70% electrocalcined anthracite (ECA) – 30% graphite (G) block). This implies that when the bar and block assembly is installed in the pot and the pot is preheated, the bar inside the slot expands more than the block/slot surrounding it. A 150 mm wide bar with about 20 mm cast iron in a 170 mm slot will thus expand > 1 mm more than the slot between 25ºC and 700ºC.

In the case of glue and paste rodding the bar is surrounded by a comparatively soft or flexible material during the first few hundred degrees of pot preheating. Since paste or glue also has lower crushing strength than bar and block in their baked stage, the difference in expansion is hence of less consequence.

If the available space between bar and block is completely filled with cast iron there is no flexible material between the bar and the block. As the temperature increases during pot preheating and start/early operation, the expansion of the bar and cast iron may crack the cathode block. These cracks will generally not be discovered before the pot is demolished. In order to avoid the cracking problem the bar is preheated (*i.e.* pre-expanded) before the cast iron is poured into the slot. If the bar and slot dimensions and the preheating temperature are correctly balanced, the bar and solidified cast iron will not completely fill the slot after cooled to ambient temperatures. Hence, a notched slot is normally used (Figure 1) to prevent the bar from falling out of the slot when the block is inverted prior to installation.

In spite of this risk for block failure there are still plants that rod cathode blocks without any preheating of the bar.

Experimental

Materials data

In order to calculate collector bar-bottom block interference thermal dilation measurements were performed on steel samples from a collector bar, cast iron and cathode block. Some materials data are given in Table 1.

Table 1. Some materials data for cathode block, bar and cast iron.

Material	Type/analysis
Cathode block	70% ECA - 30%G, vibrated
Collector bar	C = 0.17%, Si = 0.31%, Mn = 0.64% P = 0.020%, S = 0.002%
Cast iron	C = 2.93%, Si = 2.05%, Mn = 0.79% P = 1.67%, S = 0.025%, CE = 4.17%

Thermal dilation curves for each material were measured from ambient to pot operation temperatures at a temperature rate increase of 3ºC/min. The dilation curves are shown in Figure 2.

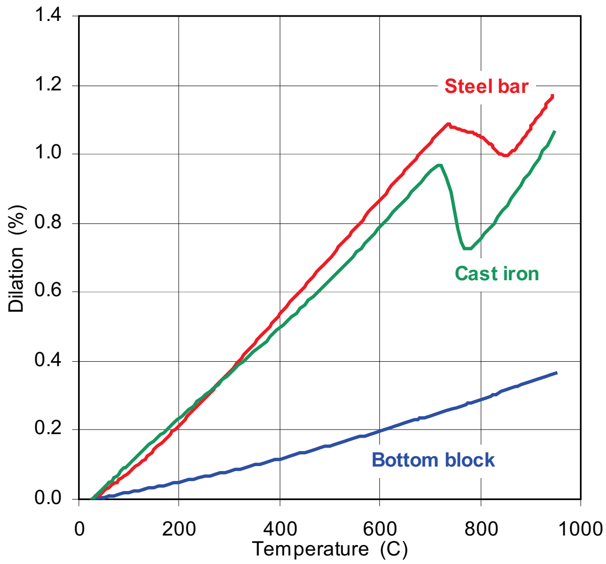

Figure 2. Thermal dilation curves of collector bar steel, cast iron and bottom block.

Rodding procedure

Cathode rodding without bar preheating is typically done section-wise. Along the cathode bar the open part of the slot is divided into several separate sections/compartments. In the sketch in Figure 3 this volume is divided into 6 sections.

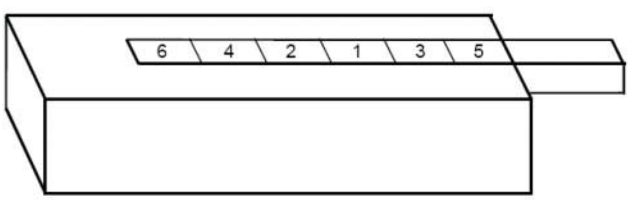

Figure 3. Sketch of typical bar-block assembly for cast iron rodding without preheating.

The cathode bar and block is at ambient temperature when section 1 is filled with cast iron. The hot iron is heating the bar at section 1 and the heat slowly dissipates into neighboring sections 2 and 3. The principle is thus that pouring section 1 will preheat sections 2 and 3, pouring section 2 will preheat section 4, and so on.

