

Comparative Analysis of KPIs and MHD Stability Between Pots with Graphitized and Graphitic Cathodes

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Abstract

Graphitized cathode blocks play an important role in energy savings, efficiency improvement and environmental friendliness for the aluminium smelting process. As a result of this, graphitized cathode blocks have been widely applied in western aluminium smelters. This paper explored an application of graphitized cathodes in Guangxi Hualei New Materials. After comparative analysis of pot KPIs, the average current efficiency of two graphitized cathode pots was found to be 1.46 % higher than in the graphitic cathode pots, and the DC power consumption was about 200 kWh/t Al lower as well. Squeezing tests were further carried out to detect the threshold of magnetohydrodynamic (MHD) stability. At the same pot voltage and other conditions, the average anode-cathode distance (ACD) of graphitized cathode pots was about 1.22 mm higher than the graphitic cathode pots. It was also found that the graphitized cathodes played a beneficial role in homogenizing ACD distribution and strengthening its ability of anti-interference deformation compared with graphitic cathode pots.

Keywords: Aluminium pots, Graphitized cathode, Graphitic cathode, MHD stability.

1. Introduction

The carbon cathode assembly constitutes one of the principal components in aluminium reduction pots. Serving as the crucial element in maintaining electrical and thermal balance, the cathode block has to possess excellent thermal and electrical characteristics. Simultaneously, as the first barrier against molten salt [1], the ability to resist corrosion and sodium penetration at high temperatures should be outstanding as well.

Regarding the selection of cathode materials, western and Chinese aluminium industries pursued different technical ways. Western giants (e.g., Alcoa, EGA, Hydro, RUSAL, etc.) started the research and applications of graphitized cathode blocks very early. The main reason could be attributed to its excellent electrical conductivity, thermal conductivity and sodium penetration

resistance. Western pots were characterized by their high current density and high current efficiency [2]. In contrast, due to the economic and labour advantages, Chinese aluminium companies preferred graphitic cathodes for a very long time. Now the cutting-edge technologies in Chinese aluminium producers have reached the world-leading standards in DC energy consumption. However, there still is a clear gap in current density and current efficiency compared to western aluminium smelters.

In recent years, domestic design and research institutes and smelters began to pay more attention to the advantages of graphitized cathodes. Some industrial explorations have been carried out in smelters. Tao et. al [3] conducted a study based on an aluminium smelter to analyse the process parameters between graphitized cathode pots and graphitic cathode pots. Statistical analyses revealed that the cathode voltage drop (CVD) of graphitized cathode pots was maintained between 240 mV and 260 mV over a very long period, while that of graphitic cells increased to 340 mV. The annual data showed that a 1.49 % higher current efficiency was obtained in graphitized cathode pots. A similar industrial trial was done by Song et. Al. [4] in Yingkou Zhongwang Aluminum. By comparing 40 graphitized cathode pots with another group of graphitic cathode pots, it was found that the pots with graphitized cathodes showed a reduction of 45.5 mV in CVD, an improvement of about 1 % in current efficiency, and a reduction of 150 kWh/t Al in DC power consumption.

Until 2020, the graphitized cathode blocks had not been widely adopted in China's aluminium electrolysis industry. An exploration of two graphitized cathode pots was started-up in Guangxi Hualei New Materials (Hualei) in 2020. This paper compares the pot KPIs between the test pots and original graphitic cathode pots. The squeezing tests were further carried out to analyse thresholds of MHD stability. The findings may provide some experience and reference for domestic and overseas smelters.

2. Comparative Analysis of Pot KPIs

Two pots (No.1202 and No.1722) were equipped with graphitized cathode carbon blocks, while two other pots (No.1328 and No.1514) were installed with graphitic cathode blocks. Table 1 presents the comparison of physical and chemical properties between the two types of cathodes. The four test cells shared similar thermal balance and lining structure designs. The startup time of all pots was within 20 days. The management procedures, production conditions and raw material were standardized across all test pots and reference pots.

Table 1. Comparison of physicochemical properties between graphitized and graphitic cathodes.

