

Cathode Life and Failure in a High Amperage CWPB Potline

Liu Zheng¹ and Yi Xiaobing²

1. Senior Engineer, Department Manager

2. Prof., Vice Chief Engineer

CHALIECO GAMI, Guiyang, China

Corresponding author: yxbgami@163.com

Abstract

With increasing number of high amperage center-worked prebake (CWPB) pots in the primary aluminum industry, the cathode life of the CWPB pot-lines will affect the economic and ecological performance more seriously. In this case, how to prolong the pot life for the large CWPB pot-lines is becoming one of our first priorities and urgent work.

Based on the basic effects of the CWPB pot cathode lining engineering, cathode materials and quality on the cathode life, the paper presents a detailed cathode failure investigation and analysis example of one 500-kA pot-line in a Chinese domestic smelter. The cathode failure causes and mitigation methods are discussed at the end.

Keywords: Potline, Potlining engineering, cathode, raw material quality, pot life.

1. Introduction

In recent years, with increasing number of larger capacity CWPB pots has been being deployed in primary aluminium industry, cathode life plays an increasingly important role in affecting smelter economic and ecological performance. Therefore, prolonging the pot life for larger CWPB pot-lines is becoming the first priority for smelters. Factors affecting pot life are multiple — engineering, material, lining, prebaked startup and operation, all of which are interconnected.

Decades of industrial practices have proved that the normal pot life could be 10 years, according to the calculation for cathode annual erosion rate (including electric and chemical erosion and mechanical wear). However, the fact is that most of larger pots could not run for 3000 days, and some were even shut down within 2000 days. The reasons why pot life is usually shorter than it should be lie in 5 aspects: engineering, raw material quality, lining, pot startup and operation. According to statistics and analysis, these influence factors account for unequal proportion: engineering – 20 %, material – 10 %, lining – 20 %, pot startup – 25 % and operation – 25 %. With improved pot control and anode effect frequency (AEF) decrease, the factors of engineering and operation have decreased while the factor of materials increased. But it cannot be ignored that all these factors are not separate but interconnected [1, 2].

Based on the basic effects of the CWPB pot cathode lining engineering, cathode material and quality on the cathode life, the paper presents a detailed cathode failure investigation and analysis example of one 500-kA pot-line in a Chinese domestic smelter. The cathode failure causes and mitigation methods are discussed at the end.

2. Lining Engineering of Larger Pots

Lining engineering of larger pots consists of thermal equilibrium and mechanical stress engineering. The key principle of lining thermal equilibrium is that the bath solidification isotherm should be located within the refractory brick structure that is beneath cathode blocks, and 800 ~ 900 °C isotherm should be located in the impermeable structure above thermal

insulation bricks so that thermal insulation does not deteriorate when compounds like bath penetrate into it, and problems caused by thermal insulation breakdown are avoided.

Fig. 1 presents the simulation of lining isotherm distribution for one kind of larger pots:

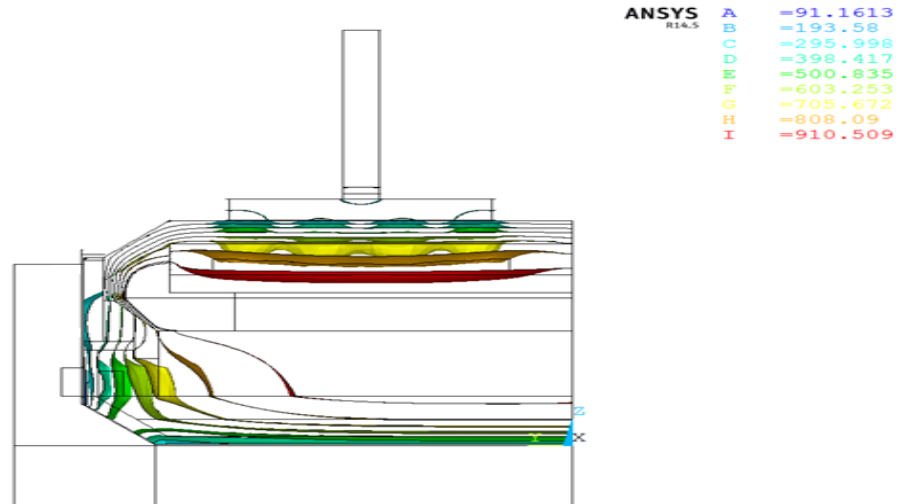


Fig. 1. Simulation of lining isotherm distribution for one kind of larger pots.