In the cathode rodding area a large number of bar-block assemblies are laid out on the floor. One or two pair of operators then performs the rodding using either hand-held or crane-suspended crucibles (Figure 4).

Measurements during rodding

The temperature in the middle of each iron pouring section along the top of the bar was measured on several bar-block assemblies during the pouring process. The temperature distribution along the bar during the rodding process for one of the assemblies is shown in Figure 5.

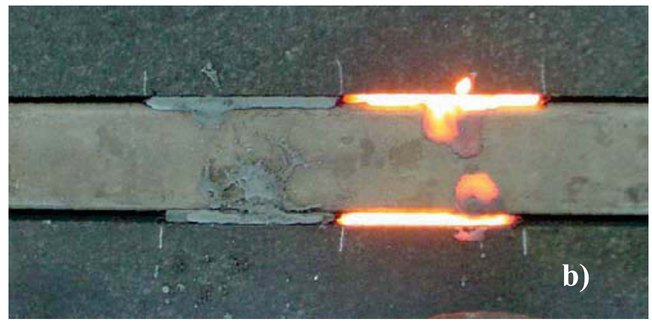

Figure 4. Examples of section-wise pouring of cast iron. a) Section 1 being poured; b) Section 2 just poured.

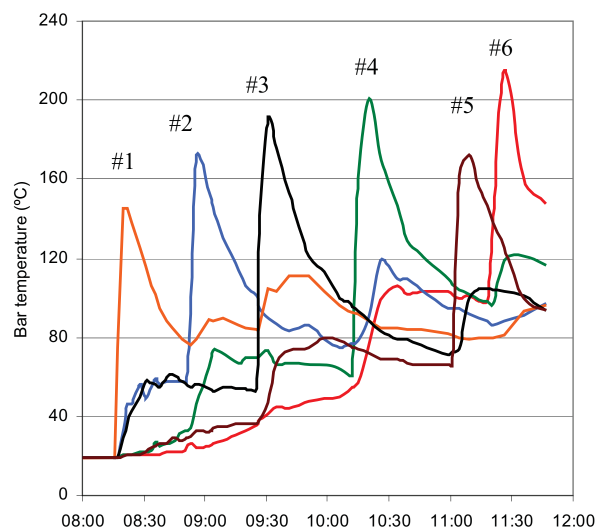

Figure 5. Time-line (hours) of temperature distribution along the bar during section-wise pouring.

To gain the maximum “preheating” effect the pouring of the next section should be done when the preheating effect from the previous one is at its maximum. E.G. the pouring of section 4 should be done when the preheating effect from pouring section 2 is at its maximum. Table 2 shows the optimal time window for pouring and the actual time that passed in preheating before the next section was poured. However, the efficiency of this type of preheating is marginal, at best, and section 1 is always poured without any preheating whatsoever.

From the bar temperatures measurements seen in Figure 5 it also appears that the bar-to-carbon stress introduced during the rodding procedure is not likely to initiate cracks at this stage.

Table 2. Actual time vs. optimal time for pouring the sections.

Section (#)	Optimal time (min)	Actual time (min)	Tmax pre-pouring (ºC)	T upon pouring (ºC)
1	-	-	19	19
2	30-50 after 1	35	59	58
3	30-50 after 1	69	61	54
4	20-50 after 2	81	73	61
5	20-40 after 3	96	80	66
6	20-40 after 4	66	103	98

Interference calculations

The interference is defined as the difference in thermal expansion (ΔTE), *i.e.* the width of bar and cast iron superimposed on the width of the slot at temperatures from ambient (assembly cooled after rodding) to cathode operational temperature. A positive interference means that the bar and cast iron is applying a positive pressure on the surrounding carbon.

Figure 6 shows calculations of the rodded bar and block thermal expansion at elevated temperatures for a given industrial design with varying preheating of the bar (and block). It is evident that in the case of the section-wise rodding the bar and cast iron thermal expansion will soon overtake the expansion of the slot as the pot is preheated prior to start. In the present case the bar and cast iron thermal expansion relative to the slot reaches a maximum of 0.90 mm at 725ºC, thus creating high mechanical stress in the block.