Physicochemical properties	Apparent density (g/cm ³)	True Density (g/cm ³)	Crushing strength (MPa)	Room-temperature resistivity (μΩ·m)	Ashes (%)	Supplier
Graphitized carbon blocks	1.71	2.16	23	8	0.14	Enterprise A
Graphitic carbon blocks	1.69	2.07	32	22	0.78	Enterprise B

The comparison data began to be collected after 6 months from pot startup. Table 2 is a summary of the consecutive data gathered from six months of normal operation of these pots. It was found that the pot voltages were nearly identical with a tiny difference of 5 mV. Process parameters such as aluminium level, bath level, and bath temperature were similar in the group. However, the average current efficiency of the graphitized cathode pots was 1.46 % higher than that of the

graphitic pots. And the average DC power consumption was reduced by approximately 200 kWh/t Al with the application of graphitized cathodes.

Table 2. Comparison of pot KPIs between graphitized and graphitic cathode pots.

KPIs		Pot voltage V	Metal level mm	Bath level mm	CR	Bath temperature °C	CVD mV	Current efficiency %	Power consumption kWh/t Al
Graphitized cathode pots	No.12 02	3.892	223	188	2.41	958	222	93.40	12418
	No.17 22	3.925	228	180	2.55	959	222	92.54	12639
	Ave.	3.909	226	184	2.48	959	222	92.97	12529
Graphitic cathode pots	No.13 28	3.912	211	188	2.56	961	233	91.45	12748
	No.15 14	3.914	219	186	2.45	962	237	91.58	12736
	Ave.	3.913	215	187	2.51	961	235	91.52	12742
Differences		-0.005	–	–	–	–	-13	1.46	-213

The industrial results in Hualei were similar with those from other smelters, such as Yingkou Zhongwang Aluminum [4–6]. The graphitized cathode pots present significant advantages in energy saving and current efficiency. Currently, it is believed these benefits can be attributed to the increased ACD due to the reduction of CVD. The graphitized cathode pots present a larger ACD compared to these graphitic cathode pots under same pot voltage. The larger ACD substantially reduces the probability of back reaction between the liquid aluminium and CO₂ bubbles.

3. Threshold of MHD Stability

In order to further investigate the underlying mechanisms of the energy-saving in graphitized cathode pots, this section conducted a typical analysis on the threshold of MHD stability. This method was also known as squeezing tests [7].

3.1 Squeezing Tests

The MHD stability of aluminium reduction pots is in a transient mode. In the test, an external perturbation was added to the pot. Then the metal-bath interface began to fluctuate with time, and it could be monitored by the anode current. In this case, a sudden drop of pot voltage was applied as manual disturbance. If the fluctuation of bath-metal interface gradually becomes smaller and go to stable state, it could be concluded that the ACD has not reached its threshold. Conversely, the interface fluctuation demonstrates an increasing trend, indicating that the ACD has reached its MHD stability limit.

In order to avoid the influence of anode changing, all tests were carried out 48 hours after anode change. The experimental process is as follows:

- 1) Pre-test measurements: measure the anode current distribution and bath temperature, and calculate the equivalent ACD distribution [8] as base case for subsequent testing.
- 2) Rapidly squeeze the ACD, manually lower the pot voltage carefully (e.g., from 3.88 to 3.80 V, a reduction of 80 mV).
- 3) After reducing the ACD, a 5 to 15-minute observation was implemented to monitor the MHD stability, pot noise and pot voltages. At the same time, the anode current distribution and bath

temperature were re-measured, and the ACD distribution was recalculated as well for comparison with the base case.

- 4) Repeat steps 2 to 3, sequentially and carefully lowering the pot voltage to 3.75, 3.70, 3.65 V, etc.
- 5) Proceed to the next step only if the interface fluctuation stabilizes again after each squeezing. If instability of the pot is observed, stop the test, and restore the ACD and pot voltage.

Figure 1 shows the squeezing process of Pot No. 1722. In the test, the bath temperature, bath level changes and other critical parameters were carefully monitored in case of any safety issues.