The principle of lining mechanical stress engineering is to make lining always under an appropriate compressive stress, avoiding the expansion of materials (including ramming paste-carbon block surface and pot shell-side carbon block surface), which could crush carbon blocks. Lining stress engineering mainly consists of potshell strength engineering and stress compensation engineering.

Stress of lining is mainly caused by expansion due to high temperature and sodium infiltration. Different materials will lead to different expansion performances. So to speak, lining stress engineering is closely related to thermal equilibrium engineering and lining materials applied. Cracks formed and propagated at cathode carbon blocks is one of the main patterns of pot lining failure. Generally speaking, cathode carbon blocks with lower degree of graphite will face higher possibility of cracking, and vice versa. If compressive stress is too large, horizontal and vertical cracks are easily formed in the lining; while if compressive stress is too small, only vertical cracks are easily formed.

Horizontal cracks will significantly increase the electric resistance of carbon blocks, and carbon blocks with horizontal cracks will carry much less current. If most carbon blocks of one pot generated horizontal cracks, the cathode voltage drop (CVD) would increase dramatically, of which the impact is even bigger than sludge. Therefore, cathode current distribution and CVD indicate whether horizontal cracks are formed: if CVD of one pot is much higher than any other pots while sludge is basically the same, it can be concluded that most cathodes blocks of this pot have generated horizontal cracks [3].

3. Quality Standard for Chinese Cathode Carbon Block

Cathode carbon block is made of electrically calcined anthracite, metallurgical coke, graphite and so on, bonded with coal tar pitch. At present, commonly-seen cathodes in Chinese market are graphitic with different amounts < 100 % of graphite, 100% graphitic and graphitized cathode.

The three types of cathode are subdivide into 5 categories as in Table-1 (refer to Chinese Standard YS/T623-2012) [4].

Table 1. Standard for Chinese cathode carbon blocks.

Performance	Unit	GS-1	GS-3	GS-5	GS-10	SM
Density	g/cm ³	1.91	1.95	1.99	2.08	2.18
Apparent density	g/cm ³	1.56	1.57	1.57	1.58	1.56
Ash content	%	8	5	4	2	0.5
Compressive strength	MPa	32	24	24	26	16
Flexural strength	MPa	10	7.0	7.0	7.5	6
Young modulus	GPa	10	7.0	7.0	6.5	7
Specific electrical resistivity	μΩm	39	35	30	21	14
Thermal expansion coefficient	300 °C 10 ⁻⁶ /°C	4.2	4.0	4.0	4.0	3.5
Sodium expansion	%	1.0	0.8	0.7	0.5	0.4

Remark:

Thermal expansion coefficient for high graphitic cathode is measured at 300°C, unit: ×10⁻⁶/°C;
Thermal expansion coefficient for graphitized cathode is measured at 25 to 300 °C, unit: ×10⁻⁶/°C.

Graphitized cathode has many advantages, and its quality and output are gradually catching up with international level, but due to some other reasons, it is not popularized in China domestic smelters by now. Compared with international advanced level, China domestic technical specifications of cathode carbon block seem to be behind:

- (1) Specific electrical resistivity of all type cathodes falls behind of international advanced level.
- (2) Apparent density of graphitized cathode is considerably smaller, so there are discrepancies in density among cathodes with isotropic coke.
- (3) Compressive strength and flexural strength of graphitized cathode are lower.
- (4) Ash content is considerably higher.