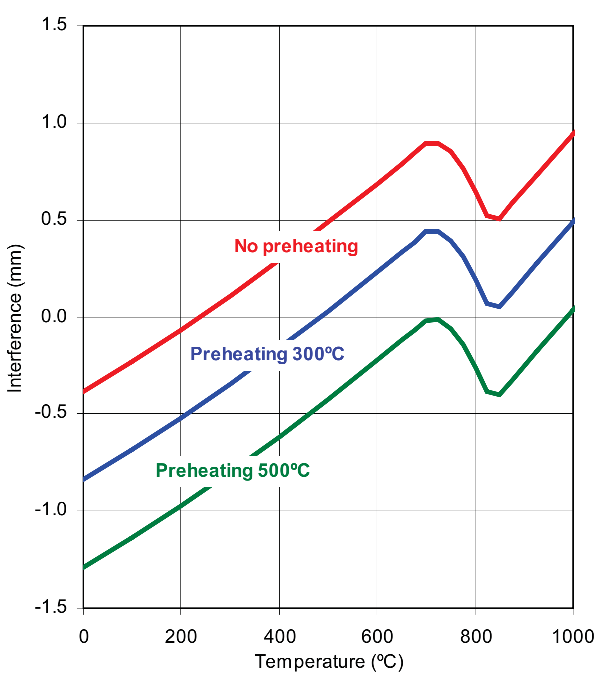

Figure 6. Interference plots for the given bar-slot design.

At a modest preheating of 300ºC the ΔTE is reduced to 0.44 mm and reaches zero at a preheating temperature of 500ºC (no stress).

Testing of block interference damage

One cathode block with rectangular slot dimension 170 mm x 170 mm was cut into five 300 mm long sections. Holes were drilled through the wings to later accommodate the test rig. Four of the samples were shipped to a smelter with a modern preheating station and made ready for cast iron rodding using steel collector bar pieces with cross section 150 mm x 150 mm (Figure 7). Two of these were rodded without any preheating of bar and block while two were preheated for 50 min in the gas fired station. The fifth sample was not rodded and served as a reference.

Figure 7. Bottom block sections made ready for preheating/cast iron pouring.

Temperatures measured on the preheated sections prior to casting were in the range 450-500ºC on collector bars and 350-400ºC on collector bar wings. Exact temperatures were difficult to establish with a hand-held IR-gun due to thermal gradients and cooling when removed from the preheating station. The bar temperature was lower by about 50ºC compared to preheating of full size bar-block assemblies, probably due to more rapid heat loss from the higher surface/volume ration of these block sections compared to full size blocks.

The rodded block sections were then subjected to a "pot preheating procedure" in the laboratory. The blocks were pair-wise put inside a steel box, packed in coke to avoid oxidation and heat-treated to 950ºC in a furnace (Figure 8).

Resistive preheating of cathodes tends to give an uneven temperature distribution over the cathode surface. Figure 9 shows temperature measurements near the block surface at three locations in a pot. Position C5 is near the middle of the pot, positions B5 and D5 are at about ¼ distances in from each end. It is seen that it may pose some problems to describe a "typical" temperature increase during such a cathode preheating procedure.

Figure 8. The steel box containing the rodded sections were heat treated in a furnace to simulate the cathode preheating procedure.

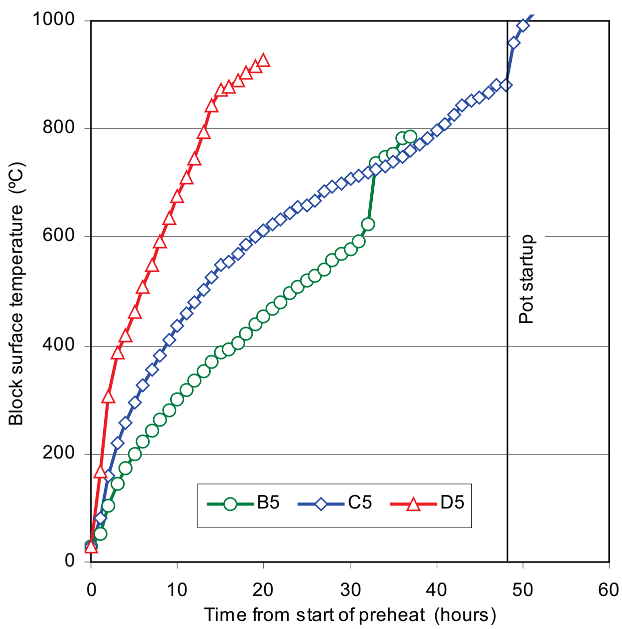

Figure 9. Close-to-surface temperatures measured at three different positions during a resistive cathode preheat.