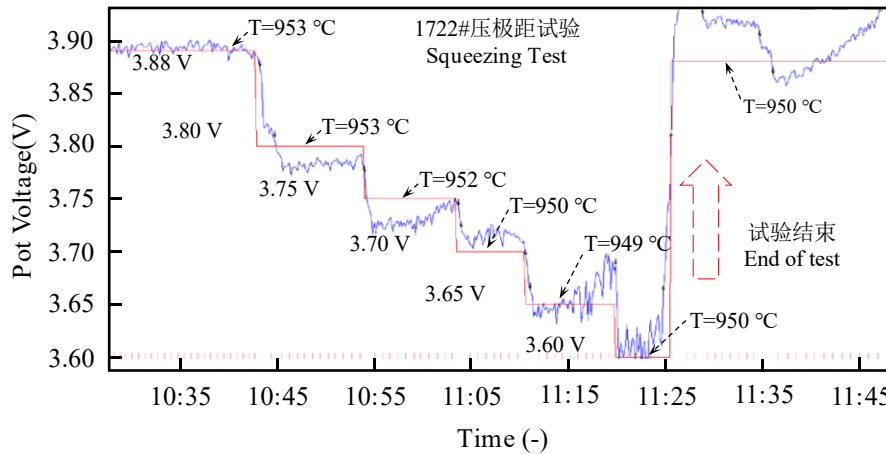


Figure 1. Process of squeezing test of No. 1722.

3.2 Results

Figures 2 and 3 illustrate the equivalent ACD distributions at different stages during squeezing tests, both for the graphitized cathode pot No.1722 and the graphitic cathode pot No.1328. It should be noted that there existed some unreasonable values for some anodes (such as anode B1 and B15 in Figure 2, anode A23 A24 and B5 B6 in Figure 3). This may be due to the abnormally low current flow. These unreasonable values were excluded from the computation of average ACD and standard deviation.

It can be shown in Figure 2, that the average ACD was 40.4 mm before the test with the pot voltage of 3.88 V. The calculated value of ACD agreed with manual measurements taken at multiple positions. The ACD distribution illustrated a multi-peak pattern, with a minimum ACD of approximately 30 mm (anode A21) and a standard deviation of 0.81. When the pot voltage was reduced to 3.80 V, the average ACD decreased to 38.5 mm while the standard deviation remained unchanged. Further reduction to 3.75 V resulted in an average ACD of 37.0 mm, accompanied by an increase in standard deviation to 0.85 mm. The increase in standard deviation indicated that the metal-bath interface began to fluctuate. At 3.70 V, the average ACD dropped to 35.9 mm, with slight current oscillations observed at anode B21. Continued testing at 3.65 V showed multi-region anode current fluctuations. This was a signal of the breakdown of the MHD threshold and the squeezing test was therefore stopped. The ACD distribution and standard deviation returned to their pre-test state after the pot voltage was gradually restored.

Figure 3 illustrates the equivalent ACD distributions of the graphitic cathode. Despite sharing the same pot voltage (3.88 V), the graphitic cathode pots presented an average ACD of 39.2 mm, which was 1.22 mm lower than the graphitized cathode pots. Also, the standard deviation was about 33 % higher. The distribution also displayed a multi-peak pattern, but four anodes (A8, B21, B22 and B24) showed their equivalent ACDs were below 30 mm. A significantly higher number

of low ACD regions were observed compared to the graphitized cathode pots. Subsequent stepwise reductions to 3.80 and 3.75 V triggered anode current oscillations (e.g. B20) that resulted in the occurrence of multi-region current fluctuations. After terminating the test and restoring the pot voltage, the ACD distribution returned to a configuration nearly identical to the pre-test state.

The graphitized cathode pot No.1202 and graphitic cathode pot No.1514 presented a similar trend with Figure 2 and Figure 3. They were not reiterated here.