Author of the paper [4] went through long-term study and came to a conclusion that considering current situation and future potential, quality standard for China domestic technical parameters of cathode carbon block need urgent revision.

- (1) It is recommended to add class-I and class-II grade as well as the technical parameters.
- (2) It is recommended to add the technical parameter requirement for indication of compressive

strength, flexural strength, Young modulus, specific electrical resistivity and thermal expansion coefficient when forming stress direction is perpendicular.

- (3) It is recommended to add indication requirement for porosity.
- (4) It is recommended to add thermal conductivity indication, and add indication requirement for parallel and perpendicular direction to forming stress.
- (5) It is recommended to establish artificial graphite standard for graphitic cathode, isotropic petroleum coke standard for graphitized cathode and requirements for other relative raw materials.
- (6) On the premise of keeping pace with international advanced level, it is recommended to adjust and optimize current standards for relative parameters.

4. A Shortened Pot Life Cases

It should be pointed out that if cathode of aluminium reduction pot has any defect, it will be observed at startup and initial running stage. If these defects worsen, like cracks and holes getting expanded or deeper, this may lead to bath and metal leakage. The leakage will corrode insulation layer and thereby cause pot bottom heave, or will corrode collector bar, to increase iron content in aluminium, and ultimately lead to forced shut-down and early failure.

One Chinese domestic 500-kA potline was facing a shortened pot life due to cathode quality. This case is worth to discuss and analyze: The potline applied GS-3 graphitic cathode and followed technical standard for ordering / purchasing as YS/T623-2012 (see Table 1 data marked in yellow). Ultimately, due to insufficient supply, the potline purchased cathodes from three suppliers (two of them as supplementary). However, when first phase of the potline started, some pots were observed to have high iron content, partly broken cathode and bath leakage after startup in a short period of time, which caused severe pot lining failure. Figure 2 shows the detail of pot #1619, which was one of the failed pots.

On the day of metal pouring, iron content of pot #1619 was 0.13 % for 3 days and then increased at a rate of 2 to 3% per day, finally reached 0.91 %. After checking anode B11 and B12 (corresponding cathode collector bar temperature was 287 °C), it was found that the cathode under anode B12 had cracks (not significant). When these cracks were mended, cathode collector bar temperature did not change a lot, but iron content kept going higher up to 0.96 %. In order not to affect potline security, technicians applied pot shut-down device in full amperage to stop this pot. Then, after disassembling the pot, it was found A13\A16\B19\B20 as leakage points. Pot #1619 is just one example among several failure pots in early operation phase.