A target preheat curve close to C5 in Figure 9 was chosen, reaching 950C in 48 hours followed by 7 hours soaking at that temperature before power was turned off and the furnace let cool.

<u>Destructive testing</u>

The rodded blocks and the one reference sample were mounted in a test rig and pulled to failure (Figure 10). The load to break the wings off the blocks was recorded.

Figure 10. A cathode block section mounted in the test machine.

Results and discussion

All cracks propagated from one inside slot corner to either the side of the block or to the top surface (Figure 11). Both samples that were not preheated prior to rodding and one of the preheated sections experienced angled cracks to the side of the block section (Figure 11b,c,d). In the other preheated section and in the reference sample the crack propagated from an inside slot corner to the top surface of the block (Figure 11a,d).

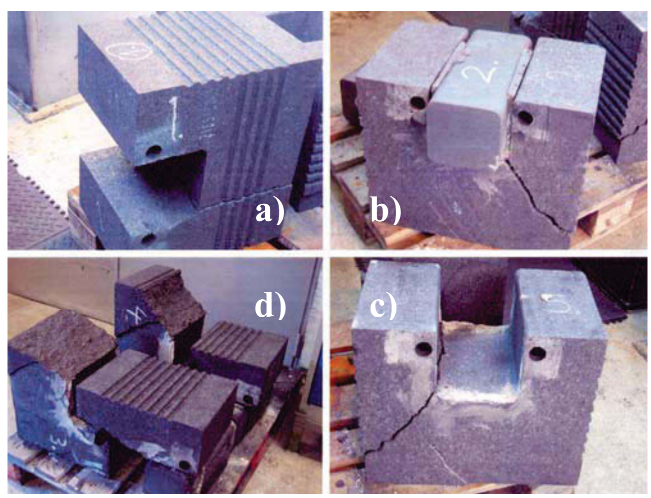

Figure 11. Broken block sections after testing. a) Reference sample (not rodded); b,c) Rodded without preheating; d) Rodded with preheating of bar and block.

The load-to-failure results for the reference sample and the rodded block sections are given in Figure 12. No difference in strength is found between the reference sample and the block samples that were preheated prior to rodding. However, the failure load for sections rodded without preheating the bar is only about ⅓ of the others.

The results verify that the section-wise rodding of cathode blocks may result in a reduced bottom block strength during operation of the pot, presumably by initiation of a crack from the inside slot corner due to by bar-block interference. The area around the first poured section, i.e. when there is no preheating whatsoever, is the one most susceptible for crack formation, but the preheating effect of other sections are probably not good enough to avoid crack initiation also there.

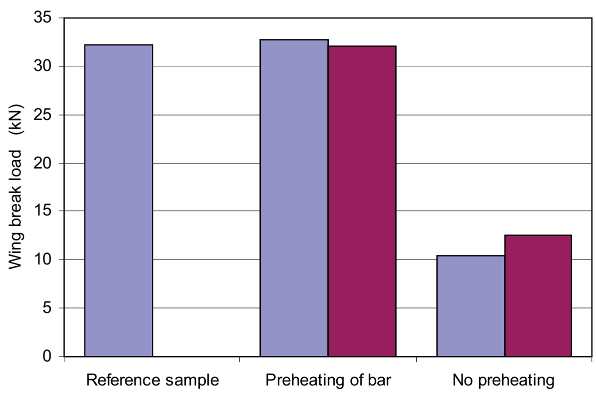

Figure 12. Results from destructive testing of block sections.

However, this is not a proof that cathode failure is caused by interference cracking, only that it may be a contributing factor and reduces pot life. During autopsies of failed pots it is not always possible to determine why blocks crack in this region.

It should also be pointed out that the resultant stress on bottom blocks in operating pots is more complex than the stress applied to these samples. This may reduce further propagation of bar-block interference cracks as well as increase their progression.

Nevertheless, the section-wise cast iron rodding procedure of cathode blocks without bar preheating creates unnecessary stresses in the cathode blocks during pot preheating. A simple bar preheat station should soon pay for itself if pot failures attributed to this can be avoided.

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