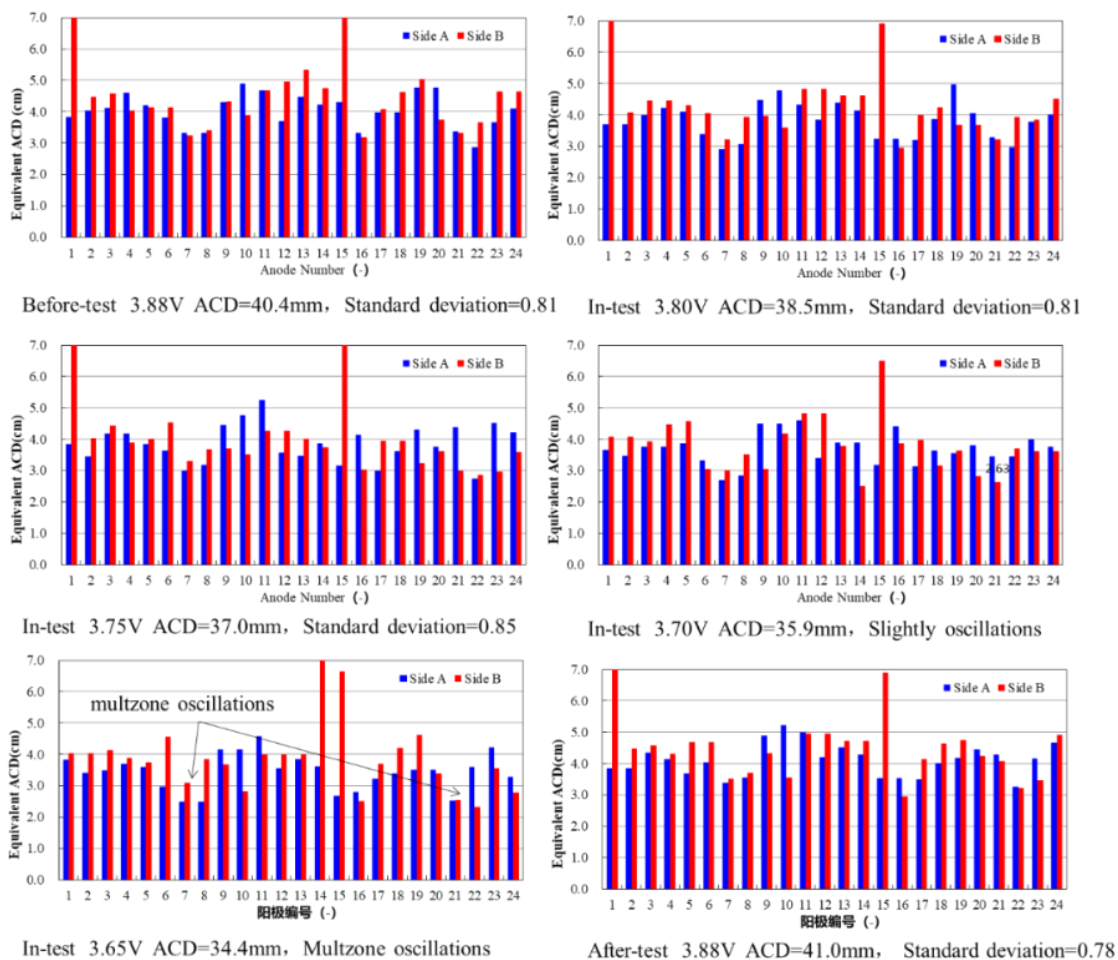


Figure 2. Equivalent ACD distribution in the squeezing test in graphitized pot (No.1722).