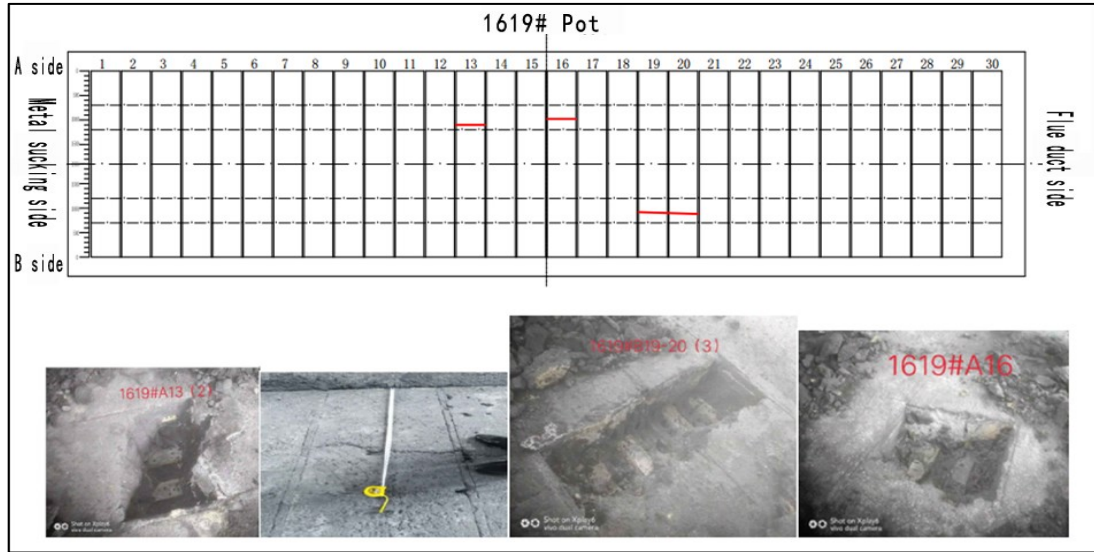


Figure 2. Pot #1619 after cut-out.

5. Causes for Pot Lining Failure

To find out the causes for pot lining failure and avoid such failure to happen again, expert team had an intensive study for cathodes of non-startup pots and finally found that there was one supplier who supplied cathode with obvious quality problem. After careful examination, experts found the surface of cathodes had holes and cracks, shown in figures 3 and 4.



Figure 3. Cracks in Pot #1540 A16.



Figure 4. Cracks in Pot #1534 B18.

After investigation, experts came to conclusion that the the reason for such phenomenon was that the manufacturer used different batches of aggregates, of which the technical parameters varied widely. Research showed that type and grain diameter of aggregates, temperature, heat-up time and vibration time had remarkable impact on the functions of chemisorption, surface wettability and capillary penetration between aggregates and the adhesive material. The impact was directly related to the infiltration effect to aggregates given by coal tar [6].

Therefore, in the procedure of kneading and shaping, it was hard to mix up the aggregates and the adhesive, and make them evenly distributed. Moreover, due to its big size, cathode carbon block

is usually heated unevenly during baking phase, volatile matter releasing rate is different and the pitch is also coked unevenly. All of these factors will cause specific electric resistance discrepancy among one batch of cathodes, and discrepancy at different parts of one cathode [7].

As Table 1 shows, at present, the standard for Chinese domestic cathode carbon blocks is relatively weak and the technical parameters standard also need to be revised. Some physical and chemical parameters are higher or uneven, and some need to be added. Specially there is no warranty given for tracing, re-inspecting and refunding of so many batches of cathodes in this project. These were the main reasons for the shortened pot life in this case of a Chinese domestic 500-kA potline.

6. Conclusions

Larger capacity pot production and ecological operating costs are closely related to pot life. The larger the pot capacity is, the bigger impact on the pot life. In recent years, although Chinese domestic aluminum reduction technology has been improved from design to operation and has stepped into international advanced level with modern constructed green-field smelters adopting 400 to 600 kA large or super large pot lines, but the pot life factor has not improved much. Especially, the quality of pot cathode carbon lining (cathode carbon block + ramming paste) and the small number of graphitized cathodes used do not meet expectation. Experts in primary aluminium industry should pay attention to this condition, so as to propel Chinese aluminium industry forward to a high-qualified, eco-friendly and sustainable future.

7. Reference

1. Wayne R. Hale, *JOM* 41 (11) 1989, 20-25.
2. Morten Sørli and H.A. Øye. Cathodes in the Aluminium Electrolysis, 3rd Edition, Aluminium Verlag, 2010.
3. Liao Xianan, Xie Qingsong. The analysis on lining design and failure problems for aluminum electrolysis Pot. *Light Metal*, China, 2002-07
4. YS/T623-2012 Standard for Chinese Cathode Carbon Block. 2012
5. Xie zhiqun, The discrepancy and revision necessity of Standard for Chinese Cathode Carbon Block, *Carbon Techniques*, China, 2018-01.
6. Yao Zhen, Liu Wei, Zhou Jun, Tu Guobiao and Chen Yi, Study on wettability of coal tar on aggregate of cathode lining for aluminum electrolysis cell, *Light Metal*, China, 2018-05
7. Li Rongzhu. Discussion on measurement uncertainty and influence factors of resistivity of carbon material for aluminum industry, *Light Metal*, China, 2017-0