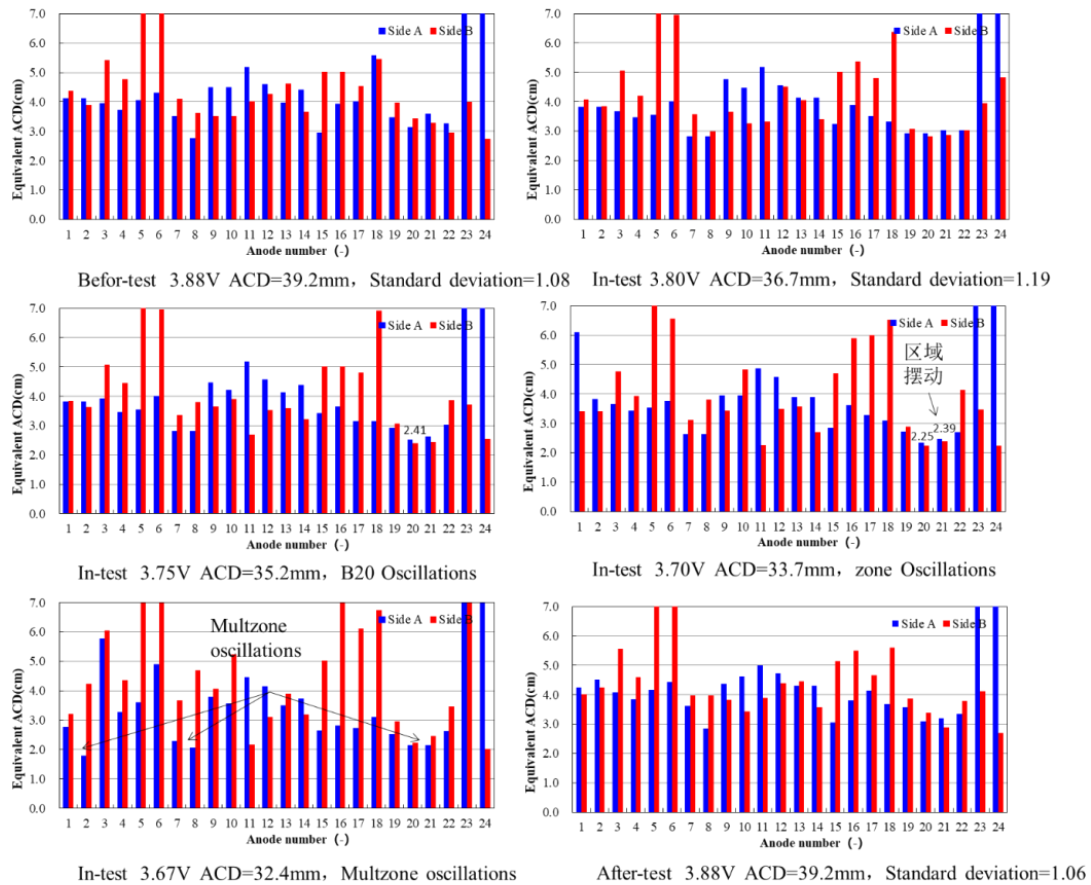


Figure 3. Equivalent ACD distribution in the squeezing test in graphitic pot (No.1328).

4. Discussion

As evidenced by the comparative analysis in Figures 2 and 3, we can see the differences between graphitized cathode pots during squeezing tests. In order to further analyse these disparities, this section summarizes the ACD and their standard deviations for all four test cells under two voltage conditions (3.88 V and 3.80 V), as detailed in Table 3.

Table 3. Comparison of the squeezing test between graphitized and graphitic pots.

Type of Pots		Pot Voltage 3.88 V		Pot Voltage 3.80 V	
		Average ACD mm	Standard deviation mm	Average ACD mm	Standard deviation mm
Graphitized cathode pots	No.1722	40.40	0.81	38.50	0.81
	No.1202	40.00	1.15	37.80	1.01
	AVE.	40.20	0.98	38.15	0.91
Graphitic cathode pots	No.1328	39.20	1.08	36.70	1.19
	No.1514	38.75	1.02	35.75	1.36
	AVE.	38.98	1.05	36.23	1.28
Differences		1.22	-0.07	1.93	-0.37

The two graphitized cathode pots were operated at an average ACD of 40.20 mm, whereas the two graphitic cathode pots showed an average ACD of 38.98 mm. There was a 1.22 mm difference in ACD between the two cell types. Regarding the electrolyte composition used in the test pots, the 1.22 mm ACD corresponded to a voltage drop of approximately 41 mV [9] in the bath layer. Comparative analysis of ACD standard deviations further revealed that the graphitized cathode pots showed a better uniformity of ACD distribution compared to that of graphitic cathode pots.

Graphitized cathode blocks have higher electrical conductivity compared to that of graphitic cathode blocks (YS/T 623-2012 and YS/T 699-2009). The graphitized cathode pots have an advantage in CVD, which gives a better pot KPIs. The above study further revealed an important part beyond the inherent physical voltage reduction: the graphitized cathodes played a beneficial role in homogenizing ACD distribution.

When the pot voltage was reduced from 3.88 V to 3.80 V, the standard deviation of ACD showed no increase in the two graphitized cathode pots. It even showed a slightly downward trend, indicating that the interface distribution of metal-bath remained stable. In contrast, the two graphitic cathode pots showed about 22 % increase in standard deviation under the same operation conditions. It illustrated the deteriorating trend of the interface pattern. This comparative analysis showed that the ability of anti-disturbances was slightly strengthening for graphitized cathode pots compared to graphitic cathode pots.

5. Conclusions

This paper analyzed the industrial data to compare pot KPIs and MHD stability between graphitized and graphitic cathode pots. Some key conclusions are summarized as follows:

- (1) Six-month data comparison revealed that the graphitized cathode pots achieved a 1.46 % higher in current efficiency and about 200 kWh/t Al lower in DC power consumption compared to graphitic cathode pots under similar operating conditions.
- (2) The tests to detect the threshold of MHD stability showed that some localized anode current fluctuations emerged at 3.70 V in graphitized cathode pots, whereas similar instabilities arose at a higher voltage of 3.75 V in graphitic cathode pots.
- (3) Equivalent ACD calculations showed that the graphitized cathode pots maintained an average ACD of 40.20 mm, which was 1.22 mm higher than graphitic cathode pots (38.98 mm). The standard deviation of ACD in graphitic cathode pots was about 33 % higher as well. The graphitized cathodes played a beneficial role in homogenizing ACD distribution.
- (4) When the pot voltage was reduced from 3.88 V to 3.80 V, the standard deviation of ACD showed no increase in the two graphitized cathode pots. The two graphitic cathode pots showed about 22 % increase in standard deviation. The graphitized cathodes played a beneficial role in strengthening its ability of anti-interference compared with graphitic cathode pots.
- (5) Based on these findings, Hualei plans to conduct an expanded trial to confirm the advantage of graphitized cathode blocks.

6. References

1. X.D. Yang and M. Liu, Innovative ideas on heat balance design of large energy-saving aluminum reduction pot, *Light Metals*, Vol.12, (2017), 21-25. (In Chinese)
2. Shenyang Aluminium & Magnesium Engineering & Research Institute. Science and technology development report of Chief Engineer of Chinalco (aluminum reduction), 2019. (In Chinese)
3. S.H. Tao, The technological parameters statistics and comprehensive analysis of graphite and graphitized cathode aluminum electrolysis pot, *Light Metals*, Vol.12, (2018), 16-20. (In Chinese)

4. S.H. Song and D. Xu, Application comparison of graphitized cathode carbon block and 50% graphite cathode carbon block in 500 kA prebaked aluminum reduction pots, *Light Metals*, Vol.9, (2019), 31-35. (In Chinese)
5. Y.F. Lu, B. Bai and X. Cao, Application of graphitized carbon cathode block in 400kA energy-saving type aluminum reduction cell, *Energy Saving of Nonferrous Metallurgy*, Vol.3, (2017), 31-34. (In Chinese)
6. B.G. Chen, Y.F. Liu and X.A. Liao, The application of graphite cathodes in aluminium reduction cell, *Light Metals*, Vol.9, (2012), 45-47. (In Chinese)
7. Wei Liu, Dongfang Zhou and Zhibin Zhao, Progress in application of energy-saving measures in aluminum reduction cells, *JOM*, Vol. 71, (2019), 2420-2429.
8. F.Q. Wang, Z.W. Wang, Q.S. Zhang, Z.B. Zhao, S.H. Tao, W. Liu and X.D. Yang, Computation and validation of ACD for aluminum reduction cell, *Light Metals*, Vol.2, (2020), 23-25. (In Chinese)
9. N.X. Feng, *Aluminum electrolysis*, 1st ed. (Beijing: Chemical Industry Press., 2006).